UNIVERSIDADE CATÓLICA PORTUGUESA

INTONASPACIO - COMPREHENSIVE STUDY ON THE CONCEPTION AND DESIGN OF DIGITAL MUSICAL INSTRUMENTS - INTERACTION BETWEEN SPACE AND MUSICAL GESTURE

Tese apresentada à Universidade Católica Portuguesa para obtenção do grau de Doutor em Ciência e Tecnologias para as Artes - especialização em Informática Musical

por

Mailis Gomes Rodrigues

ESCOLA DAS ARTES
Julho 2014

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Sob orientação de Professor Paulo Ferreira-Lopes

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Abstract

Site-specific art understands that the place where the artwork is presented cannot be excluded from the artwork itself. The completion of the work is only achieved when the artwork and place intersect. Acoustically, sound presents a natural relation with place. The perception of sound is the result of place modulation on its spectral content, likewise perception of place is dependent on the sound content of that place. Even so, the number of sound artworks where place has a primary role is still very reduced. We thus purpose to create a tool to compose inherently place-specific sounds. Inherently because the sound is the result of the interaction between place and performer. Place because is the concept that is closer to human perception and of the idea of intimacy. Along this thesis we suggest that this interaction can be mediated by a digital musical instrument - Intonaspacio, that allows the performer to compose place-specific sounds and control it. In the first part we describe the process of construction and design of Intonaspacio - how to access the sound present in the place, what gestures to measure, what sensors to use and where to place them, what mapping to design in order to compose place-specific sound. We start by suggesting two different mappings to combine place and sound, where we look at different approaches on how to excite the structural sound of the place, i.e., the resonant frequencies. The first one, uses a process where the performer can record a sample of sound ambiance and reproduce it, creating a feedback loop that excites at each iteration the resonances of the room. The second approach suggest a method where the input sound is analyzed and an ensemble of the frequencies of the place with the highest amplitudes is extracted. These are mapped to control several parameters of sound effects. To evaluate Intonaspacio we conducted an experiment with participants who played the instrument during several trial sessions. The analysis of this experiment led us to propose a third mapping that combines the previous mappings.

The second part of the thesis intends to create the conditions to give longevity to

Intonaspacio. Starting from the premise that a musical instrument to be classified as such needs to have a dedicated instrumental technique and repertoire.
These two conditions were achieved first, by suggesting a gestural vocabulary of the idiomatic gestures of Intonaspacio based on direct observation of the most repeated gestures of the participants of our experiment. Second, by collaborating with two composers whom wrote two pieces for Intonaspacio.

Resumo

A arte situada é uma disciplina artística tradicionalmente ligada à Instalação que pretende criar obras que mantêm uma relação directa com o espaço onde são apresentadas. A obra de arte não pode assim ser separada desse mesmo espaço sem perder o significado inicial. O som pelas suas características físicas reflecte naturalmente o espaço onde foi emitido, isto é, a percepção que temos de um som resulta da combinação do som directo com as reflecções do mesmo no espaço (cujo tempo e amplitude estão directamente relacionados com a arquitectura do espaço). Nesta lógica a arte sonora seria aquela que mais directamente procuraria compôr som situado. No entanto, o espaço é raramente utilizado como fenómeno criativo intencional. Nesse sentido, o trabalho aqui apresentado propõem-se a investigar a possibiliade de criar sons situados.

O termo Espaço está muitas vezes associado a algo de dimensões vastas e ilimitadas. Assim sendo e na óptica da arte situada, onde há uma necessidade de criar uma relação, parece-nos que lugar é um termo mais adequado para enquadrar o nosso trabalho de investigação. O lugar, para além de representar um espaço onde se podem estabelecer relações de intimidade (proximidade), apresenta dimensões que são moldáveis consoante a percepção e o corpo humano. Ou seja, o Homem ao deslocar-se no lugar vai ao mesmo tempo definindo as fronteiras desse mesmo lugar. Esta visão do lugar aparece no final do século dezanove quando a filosofia começa a orientar o pensamento para uma visão mais direccionada para o Homem e para a percepção humana. O lugar passa então a representar algo que é estabelecido na acção e pela percepção humana, onde é possível estabelecer relações de intimidade, ao contrário dos não-lugares (sítios mais ou menos descaracterizados onde as pessoas estão só de passagem). Re-adaptámos por isso a nossa questão inicial não só para realçar esta ideia de lugar mas também para reflectir uma bi-direccionalidade perceptiva que é fulcral para a arte situada - como criar e controlar sons inerentemente localizados?

Inerentemente porque para existir de facto uma interacção entre lugar e obra de arte sonora são necessárias duas condições: por um lado o som possa provocar uma resposta do lugar, e por outro, o lugar possa modificar a nossa percepção dele mesmo. A existência de uma relação interactiva abre espaço a um novo ponto que não tinhámos considerado anteriormente e que acrescentámos à nossa nova questão, o controlo.
Propomos como possível reposta a esta questão a construção de um instrumento musical digital, o Intonaspacio, que servirá de mediador desta interacção e que possibilitará ao performer a criação e o controlo de sons localizados. Primeiro poque o instrumento musical possibilita o aumento das capacidades humanas, através da extensão do corpo humano (tal como um garfo extende a nossa mão, por exemplo). Segundo, porque o instrumento musical digital pelas suas características, nomeadamente pela separação entre o sistema de controlo e o sistema de geração de som abre novas possibilidades sonoras antes excluídas por limitações mecâncias ou humanas. Podemos por isso visionar um acesso mais alargado a novas dimensões espaciais e temporais.
Esta tese está dividida em duas partes, na primeira parte descrevemos a construção do Intonaspacio, e na segunda estabelecemos as bases para permitir a sua longevidade.
A primeira parte começa por investigar formas de acesso ao som do lugar, composto pelo conjunto dos sons ambiente e dos sons estruturais do lugar (ressonâncias próprias resultantes da arquitectura). Pensamos que uma das possíveis formas de compôr sons localizados é precisamente através da possibilidade de poder ter os sons ambiente a gerar e a amplificar os sons estruturais. Surgem então duas novas questões de natureza técnica: Como integrar o som ambiente na obra sonora em tempo-real? Como permitir que estes excitem a resposta do espaço? Para as responder desenhámos dois mapeamentos diferentes. Um primeiro em que o performer pode gravar pequenos trechos de som ambiente que são emitidos e re-gravados criando um ciclo de feedback que excita as ressonâncias do lugar. Um segundo método onde se faz uma análise espectral ao som captado e se extrai um conjunto de frequências cujas amplitudes são as mais elevadas. Estas são posteriormente utilizadas para controlar parâmetros de vários efeitos sonoros. Colocámos ainda no instrumento um conjunto de sensores diferentes para captar o gesto do performer. Estes estão localizados em diferentes

áreas do esqueleto do instrumento de modo a permitir áreas sensíveis maiores e consequentemente um maior número de graus de liberdade ao performer. Neste momento o Intonaspacio permite extrair cerca de 17 características diferentes, agrupadas em três secções - orientação, impacto e distância. Estas podem ser utilizadas para modelar o som gerado pelo instrumento através dos diferentes mapeamentos.

Ambas as propostas de mapeamento foram avaliadas por um conjunto de pessoas durante um teste de utilização do Intonaspacio. Os resultados deste permitiram-nos chegar a uma terceira sugestão de mapeamento onde combinamos características de ambas as propostas anteriores. No terceiro mapeamento mantém-se a análise ao som captado pelo instrumento mas a informação recolhida é usada como material sonoro de um algoritmo de síntese aditiva.

A segunda parte da tese parte de uma premissa estabelecida durante o trabalho realizado nesta tese. Um instrumento muisical deve possuir uma técnica instrumental própria e um repertório dedicado para que seja considerado enquanto tal. Neste sentido e com base na observação directa dos gestos mais comuns entre participantes do nosso estudo, propusémos um vocabulário gestual dos gestos idiomáticos do Intonaspacio, ou seja, dos gestos que dependem exclusivamente da forma do próprio instrumento e da localização dos sensores na estrutura do instrumento (zonas sensíveis) e são independentes do mapeamento.

Colaborámos ainda com dois compositores que escreveram duas peças musicais para o Intonaspacio.

O Intonaspacio revelou ser um instrumento complexo e expressivo que possibilita aos performers incluir o lugar enquanto parâmetro criativo, no entanto apresenta ainda alguns problemas de controlo. No primeiro mapeamento, embora a integração do lugar seja sentida como mais directa e apresentando resultados sonoros mais interessantes (de acordo com os participantes do estudo), a sensação de controlo é muito baixa. Já no segundo mapeamento, embora tenha um controlo mais fácil, a presença do lugar é muito subtil e pouco perceptível. Esperamos que o terceiro mapeamento venha contribuir para solucionar este problema e aumentar o interesse no instrumento, principalmente por parte dos compositores com quem colaborámos e iremos colaborar no futuro.

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Ouvi pela primeira vez a palavra poliglota quando estava na escola primária. Lembro-me que me impressionou bastante. Acho que foi por essa altura que achei que deveria aprender sete línguas e tornar-me também eu poliglota. Hoje, continuo sem saber as sete. Esta tese é também ela poliglota, foi escrita a várias línguas. E não interessa muito qual a língua final em que se apresenta, para mim ela tem um bocadinho de português de Portugal, de portugês com sotaque brasileiro, um bocadinho de francês, um bocadinho de quebecois, um bocadinho de inglês, de espanhol, de italiano e até de alemão. Foram quatro anos, um nada na história, mas foram quatro anos que me obrigaram a desafiar os meus medos, tantas vezes, e por vezes abruptamente. Foram quatro anos em que cresci, desenvolvi e fiz coisas que um dia me passaram pela cabeça, mais como uma idealização do que uma concretização real. O doutoramento ajudou-me a perceber que devemos arriscar, experimentar, errar e aprender tudo de novo se for preciso. Por isso e neste percurso que juntou tanta gente e tantos sítios são muitas as pessoas a quem gostaria de agradecer.

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To K., Ana, Leonor, Luiz.

"Não sei por onde vou/Não sei para onde vou/ Sei que não vou por aí!"[1]

[1] Cântico Negro, José Régio - homage to Aurora

"Aconteça o que acontecer, eu cá diverti-me."[2]

[2]Free translation of Carlos Vaz Marques of Giacomo Casanova's motto "Rien ne pourra faire que je ne me sois amusé" in "O livro do dia" (daily radio show at TSF).

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1. Introduction

"To be (at all) is to be in (some) place." Archytas de Tarentum cited in (Casey, 1997).

1.1. Overview

Site-specific practices contemplate the introduction of the characteristics of place in the artwork itself, creating a permanent bound between place and work. The artistic creation is not independent of the place where it is placed, which contributes to the uniqueness and the aura of the work of art (Benjamin, 2008). It exists in a specific place and time, thus it is always situated.

Site-specific art is, historically, mainly associated with installation art, especially as a branch of minimalist art. Even so we assist to a progressive spreading of site-specific concepts in other artistic disciplines such as theater, dance or performance. We also find some examples of site-specific art in relation to sound art.

In this dissertation, we deal with place-specificities in sound and music composition. From the question: How to generate and control place-specific sounds?, we start by reviewing the concepts of space, place and site, in order to build the conceptual framework of this work. We then propose the design of a digital musical instrument (DMI) as a tool to provide access and control of place to composers and performers, addressing some of the issues related to the integration of the acoustic characteristics of place in sound composition. Finally, we introduce two strategies to validate and to ensure the longevity of the presented DMI - Intonaspacio - the creation of a repertoire and the development of an instrumental technique devoted to the musical instrument.

1.1.1. Motivation

Rooms have acoustical characteristics that enhance or dump certain frequencies in the spectral content of the sounds, as well as the architecture of the rooms by its dimensions creates different reverberation times that contribute to affect the perception we have of it. For centuries room acoustic research has provided us with rooms that are more and more suited to a particular audio content. Some performance rooms are especially designed for classical music, others for voice, opera, and so on. Space is frequently transformed, i.e, its acoustical characteristics are removed through equalizers, on behalf of a good listening experience.
We believe that space can as well be part of the sonic experience. This thought motivated us to pose some questions. Why can we not think about space as another creative parameter of the composition? Schumacher (Schumacher and Bresson, 2010) suggests, for example, the design of space characteristics (time of reverberation, sound trajectories, shape, etc..) before the actual implementation of spatialisation's algorithms. Even so, what we search with this work is not so much to perform a spatialisation of the sound but to introduce the characteristics of place that are inherent to it. Or, specifically, to create a sound that is dependent of place. A sound that would integrate some of the place acoustical features thus becoming a different sound or a variation of it, every time it is dislocated from place to place. We are excluding the sound that is linked to a specific place, i.e., which is not playable in another room than the one it was conceived for. Rather we are motivated by a wider perspective of site-specific practices. One that includes place as a component of the sound, i.e., place would add a random layer to sound caused by the inherent acoustic differences between places.
The goal of this work is to search for the creation of links between place and sound without being constrained to a specific place. The sound work is movable from place to place without loosing his site-specific identity. Likewise, we wanted to engage both composer and performer in the interaction between place and sound.
A musical instrument provides both the performer and the composer with tools to access and achieve a certain musical idea. Also, it implies real-time action. Thus the development of a new musical instrument capable of performing the task of introducing place characteristics on sound composition, seemed to us the most adapted tool

to arrive to site-specific sound generation. At this point we added another question to our initial interrogation. Could we envisage a musical instrument that allows to add place as a creative parameter of composition in real-time? Could this instrument be used in several situations and different places?
The creation of new interfaces for music expression introduce a series of devices that provide a range of possibilities in music creation, this is particularly true in the case of digital interfaces. Due to the separation between gesture and sound production (sound generation is no longer physically coupled with gesture and the instrument mechanics), DMIs rely mainly in the links established between these elements by the designer.

1.2. Problem domain

This work discusses place-specific practices on sound and music composition, or the intersection of sound and place. In particular we present a new DMI especially conceived for the creation of place-specific sounds - Intonaspacio. The interaction context we propose for Intonaspacio deals with place integration on sound.
Our research work lies at the intersection among several disciplines - philosophy, visual arts theory, sound design, and musical instruments design. In this chapter we frame the concept of space within our research, we present examples where sound and place share a creative bond, and we explain our stand in relation to this problem. We start by reviewing the concepts of space and place within philosophy. Place, by its dimensions and especially by its close link with human perception, reveals to be the most suitable term to use in the framework of our research.

1.2.1. This must be the place

Space is a concept rather broad and difficult to define. Mostly it is a word widely used in several contexts and research domains. Observing the evolution of the concept along the history of western philosophy, we can trace two distinct paths: one linked with the idea of State (Casey, 1997), and another of an anthropological space, associated with Post Modern thinking (Casey, 1997), (Deleuze and Guattari, 1987), (Merleau-Ponty, 1962), (Husserl and Rojcewicz, 1997), (Heidegger, 1962). Several words appear connected with space, such as void, room, region and place (Casey, 1997) We will concentrate our attention precisely on the idea of place, namely in its relation with space. Place will help us to understand the main changes these two views of space convey. It is also the concept that is most adequate in the framework of this work [1]

The conception of space, until the beginning of the XIX century, was fundamentally rooted in a measurable view, where position is the main characteristic used to describe things in space. In this scenario place is simply a container to receive objects which has no particular characteristic except that of being transparent in order to receive different bodies equally. Jammer (Jammer, 1954) says it clearly when referring to the conception of space in the XVII century in physics: "place does not affect the nature of things, it has no bearing on their being at rest or being in motion". In fact, place is so under-appreciated that it almost disappears within the idea of an absolute space Absolute space was the norm, it is a consequence of God's work. A perfect space unreachable by our senses, that needs no external body to be defined as such. The idea of absolute space is strengthened by Newton (Rynasiewicz, 2012) when he tries to define absolute motion and resort to absolute time and absolute space conceptions. Newton maintains that there is an absolute space which our senses are incapable to reach. Our senses only perceive what he defines as relative space, a sensible space that one can measure and sense with the body (Newton cited in (Casey, 1997)). Place is part of space and, thus, since Newton conceives relative and absolute space, place can be relative or absolute, depending on which space we are referring to. Place exist as a consequence of bodies, they always have to be placed in time (succession of events) and space (situation). It does not bear any particular characteristic, even if Newton considers place in his theory, he relegates it to a second plane.

Descartes follows the same line of though, when mentioning this necessity of bodies that occupy and define place. Space is inseparable from matter. He does not conceive void - space without bodies that occupy it. Even so, Descartes suggest the existence of two different places, an internal place that "is exactly the same as space" (Descartes

[1] Space is commonly seen as a vast and limitless entity, while place has boundaries and presents a level of intimacy scarcely found when talking about space. Site-specific art tends to deal with places more than spaces, since it recollects the particularities of a limited and reachable entity.

cited in (Casey, 1997)), and an external place. The former refers to magnitude and size of the body that occupies the place, external place is the description of it in relation to other bodies. The particularity of place is then this situational characteristic.
We should note here that we are dealing with relational entities, if we reduce space to position, it is always a position in relation to a fixed point. And if place is just a position in space, thus is measurable and identifiable in a x, y and z coordinate system - the underlying idea of Descartes' Cartesian model (Casey, 1997). This reduction of the importance, and especially the independence, of place regarding space (place does not have any particularity and thus it disappears in space), is developed further by Kant [2]. Kant (Casey, 1997) presents place as a mere point in space, a point that is always in relation to other points in space. These relations can be represented by measurable distances.

It is exactly when we reach a complete abstraction of the notion of place, that we assist to a change in this theory. The introduction of the human body and mostly of the human perception conveys a new vision of the definition of space. Leibniz (Casey, 1997), (Khamara, 2006) is the first to consider the human asymmetries, the difference between the left and right part of our body, as an important factor to differentiate locations in space, introducing the *analisus situs*, later developed by Kant (Kant et al., 1992). *Analisis situs* is an attempt to describe geometry without reducing it to algebra. Leibniz presents the concept of congruence instead of equality to justify the importance of viewing the object in space and in relation to other objects and not as an isolated entity. The example he presents refers to our hands, left and right hand, which although identical, they cannot change places in relation to our body, we cannot switch the left hand by the right hand, for example. Leibniz also introduces a quality in place that is of utmost importance for us, place reflects itself in the bodies/objects it contains, "to be in a place seems, abstractly at any rate, to imply nothing but position. But in actuality, that which has a place must express place in itself." (Leibniz cited by (Casey, 1997)) .
Kant precedes this thought by referring to the importance of the body and our senses in the conception of space, focusing in the feeling of something that is external to our

[2] Later Kant introduces the body in the definition of place

body. One cannot place something in space without this feeling. “The concept of space is not abstracted from outer sensations. For I may only conceive of something as placed outside me by representing it as in a place which is different from the place in which I am myself; and I may only conceive of things outside one another by locating them in different places in space” (Kant et al., 1992). This same notion of externality is also developed by Merleau-Ponty (Merleau-Ponty, 1962), which is based on the idea that we construct a body image in reference to it. This externality, or the way we construct the limits of our body, is situational. Merleau-Ponty (Merleau-Ponty, 1962) says that we adapt it to the task we are performing and to the level of knowledge we have of a certain instrument. As an example he refer to a blind person who will include in its body image his cane (he embodies the instrument). The perception and orientation we have of space is always made in relation to our body (Merleau-Ponty, 1962).
The human body and especially human perception is introduced more and more in the definition of space and especially of place. Place then regains importance because of its human proportions (unlike space that is vast and boundless, place has perceptible boundaries).

According to Husserl (Husserl and Rojcewicz, 1997), the composition of space, the way objects are disposed in space, or the way we perceive it, is accomplished through kinesthesia - the movement of the body. Our displacement along space allow us to have several perspectives of the same object while discovering space. It is similar to the underlying idea of cubism (Fry, 1966), the object is standing in the same position and the painter draws it in all its perspectives. In a real situation, the object never presents itself in all its perspectives, the only way to perceive it as a closed entity is through movement. When we displace in space two things happen: the object expands and conceals. Expands in our field of vision, allowing us to see the previous concealed parts of the object; and at the same time conceals the ones we were able to see the moment just before (Husserl and Rojcewicz, 1997). Our perception has the ability to reconstruct the object by adding and extracting these several images of the same object. At the same time, they all present a qualitative discontinuity - the quality objects have which allow us to distinguish between each other. Either way the body is not only a decoder and decoder of objects in space but, and of utmost

importance to us, “an active participant in the scene of perception” (Casey, 1997). The way I displace my body in a place produces the image I’ll have of it. We should point that Husserl is no longer referring to space but place, because he uses a human scale. A body is always an “implaced entity” and it is central to define place. We no longer see place as a quantitative entity but as something with characteristics that can only be experienced by the human body, such as color, texture, depth and so on. Merleau-Ponty (Casey, 1997), (Merleau-Ponty, 1962) expands this idea of movement/displacement by introducing two more concepts that are important to us - enaction and dwelling. Enaction (Varela et al., 1991) or enactive knowledge is a concepts from learning theory that explains that certain tasks are easier assimilated by action. These tasks can include riding a bike, cooking, playing a musical instrument, and so on. It is normally associated with tasks that include manipulation of objects. Merleau-Ponty (Merleau-Ponty, 1962) uses the term enaction to refer to the action of ramble as a way to perceive and experiencing place. Especially because Merlau-Ponty understands that the human body is the only capable of give particularity to a place, and disconnect place from space (whose characteristic is the universality). The embodiment of a place consequently allows the body to inhabit that place. The body is not in a place, it inhabits it, “The places we inhabit are known by the bodies we live. (...) we cannot be implaced without being embodied” (Merleau-Ponty cited in (Casey, 1997).
The act of dwelling or inhabit a place, and especially the intimacy that arouses from it, are important concepts to Heidegger (Heidegger, 1962) and Bachelard (Casey, 1997),(Bachelard, 2008), when explaining the importance of place.

Heidegger links space with place in a very complex tie. Place is no longer the container nor a smaller version of space and thus reachable by the human senses.
At the early stage of his thinking, Heidegger continues to associate this same idea of situational, of task with an instrument (named by him as the ready-to-hand [3]) to place, but instead of defining a body image from it as Merleau Ponty (Merleau-Ponty, 1962), he suggests that place is created after this action. Although body is referenced, he does not introduces the human body in the construction of place, at

[3]in the original “zuhanden”

least not directly. The “Dasein”, the human being as Heidegger defines it, has as his permanent condition Being-in which combines dwelling and inhabiting, thus place. Place is not provided by space, it is created by the sense of gathering and nearness of the ready-to-hand, the action of Dasein of “bring-close” (Casey, 1997) The closeness here, however, is not a matter of distance, measurable distance as in the Cartesian model proposed by Descartes. Instead Heidegger suggests that the distance is regulated by the place itself, by the boundaries of that place. Limits or boundaries are an important characteristic of place, there is no place without it. Still these limits can be pushed or even broken by the creative act, when the Dasein leaves its familiar area. We see in Heidegger again this idea of embodiment, which Merleau-Ponty (Merleau-Ponty, 1962) had already suggested. When the Dasein leaves his place, he breaks the limits of that space. This act is classified by Heidegger as a violent one, because when the Dasein destroys the boundaries it also destroys the place itself, since there is no place without limits. However this creative act can happen only when place happens, i.e., when boundaries exists. Consequently there is a precarious balance between the generation of place by bringing ready-to-hand closer and the destruction of place, by the creative act.

Another important term in Heidegger's concept of space is the one of Region. A Region is something that exists prior to place and includes a combination of places. It is not anymore the action of the Dasein that creates the region. A region is where the Dasein will move to reach the instruments (the ready-to-hand). By his movement of gathering, of coming close to the ready-to-hand Dasein creates place. Creating place however imply not just being in the immediate surroundings of a thing but to share its location. Yet, this place is also placed within a region. The regions are the ones that create room for things and thus the ones that create space. So regions are in-between place and space, mediating these two concepts. This is not a new idea however, Bruno (Casey, 1997) had already proposed that there was a mediation between place and space and that this was done by room (giving space to something). Room is a concept that suggest bigger dimensions than a place or the capacity to hold a bigger number of things. Regions are still within a human scale - they are not infinite or amazingly vast as space, we can still reach its boundaries. What is new in Heidegger is the inversion of roles, space does not create place, on the contrary, it is

created by place through the regions, i.e., places are inside regions, they are a way of giving place to things, and regions make room for this things, thus creating space. We should note that space does not locate, so place is always needed for things to have a location. "Place, then, is no mere part or portion of Space as Locke and Newton, Descartes and Gassendi had insisted. On the contrary: space is part of place, belonging to its gradual ontogenesis and implicit in it." (Casey, 1997)
It is important to acknowledge that Heidegger understands place within his study about space, place is not the main focus of his work but becomes increasingly important because it is the responsible for the creation of space.

On his book, "The Poetics of space", Bachelard presents a review on the link established between the perception of space and the degree of intimacy of that space. Intimacy is what guides our view and memory of a place, and the image we make of it. In "Poetics of space" we observe a hierarchical progression of intimacy, from the image of the house to the one of the round (the peak of intimacy according to Bachelard). This is a phenomenological approach of space. Phenomenology is one of the main philosophical currents studying space in the XX century, since the concept of space and particularly of place, drifts from a pure dimensional and measurable view to a perceptive one where the human is at the center - the anthropological space (Kaye, 2000).
In intimacy we dwell in the space, and this is closer to Heidegger, but Bachelard believes that the space is reflected in the body that inhabits it. Place is once more not a container but something that has its own inherent characteristics which are transposed to the bodies it houses. This idea of reflection was already presented by Leibniz (Casey, 1997), although Bachelard goes further with it by suggesting a bidirectional relation between place and body. "A bodily thing is extended through its qualities in(to) a given place, and the extension of place in turn results in space as the scene of coexisting things"(Casey, 1997). Bachelard leads to a new level of engagement, where the qualities of place are reflected in the behavior of the person who inhabits it. This characteristic however is not common to all places but only to our home, to the place where we feel sheltered and protected. It is almost as we

humanize place, giving it qualities that are ours - "Je suis l'espace où je suis" [4] notes Bachelard at certain moment in the text.
An important point brought by Bachelard is that boundaries of place are no longer absolute, they can expand or contract according to the perception we have of that place - the memories and also the content, i.e., the bodies that occupied it. This is especially important for our work because there is an underlying idea of mutual involvement of both actors in this relation - human and place. If on one side place triggers memories and different feelings, on the other side these will contribute to the vision one makes of place and its surroundings. The content can have influence in where one establish the boundaries of a place, sound for example makes it very clear. "Rien comme le silence sugere le sentiment des espaces ilimités. (...) les bruits colorent l'extension et créent une éspece de corps sonore." (Bachelard, 2008) [5].
The increasing of intimacy of a place implies an adaptation of the space to the body of the observer (Bachelard, 2008), inevitably a place where one feels absolute comfort is one where one perceives the boundaries of that place as perfect.

Deleuze and Guatari introduced an idea of different space organizations, and behaviors towards them, corresponding to the type of social organization in humans: state or war machine (Deleuze and Guattari, 1987). The war machine correspond to the nomad societies organized around clans and tribes were power is maintained due to mutual agreements in order to attain certain goals that are shared by most. Contrary to a State where there are mechanisms that organize and maintain power. The main difference between State and nomadism is the existence of a model. State starts from a model and always need to find a model, a constant, homogeneity is very important. The war machine, on the contrary, adapts itself to what happens on the moment, is situational, solutions are found to certain problems at a certain time, they do not necessarily become a solution used in all similar problems. These distinct approaches are reflected in the way space is composed. State has a "striated space" that is delimited "by walls, enclosures, and roads between enclosures" (Deleuze and Guattari, 1987). Nomadism corresponds to what Deleuze and Guattari

[4] "I am the space where I am" in L'état d'ébauche. Nõel Arnaud. Translated by the author.
[5] Nothing suggests limitless spaces like silence. (...) noise colors the extension and creates a kind of body sound. Translated by the author

call the smooth space "marked only by "traits" that are effaced and displaced with the trajectory" (Deleuze and Guattari, 1987). We are confronted again with a space that has no fixed limits. The striated space is the one in which the limits are defined through the displacement of the humans that explore it. We come back to the idea of kinesthesia and enaction, already enunciated by Husserl and Merleau-Ponty; and at the same time we encounter the same idea that Bachelard had previously suggested, changeable boundaries (although the context is rather different).
Although we are not trying to transpose concepts of social organization to our context of site-specific sound art, it seems that this notion of smooth space is pertinent to the representation of place in our realm. Deleuze and Guattari (Deleuze and Guattari, 1987) suggest that this dichotomy between striated and smooth space can be applied to other domains. What seems important to retain from this division is that smooth space does not have a fixed center. Place is built through the displacement of the nomads along space, therefore the center of this place - the point where we can discern the limits of the place, are defined by the position of the nomad, thus always mutable, always variable. Several centers are conceived since place does not have a fixed location and boundaries. Places in smooth space do not have clear directions, still places are localized. The nomads perform operations, local operations that themselves generate place. Following the idea of Heidegger of this instrumental places where the creation of place is dependent on the action of the Dasein approaching an instrument. The exploration and discovery of space and hence the production of place relies in a tactile behavior of the body. Deleuze and Guattari explain that "Smooth space is a tactile space, or rather 'haptic', a sonorous much more than a visual space. The variability, the polyvocality of directions, is an essential feature of smooth space of the rhizome type and it alters their cartography" (Deleuze and Guattari, 1987).

Human action as creator of place

Place regains significance with a new idea of space brought by some philosophers of the 20th century, mostly due to the increasing importance of the role of the human body. Phenomenologists, in particular, accentuated the role of human perception and human memory in the definition of space and specifically place, because it reflects a human scale. This is the main contribution from philosophy to the concept of space

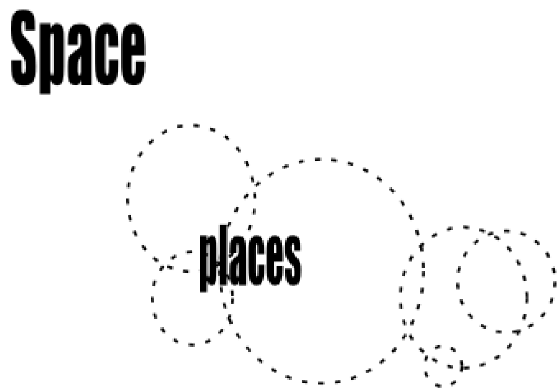


Figure 1.1.: Place is generated by human displacement in space

- the introduction of an anthropological space (Merleau-Ponty, 1962), (Augé, 1995), (Kaye, 2000).
Place is no longer a container within space, this vast and limitless thing, but rather a volatile entity that is created through human action (Heidegger, 1962), (Merleau-Ponty, 1962), (Husserl and Rojcewicz, 1997), (Deleuze and Guattari, 1987), (Bachelard, 2008) which the boundaries are discovered and created through human displacement We are no longer in presence of a box with specific dimensions, where one can go from one point to another, but rather something that is generated through action, with no clearly defined directions and no fixed center. The human body establishes the center since place is no longer external but dependent of human action and perception. As consequence we can have several places that are created with many centers that intersect with each other, as we can see in Fig. 1.1.

In our research work this notion of place is of utmost importance. If, instead of the nomad, we picture a performer that explores place, his trajectory is aleatory and he discovers and creates different points of action that becomes the center of these places. To discover a place through enaction meets our intention of having a performer using a DMI to search for particular resonant areas of a room. Therefore we understand this behavior as being closer to one where place is determined by perception (specially sonorous in our work) instead of a place with fixed dimensions where the performer can move from one specific point to another. The action of the performer, through which the performer discovers the acoustic behavior of place should imply a displacement in that place. Besides, place on a site-specific [6] framework is mostly interested in dealing with themes such as human perception and memory, than a functionalist thinking.

1.2.2. Site-specific art

"If you want to change a sculpture from a site, there is something wrong with the sculpture" (William Tucker cited in (Know, 2002)).

William Tucker's statement affirms that site-specific art entails in its genesis the appropriation of space and its characteristics on the conception of the artwork. Space, or rather place, is the locus where the work of art is presented, is the performance place. Site-specific art is grounded by questions of presence and location. The main idea is that the work captures some of the characteristics present in the place where it is presented, in such a way that it cannot be moved to another place, it belongs there, it is placed. As Richard Serra observes about his work Title Arc exhibited at the Foley Federal Plaza in Manhattan in New York, and removed shortly after, due to controversies, "Titled arc was conceived from the start as a site-specific sculpture and was not meant to be "site-adjusted" or "relocated". Site-specific works deal with the environmental components of given places. The scale, size and location of site-specific works are determined by the topography of the site, either it be urban or landscape or architectural enclosure. The work becomes part of the site and restructure both conceptually and perceptually the organization of site." (Serra, 1994). [7] Place then becomes another parameter of the creative work.
Integration of place normally arrives in two distinct ways. One where the physical characteristics of place are taken in account - size, scale, textures, etc.. Another where subjective features are more important - memory or political events among others. There is an appropriation of the place by the artwork, as Know points out "a work integrated with a site, a work that would seem to emerge so naturally from a particular place, whose meaning is so specifically linked to it, that it could not be imagined belonging anywhere else." (Know, 2002)

[6] we are referring here to the artistic domain - site-specific art, that we will introduce bellow
[7] The quotation marks were introduced by Richard Serra

Site-specific art brings a new "condition of reception" (Kaye, 2000) of the artwork. It is no longer just an interaction between the work and viewer but a third element enters in this relation - place. Douglas Crim (Kaye, 2000) notes that the viewer redirects his/her focus to place. Site-specific art displaces the attention of the viewer from the artwork to place. The artwork is the catalyst for reaching place. The goal is to make place less transparent and give sense to a specific location. We are always in presence of an actual place, which has its own uniqueness. Characteristics such as originality, authenticity and singularity are transposed from the artwork to place. This justifies why, with performative arts like music, the same piece can be presented in several places and always have a different significance. The approach is completely different from the one that modernist sculpture followed and to which site-specific art was against, sculpture is no longer in a pedestal and it's no longer movable from one place to another, neither the work of art is a reference to itself. As Know states, works "were conceived as autonomous works of art whose relationship to the site was at best incidental". Site-specific art produces works of art where place "should influence, if not determine, the final outcome" (Know, 2002).
Time, as Kaye (Kaye, 2000) refers, is as important as place, since the moment at which the viewer is in the place contextualizes this relation. Changing the place of the art work will implicate also a change in its meaning, once there is a modification of the one elements that are present.
Three elements are in relation here, place, artwork and viewer, and only when this triad is completed the work gains its full meaning (Suderburg, 2000).The viewer has to be physically present and share the same space of the artwork. We can probably establish a link here between site-specific art and the definition of Open Work from Eco (Eco, 1989) although we are not exclusively referring to openness of meaning but mostly to a openness to space. Meaning is built from the encounter of the work of art with the place through the perception of the viewer.

Site-specific art is often associated with public art. Know (Know, 2002) presents three main categories of site-specific art- art in public space, art as public space and art in the public interest. The first category is actually closely related to the definition of public art. However we do not understand site-specific art as being the same as public art. Know (Know, 2002) suggests that the accessibility is what defines a work of art as public. In theory any work that is outside the gallery and the museums can be considered as public art. Knight (Knight, 2008) however maintains that this definition is an oversimplification, he suggests instead, that public art should be defined as an artwork with which public can engage. This certainly opens the range of possible works of art included in this category, because in theory the public can create a relation with almost any artwork. We will then remain with the accessibility as the main element, and consider engagement as a feature that would derive from it. We can already establish some differences between public art and site-specific art. Public art does not necessarily, in its definition, integrates space. Several statues, for example, are placed in certain squares can be easily moved from one place to another without loosing significance. Likewise not all site-specific art is exhibited outside museums or galleries.

Site becomes place

Site, in literature is mainly associated to an idea of neutrality, of a plain space whose only function is to accommodate a body that is passing-by (Casey, 1997), (Kaye, 2000). Site is either a transitory location where bodies (people and objects) do not stay for too long, and thus do not create any kind of relation with it (Kaye, 2000). Site is an "abstract place" (Leibniz cited (Casey, 1997)), there is no relation between it and the bodies that it holds. Place, on the contrary, reflects its characteristics in the things placed on it, as Leibniz states "what is in place expresses that place" (Leibniz cited (Casey, 1997)).
If we adopt a functionalist view, site is the location of certain buildings, the ones which have administrative functions such as libraries, the Parliament, Courts, and other buildings designed to convey certain functions (Casey, 1997). Site is innocuous, does not have internal characteristics and does not have any possibility to influence what it is in it. Site is connected with an idea of seriality, something that exist in series.
Although the premises which underlies both visions are quite different from one another, one suggest site relates to transitory passage and the other with function; both can relate to the concept of non-place of Marc Augé (Augé, 1995). A non-place is a space where one is unable to relate to, intimately, to construct an identity in relation

with that location and thus does not have a memory that identifies it. Airports, supermarkets, hotels, train stations among others are examples of non-places (with some exceptions). These are the spaces where we do not stay, where our passage is ephemeral and where there is a strong trace of "solitary individuality" (Augé, 1995). Individuals cannot establish connections with each other and specially with space, consequently solitude is the main attribute of a non-place. The only relation we are able to do with a non-place is, according to De Certeau (de Certeau, 1984), through images and words or numbers (the plane ticket, the information about the track number, the boarding gate), this creates an abstraction of space. From here we can easily, and supported by Augé itself (Augé, 1995), (Merleau-Ponty, 1962), translate the two concepts introduced by Merleau-Ponty (Merleau-Ponty, 1962) - geometric space and anthropological space to site and place, respectively.

Instead, place, as we have seen, carries a meaning related with intimacy and dwelling. To create place, time is always a requirement. We do not face transient situations when we deal with it. As De Certeau (Augé, 1995) suggests, place is always connected to memory or to something that had happened, that took "place". Likewise, when we deal with site-specific art we are not referring to a non-relational space. What is always present in the relation between artwork and viewer is a place where is not only possible but desirable to produce a relation of intimacy. Thus site-specific art needs places more than sites.
We then think it is appropriate, in the framework of our research, to rename site-specific to place-specific art from now on.

1.2.3. Place-specific sound art

Since our research deals with sound and place-specificities in sound, we will have to modify the triad (presented in the previous subsection) with new elements more related to our work. In this context we will use sound artwork, performer and performance place instead of artwork, viewer and place, respectively. This connection shapes a bidirectional relation between sound art work and the performance place, i.e., is not only sound that fills up place but also place that changes the way the sound work is perceived. Sound reflects the acoustic characteristics and properties of place - reverberation time, resonances, as well as place modulates sound and how we understand it. Thus, a place-specific sound work requires two main conditions:

- the sound work belongs to a place and expresses it. Place has a sound body with unique acoustics and it influences the content of the sound work.
- as consequence of the first premise, the perception one has of this place is re-configurable according to the evolution of the content of the sound work.

Sound on place

Bachelard (Bachelard, 2008) presented the relation between sound and place as the one responsible for defining the boundaries of a place. Silence would represent a limitless space while sound would limit and confine it. Hence sound would give the means to transform space in an adjustable place - whose boundaries were contracted or expanded depending on the existence of sound or not. Place itself could be re-design, perceptually, along with the sound present in the room.
Similarly, Murray Schaefer (Schafer, 1994) when introducing the discipline of Soundscape Design, mentions this intersection between sound and space perception. One of the characteristics of sound is, precisely, to inform about the space where it is. Muecke (Muecke and Zach, 2007) reinforces this idea by stating that "the reverberation of sound in space and the quality of reflected sound, both affected by geometry, proportion and material - in other words, by architecture - could considerably enrich the sense of volume and space". Low and high frequencies give different perceptual images of space and contribute to modulate the boundaries of a place. Schafer (Schafer, 1994) presents a connection between them as can be seen in table 1.1.

Schafer (Schafer, 1994) presents bass sounds as responsible for creating a feeling of immersion, that involves creating something like a sound wall (where no dynamics are perceived in the sound, it is a dense mass). High pitched sounds, on the contrary, are always perceived as having a source for which one can discern the location. This creates a feeling of facing something that is concentrated, where one can have a perspective and where changes in dynamics are recognizable. Clearly none of this is new, but what it is interesting for us in this table is the notion of a modulated place based on sound. Carpenter (Carpenter and McLuhan, 1960) insists in this same idea,

Table 1.1.: *Perceptive features of high and low-frequency sounds according to Schafer (Schafer, 1994)*

High frequency	**Low frequency**
Sound has a source	Sound involves
Perspective	Presence
Dynamics	Sound wall
Concentration	Immersion

when he suggests that the auditory space, the space defined by the range of sounds perceptible to our ears, “It’s a sphere without fixed boundaries, space made the thing itself, not space containing the thing. (...) dynamic, always in flux, creating it’s own dimensions moment by moment. It has no fixed boundaries”. Carpenter justifies this volatility of auditory space in the ear’s characteristic of having a wide range of attention, unlike the eyes. Similarly Labelle (Labelle, 2006) understands sound as something that can help us to access space - what we listen in a place is really a convolution between the original sound and the response of the room, “as the wave travels, it is charged by each interaction with the environment” (Barry Truax cited in (Labelle, 2006)).

The questions raised by this relation are not new tough. Greeks already had several studies on room acoustics, but we are not interested here in doing a full review of the history of room acoustics. Instead, we will present some examples where space is more than a physical parameter (adapting the acoustics of a room for a specific task like voice emission or classic music, etc.) but a truly creative inclusion to sound and music composition. Examples where place is part of the sound artwork and not canceled.

Saint Mark’s Basilica in Venice in Italy has a particular acoustic feature. The two choirs of the church are facing each other at a great distance, thus the time sound takes to go from one to another is quite large. Giovanni Gabrielli (Pratt, 2007) Italian composer of the XVI century and headmaster of the Basilica’s Choir created the Venetian polychoral style which took in account the latency caused by the acoustics of the church. He integrated the characteristics of the place as a creative

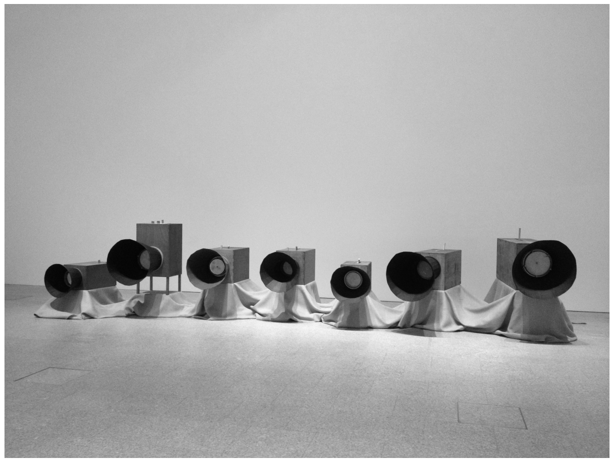


Figure 1.2.: Replicas of Intonarumori.
Source: Mailis Rodrigues

element of the vocal performance.

In the 20th century it is possible to find many examples where the assimilation of space in sound and music creation is patently obvious. This is done in several directions. Firstly, by widening the range of what is considered musical. The futurists and Luigi Russolo in particular when he publishes his Manifesto *L'Arti dei Rumori* (Russolo, 1986) where he proposes the integration of noise as a source of musical creation. Russolo states that in an industrial era is incomprehensible for composers to continue to create always the same music, limited to a closed set of sounds. Intonarumori, Fig. 1.2 the instruments designed by him, are an ensemble of musical instruments that reproduce several daily noises - wind, machinery and so on.

Yet, Intonarumori do not simply mimic these sounds, their qualities (frequency, timbre or rhythm) can be modulated. Russolo states (Russolo, 1986) that even if they are inharmonic, these sounds have a fundamental frequency, and thus are a viable choice in sound creation. Later, Pierre Schaeffer (Schaeffer, 1966a) introduces the concept of *objet sonore* and *musique concrète* and John Cage presents music as an organization of sounds (musical and non musical, i.e. noise). Daily life sounds are increasingly introduced in music. We no longer can remain in the classic concept of music (Labelle, 2006).

Secondly, composers search more and more for unusual performance places, different from the traditional concert hall. Erik Satie (Vogel, 2010) proposes the *Musique d'Ameublement* in a manifesto with the same name. This new genre did not address particular questions of place-specific sound art, Satie searched for functionality more than a relation between place and sound. The intention was to compose music which, like any other piece of furniture, had a function in the space where it is placed, even purely ornamental. Musicians were distributed around the room and audience should behave as if there is no music playing at all. Cage (Cage, 2009) notes that the goal of *Musique d'Ameublement* was to create a music that is lost in the place, i.e., that does not cause people to notice it. As a consequence music would become a piece of furniture like all other in the room, or better, like any other sound in the room [8]. John Cage composed for Muzak (Vanel, 2008), a system for music ambiance in public spaces such as restaurants, elevators, hotel lobbies where the goal was to disseminate music, easily unnoticed, through speakers installed in the space. Cage's first attempt was the Silent Prayer, a composition of almost 4 minutes of silence that was never played in the Muzak system (Vanel, 2008). In a text called "Rhythms, Etc. the Muzac-Plus", Cage suggested an aleatory music created by the movement of people in the room, the listeners would be at the same time performers and composers. This idea, as Vanel (Vanel, 2008) observes, was never implemented: "No work by Cage bears the title Muzak-Plus, and it would seem reasonable to assume that it has actually never be given any other form than a written one: a dream of a music that would rely only on the constant flux of a crowd of listeners whose interaction with the space would actually generate the musical execution". Even so, after an invitation from the sculptor Richard Lippold, both proposed a similar project as the musical accompaniment of the sculpture Lippold created. The room would have a Muzak system and an ensemble of noise generators. When people walked by the lobby they would trigger a set of sounds previously recorded by both of the artists and actuate the Muzak system that would had a number of Cage compositions ready to play. Once more this idea presented some problems, and in the end only the sculpture was

[8]It is important to make a remark about the intentions of Satie. His proposal is primarily to demystify the social event of the music concert. Satie makes an effort to deconstruct this paradigm but with this act he transforms the performance place radically and thus also modifies the perception the audience has of the place.

presented. This however was the idea that later become Variations V.

Thirdly, composers search for new architectures for the concert hall, more suitable for the music they compose. The Phillips Pavilion at the Expo 58 at Brussels, designed by Le Corbusier and Xenaquis for the public presentation of *Poèmes Electroniques* from Edgar Varèse, is a good example. The pavilion was inspired by hyperbolic and parabolic figures, it had a sound system with three hundred and fifty speakers, plus a video and light system that ensured a total immersive experience.
Another example is the German pavilion at the Expo Osaka in 1970, the first spherical concert hall. The aim was to create an immersive experience with sound where the audience was surrounded by sound. The room was conceived in order to allow different combinations of sound spatialisation, not only through the distribution of the musicians around the room but also through the technical apparatus - the room was equipped with fifty five loudspeakers assembled in seven circular rows around all the surface of the pavilion. The audience was sat in a platform under which there were more speakers, which gave them a sensation of the sound moving around the room. Stockhausen explains the sensation he searched for the audience: “To sit inside the sound, to be surrounded by the sound, to be able to follow and experience the movement of the sounds, their speed and forms in which they move: all this actually creates a completely new situation for musical experience.” (Stockhausen cited in (Kurtz, 1991)).

Stockhausen example refers to spatialisation of sound. Let us make a parentheses here, to explain that we are not, in our research dealing with spatilisation questions, place-specific is not equivalent to spatialisation. Sound spatialisation refers to the output of the sound, it is the design of the space as the way sound will travel in it, as (Nunes, 1994) explains: spatialisation is oriented perception. Several techniques exist nowadays to perform sound spatialisation (wavefield synthesis (Berkhout et al., 1993)(Baalman, 2004), ambisonics (Malham and Myatt, 1995) (Daniel et al., 2003) (Baalman, 2010) and so on) but they all are applied at the end of the sound chain, see Fig. 1.3, with few exceptions (Schumacher and Bresson, 2010).
Place-specific on the other side relates to the input of space in sound. The aim of place-specific is to incorporate place and its characteristics within the sound art work,

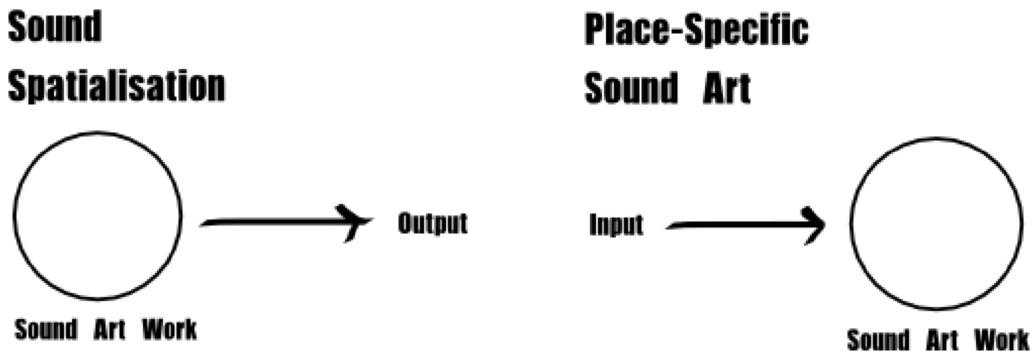


Figure 1.3.: Sound spatialisation vs Place-specific sound art

thus it cannot be added after the composition of the sound, once sound is created with it, refer to Fig. 1.3.

Despite the fact that sound spatialisation and place-specific sound art are in opposite sides of the sound creation chain, they are not incompatible. Emmanuel Nunes *Quodlibet* is a good example of the combination of both processes. This piece was composed exclusively to be performed at Coliseu dos Recreios at Lisbon, where he benefits from the acoustics of the room to spatialize the sound. Nunes knows how each instrument propagates in space and in which way the acoustics of the room will influence the timbre of the instruments. "(...) la mise en espace de n'importe quelle source sonore apporte en soi une diversification des phénomènes agissant sur la perception sonore (...)."[9] In reality, by placing the musicians around the concert hall, Nunes creates a relation between several elements - the distance the audience is from each instrument, the way each instrument diffuses in the room and finally, the different reverberations that each location in the Coliseu generates (Nunes, 1994). Nunes defines place as an ensemble of micro-specifities, acoustic characteristics that are particular to each location - propagation, amplitude, distance, direction, timber, filter, levels of recognition of the sound location and so on. These compose a filter or an envelope of "hauteurs et/ou de rythmes" [10], and defines what he calls *Espace composable*.

[9] "(....) the staging of any sound source brings several phenomena that influence sound perception (...)." Translated by the author.
[10] "pitch and/or rhythmns". Translated by the author.

The concept of soundscape introduced by Murray Schafer (Schafer, 1994) deals also with place-specificities. However, Schafer amplifies the specificity of place to a wider range. Soundscape design covers a multitude of situations, it can be a music composition, the content of a radio show or the sound ambiance of a room. Schafer introduces a new discipline in sound - acoustic design, where someone composes the soundscape of an ambient, how sounds are organized in space [11]. He classifies sound based in an sociological perspective where sound is a referent for the understanding of a particular society. Hence we can have a keynote sound - a sound that is defined by the geographical qualities of a place; a signal - a sound that detaches from the background, normally these are warning sounds such as sirens or bells; a soundmark - a sound which it is characteristic of a certain community; and finally an archetypal sound - a sound that prevails over time.

Acoustic design and the idea of soundscape has a broader range, that surpasses the one we are dealing with. Considering spatiality, we cannot speak of place anymore, Schaeffer's concern is with space, mostly. Yet, we can purpose a micro soundscape in every place. This micro soundscape is characterized by the organization of sounds that are present in this place composed by found and structural sounds. Both notions were introduced by Labelle (Labelle, 2006), found sounds is a reference to the notion of *objet trouvé* widely used in visual arts, these are the sounds that are in the place, roughly the sound ambiance of a room, or the Background Noise. Structural sounds are the ones that are part of the architectural structure, the resonances of a room.

Labelle (Labelle, 2006) notes that sound is inherently place-specific since it is always the result of a reflection within place and bears a portrait of it. Consequently he considers that sound art must always be associated with place specific, i.e., the history of sound art and place specific art should be linked. Sound is "boundless on one hand and site-specific in another".

In Background Noise, Labelle presents an extensive review of place-specific sound art. It is not our intention to undertake the same task here, instead we will present three works that demonstrate different ways of integrating place in sound.

[11] Shaeffer here refers to space as a city or the countryside

Silence as an open door for place

When Cage starts to think about silence in music, first in Silent Prayer - the piece composed for the Muzak system that was never executed, he starts to think in a way to introduce place in the music composition. Cage presents silence as the ensemble of non-intentional sounds, i.e., sounds that are not produced by a performer. Silence represents, according to LaBelle (Labelle, 2006) the epitome of the connection between daily life and music, trough it we have access to the architecture of the place. Silence is the ensemble of found sounds, and 4'33", the silent composition of Cage(Cage, 2009), (Joseph, 1997) is actually an *assemblage des objets trouvés* - sounds. The composition enables the listener to perceive place, by listening to the sounds that are associated to place without any external intervention - the performer does not produce any sound. The place is responsible for the material [12] of the music composition, when Cages chooses where the performance would be held, he is actually choosing the sound material. He starts from the premise that silence does not exist, "There is no such thing as silence. Something is always happening that makes a sound. No one can have an idea once he starts really listening" (Cage, 2009). What prevails here is the act of listening, there is no external sound to the ones that are in place. The audience can listen attentively to place. It is in this context that LaBelle (Labelle, 2006) does the association with visual arts when he classifies this sound as found objects. Like a Pop Art artist, Cage works with the sounds he finds.

Silence and sound share the same features. Cage introduces the "total sound-space, the limits of which are ear determined only, the position of a particular sound in this space being the result of five determinants: frequency or pitch, amplitude or loudness, overtone structure or timbre, duration, and morphology (how the sound begins, goes on, and dies away)." (Cage, 2009). To change one parameter in any sound is to alter its position in space. We can, therefore, control the position of sound, by controlling these elements.

Silence was already used in music before Cage but, as he explains, the focus was substantially different (Cage, 2009). Silences were used to punctuate, to highlight a

[12] Cage considers three elements in composing music - material (sound and silence), method ("note-to-note procedure" (Cage, 2009)) and structure (the length, the "division of the whole into parts" (Cage, 2009)

structure and to emphasize certain sounds. If not used with these purposes, silence becomes sound with random and unexpected behavior since it is a non intentional sound.

Where sound meets acoustic

Michel Ascher's work (Labelle, 2006), (Ascher, 1983) searches to fuse the exterior with the interior of the art work. Ascher modifies the architecture of the room as to enable the sounds, the lights and the air flow from outside to enter the room, and once inside, place is modified in such a way that it amplifies or absorbs the exterior elements (using walls with damping properties, or sound generators tuned to resonate with the room, playing with white and black walls to reflect or absorb the light, and so on). By acting on the acoustics of the room, he fully integrates place in the work. What the viewer enters is the core of the work, instead of viewing it from the outside, he is inside, and he is forced to orient the perception to place itself.
At La Jolla Museum of Art, Ascher transformed the room of the museum in a sound absorbent room, where the walls, ceiling and floor had damping materials. He used one tone generator, one amplifier and one speaker placed in the entrance of the room. The sound generated had the same frequency as the stationary wave produced by the walls of the room. An acoustic phenomena took place, the tone generated by the oscillator was amplified and at particular points, where the waves concealed each other (the wave generated by the oscillator and the stationary waves) there was no sound at all. Viewers were led to focus their attention to place, and particular to the way place modulated sound.
Spaces and the Installation at Pomona College, followed a similar approach to this installation, but in these, Ascher did not used a sound generator, instead he utilized the found sounds of the museum (in Spaces) and of the surroundings of the gallery (in the installation at Pomona College). In both works, Ascher transformed the room as to generate acoustical and visual phenomena. Spaces was presented at MoMa (Museum of Modern Art), Ascher built a place within the place, a small room where sounds where gradually absorbed. The viewers, as they walked through the room would hear a lowering in the sound level until its complete absorption at the corner end of the room (Ascher, 1983). The work Ascher presented at Pomona College had

a very similar approach, once more the sounds that enter the room are the ones non intentionally produced, as Cage would note. The installation is composed of two different spaces, two triangles, in the first one the sounds are amplified and in the second one damped (Ascher, 1983). The idea in both works, is that the viewer could, as the viewer enters the work, be immersed in the work, forgetting the outside. Ascher however plays with this hybrid situation where, at the same time, the viewer is increasingly absorbed in the work and never completely abstract from the exterior. As Labelle suggests, Ascher constructed his installations with "the found environment as sound-producing source" (Labelle, 2006). Michel Ascher continues the approach of Cage, he also uses silence as the material of his installations, but at the same time he extends it, introducing the use of acoustic phenomena to direct the viewer to place itself.

Listening to place

In 1969 Alvin Lucier presented his sound installation *I am sitting in a room* (Labelle, 2006). The work consists in Lucier's voice recorded while he reads a text where he explains the procedure of the work. "I am sitting in a room different from the one you are in now. I am recording the sound of my speaking voice and I am going to play it back into the room again and again until the resonant frequencies of the room reinforce themselves so that any resemblance of my speech, with perhaps the exception of rhythm, is destroyed. What you will hear, then, are the natural resonant frequencies of the room articulated by speech." (Davis, 2003) The act of recording the same speech over and over again in space, will corrupt the sound little by little until we no longer are able to discern Lucier's voice but rather a slow lament where only the rhythm of the speech prevails. Lucier ground this work in an acoustic phenomena where the resonant frequencies of the room are excited by his voice. It is a process in time as well as in space. Feedback helps to make notice the filtering effect of place, in other words, the physical action of place on sound.
Lucier has been, since his early works, interested in spatial issues, namely this blend between acoustics and music (Davis, 2003). He creates these sounding places, where a precarious equilibrium is achieved between the several elements of the work (place, sound, viewer), and the smallest change cause "the space to sound" (Davis, 2003).

Quasimodo the great lover the work that followed *I am sitting in a room* proceeds with the same idea. A sound that explicitly carries the place characteristics in its composition. Yet, Lucier goes further, this time the sound does not stay in a specific place but travels through places. He describes the work "for any person who wishes to send sounds over long distances through air, water, ice, metal, stone, or any other sound carrying medium, using the sounds to capture and carry to listeners far away the acoustic characteristics of the environments through which they travel". (Lucier and Simon, 1980). We are no longer in a single place but confronted with sound as an object with memory, a material that gathers information about its traveling, just like a travelers' journal. Sound is place-specific and carries memory. It is a spatial and temporal phenomena.

Lucier's work no longer uses silence (non-intentional generated sound) as a material for his music, like Cage or even Ascher, instead he produces sound hints that trigger a response from place. In *I am sitting in a room* it is his voice that excites the filtering action of the room, in *Quasimodo the great lover* are the performers when they play. He combines sound art with acoustics. The structural sounds of the room (Labelle, 2006), the resonant frequencies that are dependent of the architectural structure of the room. Both the sound works are movable from one place to another, but the connection with place is not lost with the relocation (as Withman's statement suggests) because the tie is so deep that place is always present in the final sound outcome. The work is the same but the sound result is different because one of the parameters in the creation changed.

Lucier, Cage and Ascher achieved a total integration of place in sound, thus moving the work is not a problem because what is important is the link between both elements (place and sound) that reveals the uniqueness of each place.

1.3. Structure of the thesis

Sound art demonstrates that there is an unbreakable link between sound and place. Both influence each other. Still, we perceive in some works a more solid presence of place, where we hear its own sounds. This is not only obvious when Cage, for instance realizes the non-existence of total silence (silence as the absence of sound)

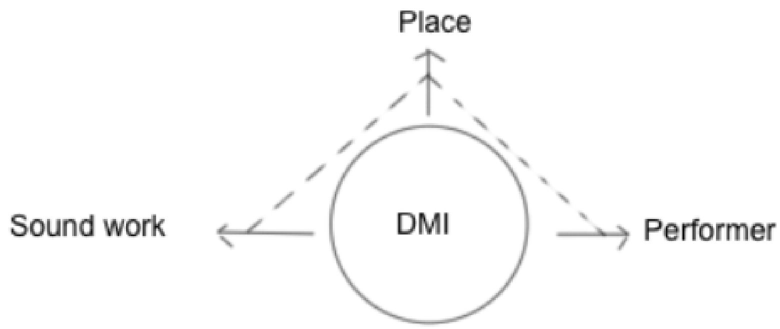


Figure 1.4.: Sound art place-specific triad with DMI as mediator between the actors

but studied by acoustics - a room has an inner set of resonant nodes that amplify and absorb certain frequencies. When amplified these are audible and can be used as musical content. Consequently, place can be understood as a musical instrument of its own, with a sound generator and a resonator system. Still these musical qualities are hard to control and to integrate in the sound work without easily producing feedback, and sometimes this is not the intention. Thus we purpose the use of a digital musical instrument (DMI) as a mediator between performer and place, in order to give control to performer over place. A DMI would then extend the possibilities of place. Hence, we purpose to change the triad of the work reception of place-specific art, to one where the musical instrument is the mediator between the three actors, refer to Fig. 1.4.

Our research work started with the question on how to create and control place-specific sounds? As a possible response we suggest the use of a musical instrument, precisely because of this capability of mediating between the two other actors of this relation - place and sound work. In a logic similar to one chosen by Russollo we also design a new musical instrument to explore new ranges of sound. Hence this dissertation is structured in three sections that revolve around Intonaspacio. In the first section we introduce some of the questions related to the design of a digital musical Instrument, comprising chapter two and three. Chapter two is an introduction to the definition of the DMI, where we present two premises that allow us to differentiate a musical instrument from a musical toy/gadget; and contribute to the longevity of the DMI: the existence of an instrumental technique and the creation of a repertoire devoted to the instrument. Chapter three includes a technical report on the construction of Intonaspacio. This chapter starts by introducing the issues we faced when integrating place's acoustical response as one of the features of Intonaspacio. It also describes the options on the frame material, choice of the sensors and their placement. We also present the three versions of the instrument.

In the second section, which comprises chapter four, we concentrate on the design of the Intonaspacio's mapping, namely by proposing three different approaches to create place-specific sound, and the different results these present. We have carried an experiment with users where we validate Intonaspacio through a questionnaire. We have recorded video and sensor data from each user in order to search for common gestures between users. The third section composed by chapters five and six, focus on the two premises to grant continuity to DMIs, previously presented on chapter two. In chapter five we design a gestural grammar of the idiomatic gestures of Intonaspacio based on the analysis of the experiment presented in the previous chapter, and on the conclusions of a second experiment we carried with an actor. Chapter six introduces the two music compositions developed during this research work and as a result of a collaboration with two composers.

Finally, we present a global discussion on the concluded work and present some possible research orientations for future work.

2. The DMI

This chapter introduces the notion of DMI and gestural acquisition. We understand a DMI as the combination of three elements: sound controller, sound generator and mapping layer. The sound controller can be included in the definition of tangible user interfaces (TUI), even if DMIs exist long before TUIs. [1].

Along the chapter we explain what are the main differences between a digital musical instrument and an acoustic instrument as well as the consequences of those differences. A DMI has a different conceptual structure that includes a mapping between the sound controller (the gestural interface) and the sound generator (the sound synthesis). Gesture is a complex concept and its definition is highly dependent on the research framework. We present some directives to understand the notion of gesture, centering it on the idea of musical gesture. Finally, we propose two important characteristics to distinguish a DMI from a musical gadget - the introduction of a musical technique, highly dependent of the idiomatic gestures of the DMI; and the creation of a repertoire.

2.1. A tangible interface

Tangible User Interfaces (TUIs) are physical objects that mediate the relation between user and digital information. They enable the physic manipulation of digital data. For a long time the interaction model between humans and machines was performed, with few exceptions (Hornecker, 2010), using GUIs (Graphical User Interfaces). GUis are the common graphical buttons, menus and windows which represent abstract data (calculations, access to digital functions and so on) that we control through

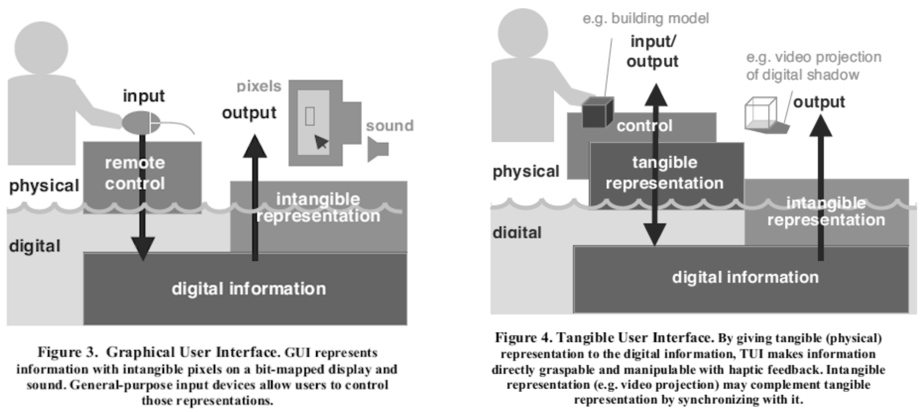
[1]Some DMIs have a non tangible interface as well. In this thesis we will concentrate on those who have it, since Intonaspacio is part of that group

the mouse and the keyboard. This approach, even if suitable for general purposes, has some important constraints that limit interaction. Namely it works based on a time-multiplexed (Ishii and Ullmer, 1997) system where the user can only control one window at a time. Also, GUIs not make minimal use of human skills to manipulate and grasp objects other than the computer mouse.

The idea of a tangible medium as the interface between human and machine had previously appeared in some works such as the Marble Answering Machine from Durrel Bishop in the 1990s (Hornecker, 2010) or some of the work of Robert Aish (Hornecker, 2010) or John Frazer (Hornecker, 2010) with 3D modeling for architectural purposes in the 1980s. However, tangible interfaces are only introduced in 1995 with the Graspable User Interfaces concept proposed by Fitzmaurice(Fitzmaurice et al., 1995), where he uses bricks as a way to control a digital image (zoom and rotation among other control parameters). Ishii (Ishii and Ullmer, 1997) a few years later suggested a new expression that covered a greater scope - Tangible User Interfaces (TUIs).

As proposed by Ishii (Ishii and Ullmer, 1997), (Ishii, 2008) Human-Machine Interaction (HMI) is based on two main elements: the control and the representation. Whit GUIs the interaction model is a Model-View Controller (MVc) where there is an input - the control, and an output - the view or representation. This model implies the existence of a great cleavage between the physical and the virtual world, as can be seen in Fig. 2.1. In the Model-Control Representation Physical Digital model (MCRpd), however, this cleavage is reduced because the control and representation elements are mixed within the physical object.

The input is also part of the output. For example, Intonaspacio senses the performer gestures (the performer can control the musical parameters with his/her actions) and at the same time creates the sound, so there is not a clear barrier between the input and output parts of the system. As Fig. 2.1 indicates there are two different representations, the physical and the digital. Representation in this context refers to the semiotic discipline, it is a sign (Peirce and Hoopes, 1991) that represents a real object, like an icon, a symbol or an index. In HMI it represents abstractions of the real world that the user can manipulate through a graphical or physical interface.



(a) GUIs interaction (b) TUIs interaction

Figure 2.1.: Differences between GUIs and TUIs interaction. Model proposed by Ishii. Source:(Ishii, 2008)

The main advantages of TUIs over GUIs were presented by Fitzmaurice (Fitzmaurice et al., 1995). TUIs seem to be more engaging, since they make use of the human natural ability to manipulate and grasp objects as well as our previous knowledge on interacting with objects. They are also more suited for specific applications, the TUI is designed for a particular task and is not easily transferable from one to another. For example, the Urp (Ishii, 2008) application where blocks of buildings are used to control the direction of light in an urban planning, they are designed to resemble buildings and it is hard to use it in an application where the goal were to design a flat interface like a musical carpet(Cardoso and Ferreira-Lopes, 2012). TUIs also enable two hands manipulation, which is a great advantage because we are no longer in a time-multiplexed system but in a space-multiplexed one(Ishii and Ullmer, 1997), (Ishii, 2008), where the user can perform several tasks at the same time in the same space.

In the musical domain TUIs were since their early appearance largely used. Jorda (Jordá, 2005) explain it by the great possibility they give to collaborative interaction, the possibility of having more that one user manipulating the same object in different spaces (telematic presence); the option to give a more intuitive approach to abstract parameters as in music; the manipulation abilities and previous knowledge performers have from antecedent experience with musical instruments; or the control of several parameters at the same time which is of great importance in music creation.

2.2. What defines a DMI?

Andre Leroi-Gourhan (Leroi-Gourhan, 1993) stated in his work Gesture and Speech, that humankind was born with the invention of language and of the instrument. According to him, this is the moment that initiates an evolution of the human being based on technology and not on a biological transformation as before. Even if this view is quite dated what is interesting in Gourhan is the view of the instrument as an extension of the human body conceived to compensate its inner limits. Especially, they free our mouth from an exclusively nourishing task and enable us to communicate. Musical instruments have the particularity of facilitate the creation and exploration of sound.

New instruments appear due to a necessity of new sounds and technological evolution. As Chabade (Chadabe, 1997) suggests, an electronic era demands for electronic instruments and a digital era demands for digital instruments. Still, the definition of musical instruments is also highly dependent on the time and culture of a society (Kartomi, 1990). A recent example are percussion instruments which until the beginning of the XX^{th} century were not classified as musical instruments. DMIs bring one major difference when compared to acoustical music instruments. The sound generation and the sound control are no longer coupled, instead they are related through a series of parameters that connects the extracted features of the DMI physical interface to the variables of a sound synthesis algorithm - mapping. Two main consequences arise from this: first, the sound is no longer a direct causality of the gesture; and second, the generation of sound is no longer dependent on a mechanical sound source.

This decoupling imposes a lack of intimacy (Cook, 2003), (Marshall, 2008) between the performer and the instrument. Intimacy that is present in the traditional interaction between performer and acoustic instrument. This deficit of intimacy is mostly

felt due to a lack of haptic feedback from the instrument [2], as well as the sensation that the sound is not produced by the instrument itself, and the latency it creates. The DMI is mostly felt as a controller rather than a musical instrument.
On the other hand, the detachment of the physical interface from the control body of the instrument brings a number of design possibilities, since we are no longer constrained by the mechanical and physical laws of sound production. The design of an acoustic instrument is directly related to the sound it produces, the size of a tube in a wind instrument defines the frequency it will generate, the size and thickness of the string fixes the size of the instrument itself. Bongers (Bongers, 2000) gives the example of a violin and a cello, the violin has a sound with more high frequencies than the cello that generates lower sounds, due, in part, to the size of the strings. The design of a DMI is freed of this physical constraints, so in theory we can design an instrument with any possible shape and produce any sound (with the digital synthesis algorithms, for example). Moreover this freedom of design allows the creation of interfaces that use different parts of the body, that are not commonly used to play an instrument, such as bio signals(Tanaka, 1993), (Miranda, 2011), (Miranda and Wanderley, 2006); musical instruments where there is no contact at all (Miranda and Wanderley, 2006), or even instruments that demand interacting with the whole body such as immersive musical instruments (Bongers, 2000), (Miranda and Wanderley, 2006).
At the same time, this also makes possible the creation of DMIs that can interact in different spaces - the telematic objects. Global String (Tanaka and Bongers, 2001) is an example of one. It consists of a string "coupled" from Paris to Tokyo and played by two performers, one in each town. DMIs introduce time issues also - latency, the delay between the command to generate sound and the sound reproduction, is a term mostly used in computer science and it is caused by the system processing. The ear is sensitive to delays bigger than 10-15 milliseconds (Barbosa et al., 2005), after which it no longer understand a sound as real-time. In network sound, latency is an important factor to deal with, in order to have both performers understanding the actions of each other. Several authors (Jordá, 2005), (Miranda and Wanderley, 2006)

[2] Currently there are some haptic devices that try to recover this feeling of intimacy (O'Modhrain, 2000)

defend that a DMI need to be able to work in real-time, unlike composition that is a non real-time situation.

In acoustic musical instruments it is impossible to separate the part of the body that is responsible for the generation of the sound from the one that controls the sound. Imagine a snare drum that a performer hits with a stick. The membrane that vibrates is the one that controls the sound and at the same time is also the responsible for the generation of the sound. The way an acoustic instrument is designed is very complex and all the constituents of the body contribute to the sound. This link is also responsible for a causality between the gesture and the sound produced. The snare drum, for example, when stroked by the performer, if the performer hits it softly the emitted sound would have a lower amplitude than if he/she had hit the snare with all his strength. Thus, there is a energetic continuum (Cadoz, 1999) between the gesture and the sound generated, that is not necessarily present when playing a DMI.This connection between the sound generator and the sound controller is made by mapping the gestures to a sound synthesis algorithm. This situation carries new possibilities when working with a DMI. If, on one side it enables the construction of new relations between gesture and sound, namely some that were physically impossible because of the constraints present in the instrument or in the performer (playing extremely fast notes), or unexpected, on the other side, it lacks the tactile feedback as well as the intuitively notion than the instrument can grant when a performer is playing it (knowing how the instrument responds to the gesture helps the player to learn what gestures to perform in order to achieve a desired sound result).

The sound controller is separated from the sound generator and mediated by the mapping layer. This divides the design of a DMI in three distinct layers: the sound controller which includes the gestural acquisition method and extraction of important features for sound control, the sound generator which includes the choice of parameters of a sound synthesis algorithm or a sound sampler for example, and finally the mapping which implies the choice of a mapping strategy and mapping metaphor. In our work we will consider these three components of the design of a DMI, using as example the design of Intonaspacio.

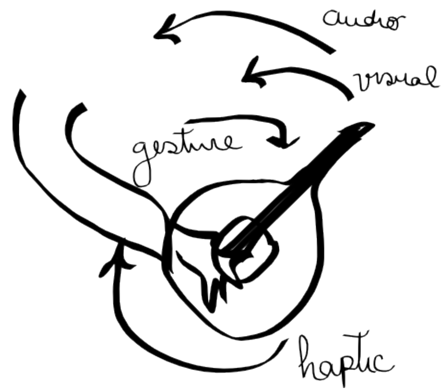


Figure 2.2.: The feedback modalities of an acoustic instrument: audio, visual and haptic

2.2.1. Feedback modalities

Playing a musical instrument demands more than a simple gesture-sound relation. There are plenty of other perceptual signals present in this interaction. Some authors (Cadoz, 1999), (Miranda and Wanderley, 2006), (Marshall, 2008), (Bongers, 2000) have introduced a diagram describing the interaction between the performer and the musical instrument. They are very similar to each other, presenting only slightly differences on the number of elements involved in the chain. Bongers (Bongers, 2000) includes the audience, for example.

In a classical representation, or more correctly when interacting with an acoustic instrument, there are two elements represented, the performer and the instrument. As it is visible in Fig. 2.2, when a performer plays the instrument, his gesture produces three loops, each carrying a different information. An audio loop, the product of the action over the instrument; a visual loop, which inform each areas of the instrument were played to produce that sound; and a tactile feedback, which informs about the response and behavior of the instrument. The tactile feedback is composed by the small vibrations of the structure of the instrument that the performer feels with its skin receptors. These vibrations help the learning process of the instrument, and some authors(Keele, 1973) indicate that an experienced performer rely mostly on them, no longer needing visual cues as beginners do. The acoustic instrument is a natural feedback system (Cook, 2003).

With a DMI, we face a new situation, not only we introduce a new element on

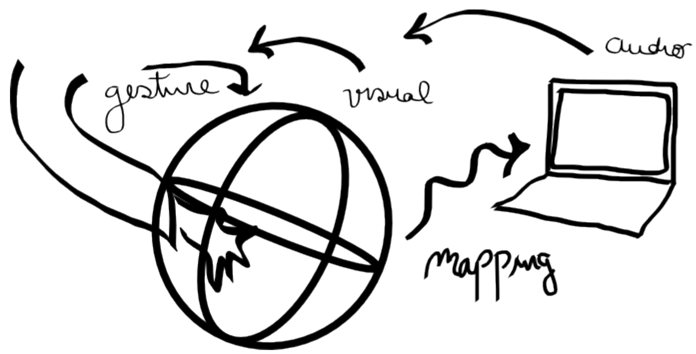


Figure 2.3.: The feedback modalities of a DMI: audio and visual. Notice that there is an extra element in the chain.

the chain - the mapping, but also because the DMI is, mostly, a feed-forward system (Cook, 2003). It lacks the haptic feedback, the one that contributes to the feeling of intimacy and embodiment of an instrument. In Fig. 2.3 is represented the structure of a DMI.

The physical interface is where the interaction between performer and instrument is accomplished. As Marshall (Marshall, 2008) defines it, the physical body has three parts: the body instrument, the sensors and the actuators. It is the element of the DMI that senses the tangible world and provides feedback to the performer (with actuators). The sound synthesis system is the one where sound is generated through a synthesis algorithm. Finally, the mapping system is the one that relates both (physical interface and sound synthesis) by connecting the features extracted from the physical interface to the parameters of the sound synthesis algorithm and vice versa (when haptic feedback is provided). Thus, it is possible to create different relations between the physical interface and the sound itself, designing different mappings. This means that the same physical interface can have different behaviors. The way it produces and controls sound becomes more and more a choice of the designer of the DMI than a consequence of its physical or mechanical constraints. Due to that, a DMI can open up the pallete of sounds, generating sounds that weren't heard before or that are difficult to control or even create by an acoustic instrument. Our research has its main focus on the physical interface and the mapping system, we will not deal with the sound synthesis system. For the physical interface we have chosen an ensemble of gestures mostly suggested by the shape of the instrument (we will explain in detail

the options we took on chapter 3). Mapping in Intonaspacio is where we design the possible approaches to integrate place on the sound work. In this work we proposed three different strategies, on chapter four, we will debate the pros and cons of each one.
To answer the problem of the decoupling of the gesture and sound, one must design a mapping (Miranda and Wanderley, 2006), (Hunt and Wanderley, 2002), (Fels et al., 2002), (Goudeseune, 2002) that will define the behavior of the instrument. We will refer to mapping on chapter 4.

2.2.2. Classification of DMIs

Until recently, the majority of DMIs relied on a keyboard paradigm (Miranda and Wanderley, 2006), (Marshall, 2008). The keyboard can facilitate the first interaction with new interfaces, since it benefits from previous knowledge of performers on how to play an instrument with such interface. On the other hand, sensors were very expensive and complicated to employ, just recently with the appearance of MEMS (Microelectromechanical systems), they began to shrink and become easier to use. Finally the MIDI protocol with discrete information slowed down the experimentation on new designs of the physical interface. [3]. Currently, there are several different designs of DMIs. Marshall (Marshall, 2008) looked at the papers and posters presented at NIME from 2001 to 2008, and concluded that a great number of DMIs use a physical interface that no longer relies on the keyboard. Also the number of alternate controllers (controllers that do not have any resemblance with a known instrument) was growing. Moreover the DIY community, contributes to this situation by developing a number of interfaces using home-made sensors. Nevertheless, choosing the right sensor for an interface depends mostly in what type of gesture the performer does, different sensors can sense the same variable. Marshall (Marshall, 2008) presents in his work an experiment about finding the best sensor for a certain given task.
Since, there are many different DMIs, some authors (Miranda and Wanderley, 2006), (Bongers, 2000), (Marshall, 2008) have suggested a classification for DMIs. They divide it in four different categories according to their resemblance or not to an acoustic

[3] The keyboard treats information discretely so it is quite useful when dealing with the MIDI protocol

instrument.

- **Augmented instruments** An acoustic instrument coupled with a set of sensors that expand the possibilities of the instrument. (Miranda and Wanderley, 2006), (Palacio-Quintin, 2008)
- **Instrument-like instruments** DMIs that try to recreate an acoustic instrument (Miranda and Wanderley, 2006)
- **Instrument-inspired instruments** DMIs that have the same shape as an acoustic instrument but do not necessarily sound or try to sound as the instrument that inspired them. (Miranda and Wanderley, 2006)
- **Alternate controllers** DMIs that do not resemble any other controller or instrument (Miranda and Wanderley, 2006), Intonaspacio falls in this category.

Mapping is the genesis of the DMI, since it is here one defines the conceptual limits of the instrument. We are in the presence of completely different kind of relations than the ones between a performer and an acoustic instrument. Besides the question of the intimacy, a DMI also introduces a new access to sound. The staff or the ensemble of graphic symbols that represent traditional musical notation are no longer the only available symbols. DMIs introduce spectral representations, where the performer directly manipulates the sound spectrum (Jordá, 2005) or manipulates the *objet sonore* (Schaeffer, 1966b) - the performer works over the recorded sound. This new paradigm allow us to leave the note level and enter in a thorough control where we can, at the limit, have access to the sound grain (when working with granulation synthesis (Roads, 1995), (Roads, 2001)).
From this proposition, and according to Jordá (Jordá, 2001), we can conceive DMIs as intelligent instruments, since they are able to control several processes in the composition enabling the performer and the composer to develop strategies with high level languages (Jordá, 2005). We can deduct that this characteristic frees the composer from certain tasks and gets him more and more involved in the design of the instrument, since we can delegate to the instrument what once was delegated to the performer. The instruments achieve a certain autonomy and become personal. The roles of performer, luthier and composer intersect and the composition work is

widened from the musical structure to the design and conception of the instruments and the performative act. On the other hand, as a consequence of the individualization and customization of the instrument, we are confronted with new techniques of instrumental execution; and we progressively assist to a divorce from the traditional musical notation (Manoury, 1990) (refer to chapter 5). To address this situation the composer can apply new methods of transmission adapted to this new reality, however, Toeplitz (Toeplitz, 2002) concludes that the patch (computer code or set of codified instructions) should not replace the musical score. Instead he proposes that the composer changes the kind of information that is on the score, changing from the gesture notations to the transmission of the musical idea. In this scenario the performer is responsible by the design of his/her own instrument, with no conceptual restrictions besides the ones imposed by the composer. Nevertheless, the design of a DMI implies already an ensemble of conceptual and formal choices that musically influences the final work. Consequently, this situation prevents a generalization of the instrument, the transmission becomes harder as well as the exchange of instruments between performers.

2.2.3. DMI vs gadget

Kartomi (Kartomi, 1990)stresses that the cultural and social context where an instrument is designed, contributes to its classification as a musical instrument. This vision is, nevertheless too categorical. Nowadays, with the easiness of combining sensors, a significant number of interfaces for musical control appear every year. How can we separate a mere gadget or musical toy from a musical instrument? Although the question is not easily answered, we can state at least two conditions for considering a musical instrument as such: the existence of an instrumental technique that is unique to the instrument, and a repertoire (Rodrigues and Ferreira-Lopes, 2010), both are guarantees of a continuity of the life-cycle of the DMI.
Music demands a structure and an intention, a DMI becomes an instrument the moment it requests an instrumental technique to be played and it is shared among the performers of the instrument, enabling the transmission and development of this technique. This situation helps to make this technique permanent and at the same time the creation of a repertoire of music pieces dedicated to the instrument. In a

sound installation the status of a DMI is completely different: in theory there is not a musical intention, per se. Instead the DMI acts as a generator of sound that appeals to spontaneous intentions based in sound delight (Ferreira-Lopes, 2004).

The technique of a musical instrument is the set of gestures that a musician makes in a certain interface in order to play specific sounds. In an acoustic instrument, this gestures are learned along several years of practice, the so-called learning curve is very long. In most of the DMIs this is not exactly true. First, Instrument-like DMIs take advantage of the previous knowledge of performers, so it is easier to introduce it to a new player. Secondly, a big number of DMIs relies in a simple and intuitive mapping that helps the player to easily gain control over the instrument. This option normally results in a lack of expressivity. In general the learning curve of a DMI is shorter than an acoustic instrument (Jordá, 2005), people learn it easily but at the same time they usually do not explore it as much as an acoustic instrument. Also, most of the DMIs do not show the same level of expressivity as an acoustic instrument. The difficulty in adding more expressivity to a DMI relies, normally, in having a greater number of freedom degrees that add more complexity to the physical interface and the mapping itself. In this situation the DMI designer is faced with a larger number of options that can be coupled in order to contribute to change different parameters of the sound. It would create a situation similar to the kind of complexity we encounter on an acoustic instrument. Hence, the balance is between control and expressivity, or rather easiness of control and expressivity. The easier to control, normally, the less expressive and vice versa. We should not, however, see the difficulty and a larger learning curve as a disadvantage, after all, acoustic instruments are harder to master and people are still playing them and investing years of study on them.

The design of haptic interfaces may also contribute to increase the expressivity of the instrument, precisely by providing a mechanical response of the instrument which facilitates the feeling of intimacy between performer and musical instrument (Scumacher et al., 2013), (Marshall and Wanderley, 2006). Greater expressivity can contribute to a development of an instrumental technique for the instrument and eventually the appearance of virtuoso players. Acoustic instruments have complex mappings, to change a sound parameter is necessary to combine more than one action (Hunt and Wanderley, 2002). Sound parameters are rarely controlled in a direct way as is observable in a wide number of DMIs. This does not necessarily mean that we should not try to envisage to design an intuitive and expressive DMI, especially through mapping. Mapping can become more intuitive when using a metaphor that facilitates the understanding of the behavior of the interface (Fels et al., 2002). Intonaspacio has a ball shape which makes interaction with it very straightforward. The player knows already what kind of gestures the interface demands.

2.3. Gesture

It is extremely difficult to find a common definition of gesture. Besides being a term used in several disciplines, it comprehends several senses. Normally, gestures and their definition must be framed by the specific context of the study being carried out. It is not our goal to analyze the various meanings of gesture, there are already some literature about the subject (Kendon, 2004), (Cassell, 1998), (Kurtenbach and Hulteen, 1990) as well as about musical gestural (Wanderley, 2010) (Godøy and Leman, 2010) (Cadoz and Wanderley, 2000) specifically. We will, however, present a small survey on the definition of gesture in order to frame it in our research.

A gesture can be considered as a body movement that transmits some meaning and is settled in a specific cultural context (Godøy and Leman, 2010).The study of gestures is of utmost importance when designing a DMI. Research concerning the study and analysis of gesture has followed two main tendencies, that complete each other. One, studies gesture as a measurable body movement that could be described in time and space using physical coordinates and relates to the gesture extension. The second is a subjective approach and understands that gesture should be studied in the context it was made and in relation to the meaning it carries. The focus is in the intention of the gesture.

In our work we are interested in defining instrumental musical gestures. Musical gestures are, roughly, the ones that participate in the production of sound, directly or indirectly. As directly participating in the process we can include the gestures made by the performer to activate an instrument and the gestures that are used to make some arrangement in the sound (modulate, select, gestures that interact with the instrument but do not actually generate a new sound). In the indirect ones, we can consider the ones made while communicating with the audience or others performers on stage, the ones that help to prepare the body for the next sound or the ancillary gestures, the ones the performers do while playing and that are observable in every performer (Godøy and Leman, 2010) (Cadoz and Wanderley, 2000).

Furthermore, when analyzing gestures we must consider if there is manipulation of an object or not, instrumental gesture or free hand gesture, respectively. In our work we will focus on the former, since we are studying the design of a tangible DMI. Cadoz (Cadoz and Wanderley, 2000)(Cadoz, 1999), proposed a typology for the musical instrumental gesture that we will apply in this work. When a performer plays an instrument several loops of action/reaction are created between the two (instrument and performer). These convey information about the instrument that helps the performer to learn how to play it and embodied it. Embodiment is necessary in order to give the performer the feeling that the instrument is not an external object to his or her body.

According to Cadoz (Cadoz and Wanderley, 2000), the instrumental musical gesture can be divided in three types, dependent on their function: the excitation gesture, the modulation gesture and the selection gesture. Wanderley (Wanderley, 2010) (Cadoz and Wanderley, 2000) adds a fourth one, the ancillary gesture.
The excitation gesture is the gesture that carry energy to generate and produce sound. It can be a percussive gesture when the sound and the gesture are synchronous, or a continuous gesture when the sound prevails after the gesture has stopped. Plucking a guitar string is an example of the first one, bowing a cello string is a continuous excitation gesture. When the performer is making small alterations on the sound but not conveying energy, he is performing a modulation gesture. Placing the finger in the middle of a guitar string to change the pitch is a modulation gesture. The selection gesture appears when the performer can select one or more voices on the instrument. For instance select a string to play in a guitar. Finally, the ancillary gestures are the ones that the performer makes while playing but do not affect the production of

sound. These can be observed both in expert players as beginners. [4]

The study of gestures typology is important for the definition of the gestural acquisition method. The gestural acquisition is the input layer of the musical instrument. Is the one that enables us to measure and monitor the "external world" and compute it. For an expressive and challenging interface it is important to try to recreate the complex connections that an acoustic instruments provides. This is achieved not only with a complex mapping strategy but also creating a good gestural acquisition system. Wanderley (Wanderley, 2010) purposes three different ways of capturing gestural data: direct acquisition, indirect acquisition or physiological signal acquisition. In our work we will focus on the first two methods, since these are the ones we use in Intonaspacio, for information about the third method please refer to (Wanderley, 2010) and (Miranda and Wanderley, 2006).

- **Direct acquisition** is the use of electronic sensors that translate a gesture in a physical variable such as force, pressure, displacement, etc. Normally for each feature a single sensor is used.

- **Indirect acquisition** is the analysis of the recorded signal that provides information about the signal. A good example is to use a microphone to record sound and then perform an FFT (Fast Fourrier Transform) analysis of the signal to identify the fundamental frequency, partials, spectral brightness and so on.

2.4. Conclusion

The introduction of tangible interfaces in the discipline of HMI brought new opportunities to interaction. TUIs enable users to use their previous knowledge of manipulation and grasping objects. It also admits the use of both hands, which is a main advantage when compared to traditional GUIs, and enables a space-multiplex interaction, i. e., the user can perform more than one action at a time. The TUI

[4]please refer to (Cadoz and Wanderley, 2000) for further information about these gestures in clarinetists.

couples the input and output of the interaction chain, which make it very useful when dealing with complex tasks with abstract forms of representation such as music.

Musical instruments are tools that facilitate the production and creation of sound. Throughout history different musical instruments had been designed, and their introduction in the cultural instrumentarium depends on the social and cultural context. The definition of musical instrument is highly historical and cultural dependent.Their classification and organization in an instrumentarium help us to understand at every historical period the thought that sustains the classification of musical instruments as such. The evolution of technology promotes the creation of new musical interfaces. The electronic and digital musical instruments create a new paradigm on the musical instruments field, which is reflected in two specific points: the sound controller and the sound generator are separated bodies and there is no direct causality between gesture and the emitted sound. This disruption contributed to the creation of new designs, since it no longer depends on the mechanical constraints of the production of sound. This reality, in theory, allows for the establishment of any imaginable link (mapping) between these two elements (gesture and sound generation), opening infinite possibilities. Consequently we can envisage highly complex relations, where the musical instrument assumes functions previously taken by the performer, freeing him to do other tasks. On the other side, this link can be simple enough to facilitate the access of amateurs and non musicians to music. Besides, there is an increasing use of these musical instruments outside the musical universe, for example on interactive installations. All this assorted possibilities cause an indefiniteness on the concept and status of digital musical instrument. Is it still possible to call musical instrument to an interface used on an installation where the audience can easily "compose" music? Or should it be consider a musical toy or rather a musical gadget? The answer becomes more complex when we rely mostly on the mapping to classify the instrument as musical or not. For example on a situation where the exactly same interface is used in different situations (in a concert and in a museum) with a complete different mapping. Is it a musical instrument in the first situation and a musical toy in the second? We propose two main conditions to define a musical instrument as such: the existence of an instrumental technique and of dedicate repertoire.The instrumental technique is the set of gestures performed by the performer to play a certain sound

and it is transmitted from performer to performer. These will permit the mastery of the instrument as well as the creation of a repertoire - an ensemble of music pieces written specifically for the DMI.
A DMI is divisible into three layers - interface, mapping and sound generation. The physical interface is the one responsible for the sensing of the gestures of the performer. The sound synthesis algorithm consists in a set of variables that generate and control sound. Mapping is the ensemble of connections between this two systems. The physical interface will define the gestures a performer will be able to do when playing the instrument, and the mapping will define the musical idea of the instrument.
Due to the cleavage between the sound generator and the sound controller in DMIs, the gesture is no longer directly responsible for the sound, there is no longer an energetic continuum, as Cadoz (Cadoz, 1999) states it. The energy in the gesture is not necessarily reflected in the sound produced. This characteristic, as well as the lack of haptic feedback - the small vibrations on the structure of the instrument when played which inform the performer about the behavior of the instrument, and the separation between sound instrument itself and the reproduction system (speakers), contribute to what Cook (Cook, 2003) defines as a lack of intimacy. Intimacy can be recovered by the use of actuators in the body of the instrument, for example. One of the main struggles in the design of a DMI is the balance between the expressivity and easiness of control. It is important to rely on a complex mapping in order to provide various options of control - this gives more expressivity to the instrument and keeps the instrument interesting enough for further exploration. Although a complex mapping can turn the instrument very difficult to play, some authors suggest the use of mapping metaphors (Goudeseune, 2002) to facilitate the general understanding of the instrument behavior.
The arrival of a whole new assortment of electronic sensors, which are smaller and smaller, easier to use and cheaper, contributes to the emergence of several new DMIs, especially alternate controllers. This situation poses a set of questions that discuss the difference between a digital musical instrument and a musical gadget.

For such characteristics we believe that a DMI can be a tool to enable the creation and control of place-specific sound pieces. The performer could use the musical instrument as mediator between him/her and place and have access to the sounds present in place or generated by its acoustical response.

3. The interface

3.1. Introduction

In this chapter we introduce the DMI we designed in our work, Intonaspacio. We make a small introduction to some interfaces that have a similar design and helped us to understand some of the problems and the solutions this design entails. Afterward we present the structure of the instrument, how it was built and the decisions it involved. The shape of Intonaspacio led us to foresee an ensemble of gestures that were inspired by it. These gestures were the ones we took in consideration when choosing sensors and their placement. For that reason the sensing layer is divided according to gestures type: orientation, impact, distance and pressure. We have designed two versions of Intonaspacio, each one with a different material for building the frame. These changes forced us to rethink some of the options we were using in version 1.

3.2. Having access to place

From the works presented on chapter one (please refer to subsection 2.2) we observe a progressive flow from a purely integration of the background sound of the place (present sounds in the place, e.g. crowd whispering, people walking, birds, etc.) in the work (as Cage does in 4'33") to a continuous blending of these sounds with the acoustical behavior of the place (as in the Ascher's works), and finally to a complete merging of place in the work (Lucier's approach).

Our research work intends to deal with these questions, combining these three moments in Intonaspcio, i.e., given the performer the possibility of working both with the acoustical properties of the space as well as with its background noise. Creating pieces where the sound work is dependent of place (it carries its sonorous imprints) and at the same time completely independent (the same piece can be performed in different places resulting in a different piece). Lucier has showed us with his work "I'm sitting in a room", that we could create a highly context driven work (the way the place responds to the recorded voice of Lucier is part of the work itself) but mostly independent of that same place since the same piece can be presented in any other space (different from the original one) and still maintain its place-specific character. With Intonaspacio our intention was to create means to give the performer the possibility of working both with the sound ambiance (either by recording the sounds already present in the place or by producing new ones with voice, body or interaction with other players) and the responsiveness of place, namely by creating the conditions to allow the background noise to became the trigger of place response. Having a portable and straightforward tool (no need to create complex set-ups) to integrate place as a parameter of composition of the sound work. In this process two main questions arose:

- How to integrate the background noise on the sound work on real-time? What are the best technology to do it?
- How to allow these sounds to trigger the responsiveness of place?

The field of place-specific sound art is broad and includes a number of different conceptual approaches (soundscape design, field recording composition, spatialisation, sonification among others), from which we will include in this thesis only the ones where exists a clear place-responsiveness in the art work, in other words, where place is "an active agent that shaped the artwork's form" (Anderson, 2008).
Table 3.1 [1] includes a summary of several place-specific sound works presenting the different technologies used to access place. We are only interested in understand the technology used and not the underline concept of the presented artistic works.
As we can see, the majority uses either the loudspeakers or the microphone. Loudspeakers are usually used to excite the structural sounds of the room, for example the works of Brewster (Brewster, 2001) (Labelle, 2006) where the artist reproduces specific frequencies and combinations of timbres to create patterns on the place of the installation. This is a strategy similar to the one Ascher (Ascher, 1983) uses in his

[1] The references for the work presented on the table are present on the text.

works and ultimately Lucier (Lucier and Simon, 1980)(although Lucier uses specifically the voice and speech to excite the structural sounds of the place). Similarly, Leitner (Leitner, nd) transforms the place to adapt it to a certain acoustical response, response that he excites by reproducing an ensemble of sounds (a combination of musical instruments with body sounds) that creates patterns of movement within the place. Microphones on the other side are mostly used to record the background noise of the place. Works like Times Square(Nehaus, 1977), Streets(Anderson, 2008), City Links(Amacher, 2010) (Labelle, 2006), Monitor unit for solid vibration (Hatanaka, 2000) or Sound grid (Labelle, 2006), use the microphones to record sound that is present in the place or that is generated by the audience (Sound grid for example). Introducing a completely different path is the work of O.blaat (O.Blaat, 2007) and Rafael Toral (Toral, 2010), both performers, where they displace the microphone to excite particular frequencies of the place. On a similar fashion Di Scipio (Scipio, 2003) spreads along the room an ensemble of microphones which allow him to record the spectral pattern of the room that changes according with the people inside the room. Finally Roberto Pagliese (Pugliese, 2011) creates a micro place-specificities by placing a group of movable microphones in front of a group of speakers creating a feedback loop which originates a very delicate equilibrium between sound and noise. The last column of the table presents examples where musical instruments were used to excite the room. Playing the building (Byrne, 2012) uses a piano to trigger several hammers that are spread all over the room causing the walls to sound. Both Nunes (Nunes, 1994) and Fontana (Fontana, 1996) use musical instruments (traditional and customized in the work of Bill Fontana) to stress some of the acoustical characteristics of the place.

Our initial idea to access sound ambiance (in such a way that with Intonaspacio the performer could creatively use it on the composition - modulation, signal processing, etc.) was to use a combination of the performer's location on place combined with a pre-analysis of place acoustic response. By making a preliminary analysis of the acoustics' of place using common techniques used by sound technicians when equalizing the room's sound (recording the impulse response of the room), we could then compare it with the position of the performer in place and modulate the sounds generated by Intonaspacio according to this acoustic response. The displacement of the

Table 3.1.: *Examples of technology used on place-specific sound artworks*

Loudspeakers	Microphones	Music Instruments/Objects
I'm sitting in a room	*Streets*	*Playing the building*
A. Lucier (1969)	S. Anderson (2009-2011)	D. Byrne (2005-2012)
Installation at P. College	*Nodar social composition*	*Quodlibet*
M. Ascher (1970)	O.blaat (2007)	E. Nunes (1990-1991)
Spaces	*Space program*	*Landing ground for waders*
M. Ascher (1978)	R. Toral (2003 - 2010)	B. Fontana (1983)
Times Square	*AESI*	
M. Nehaus (1977)	A. Di Scipio (2003)	
allAROUNDyou	*City links*	
M. Brewster (1998)	M. Amacher (1967-1980)	
full o' stuff	*Monitor unit for solid vibration*	
M. Brewster (2000)	T. Tsunoda (2000)	
See Hear Now	*Sound grid*	
M. Brewster (2001)	A. Wollscheid (2002)	
Sound Space	*Equilibirum variant*	
B. Leitner (1984)	R. Pugliese (2011)	

performer in the place would reflect the acoustics of that same place. This however proved to be a rather complex set-up, where we will always need an external set of sensors in order to locate the movement of the performer (namely using computer vision or ultra-sound sensors). On the other side the use of external (in relation to the instrument) sensors would create a lack of self-sufficiency of the musical instrument, a more complex and time consuming set-up and a the introduction of a greater tech dependency of the system (the more sensors we introduce on the set-up the greater the probability of having technical problems). One of our main concerns when designing Intonaspacio was to have a portable musical instrument and independent of external sensing, as this facilitates the possibility of using Intonaspacio in different places and dissociates it from a sound installation scenario.
The use of a GPS (Global Positioning System) was also considered but this solution would imply a larger performance place since the sensitivity of the GPS is rather low in comparison with the dimensions of most performance rooms. In view of these possibilities, we decided to use microphones as the sensing technology. The microphone enables two important features of the instrument. First, the performer can record the sound ambiance of the place and immediately reproduced it, with or without further processing (Direct). Second, the sound input of the microphone is analyzed in real-time through an FFT algorithm where an analysis of the room spectral response is extracted (this procedure is explained in detail in chapter 4 (section 2.1 and 2.2) (Indirect) [2]). The procedure is made over time, i.e., its output changes with the sound generated in the place. The analysis does not result in an accurate acoustic response of the room (this is not our intention), it rather opens space to a randomness that is dependent of the action of the performer, thus creating an interaction between place and performer - each reaction is dependent of the action of each element of this relationship).

The blending of sound and place happens when this interaction is establish. The sound produced and recorded by the performer as well as his/her further modulations of this sound (using the other sensors implemented in Intonaspacio (presented on the next section)) is filtered by place at the same time that provokes an acoustic response

[2] Other techniques can be used such as convolution, spectral density, etc

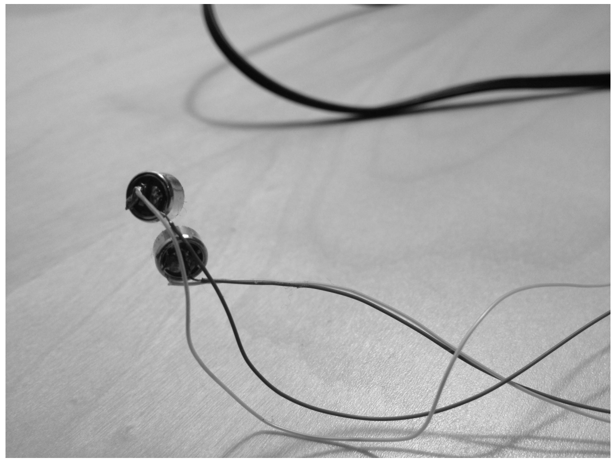


Figure 3.1.: Binaural microphone.
Source: Mailis Rodrigues

of this same place. This response is continuously added to the sound output of the instrument, either by recording it or by performing an analysis to its characteristics

In version 1 of Intonaspacio we designed an homemade binaural microphone, Fig. 3.1.

A binaural microphone is an ensemble of two similar microphone capsules which have the same polar pattern and the same frequency response. By calculating the distance between the two microphones this system can simulate the human audition by introducing the HRTF (Head-Related Transfer Function) response. As a result a binaural microphone can record sound moving in place, recreating the human hear response to that sound (Flannery, 2013). The motivation for using a binaural technique was to have a stereo image of the sound present in the room [3]. The distance between the sounds would be dependent not on the size of the human head but on the size of the instrument. Intonaspacio would then be an autonomous entity that listens to the place.

We used two condenser microphone capsules with an omnidirectional pattern, spaced about 30 cm (the diameter of the sphere) and sewed in the cover of the instrument. This approach had some limitations, namely the impossibility of having a wireless system since the microphones need to be supplied with 3V electrical charge.

[3]By present in the room we mean the sound ambiance of the room (background noise) as well as the resonant frequencies of the room (structural sounds) as defined by Labelle (Labelle, 2006)

The solution was to use a wireless microphone. This microphone is placed in the middle of the the central platform of the instrument and is connected to a FM transmitter. It has a omnidirectional pattern and a fairly flat response in all the audible frequency range. The main goal was to have an even recording of the sound, with no particular amplification over any frequency. But this microphone also presents some limitations, namely it has to be tuned to a particular frequency that most of the times present interference and introduces noise on the sound. It is always necessary to calibrate the frequency each time the performer uses the instrument in a different room. Another limitation is the noise introduced by the antenna that is in contact with all the metallic parts of the structure of Intonaspacio. The performer needs to find a good position of the instrument to capture the signal with a higher signal-to-noise ratio.

3.3. A ball that makes music

Intonaspacio has a ball shape, this shape is quite common in musical interfaces. One of the main reasons is because it is a known object, thus easy to interact with. People have previous knowledge on how to manipulate it and what to expect from it. This shape also has a playful side, a ball is something we use in games, so it is normally easy to get people to interact with.
There are a number of DMIs that use a ball shape(gan, 1998), (Broson, 2011), (Yeo et al., 2007), (Verplan, 2001a), (Hermann et al., 2002), (Blaine, 2000), (Verplan, 2001b), (Aimi and Young, 2004), (Milk, 2011), (Bowen, 2005), (Rasamimanana et al., 2012), (Yamaguchi et al., 2010) and (Yeo, 2006). These are usually designed to create a collaborative musical instrument, where two or more performers can play the instrument at the same time. The idea of collaboration is visible on the type of gestures performed with these instruments - throwing the instrument between performers (Yeo et al., 2007) and (Yeo, 2006), and also in the activities they are used in - to sonificate collective sports like soccer or basket ball (Rasamimanana et al., 2012), (Hermann et al., 2002). When designing a DMI with this shape, it is important to have a material that is at the same time light and robust. A ball can inspire gestures like throw, roll or dribble, gestures that demand lightness and stability (to sensors).

Several different materials are used to make these ball-shaped instruments, most commonly plastic (Broson, 2011), (Milk, 2011), (Blaine, 2000), (Yamaguchi et al., 2010), (Aimi and Young, 2004) and (Bowen, 2005), and the sponge (Yeo, 2006). However, they present a number of issues that we tried to solve, namely the easiness of access to the electronic parts of the instrument, which the sponge or foam make it more difficult because of the compact aspect of this type of material. Brosson (Broson, 2011) notes the same issue on the Orbison (made of plastic), which in cases such as the one presented by Milk (Milk, 2011) (Milk also uses plastic) do not seem to be a problem, once the interaction is restricted in time (spectators interact with the ball in a specific moment of the music concert). It appears to us that the solution found for Intonaspacio - the frame structure covered with fabric, provides not only easy access to the sensors and the other electronic parts (batteries, wireless system) but also a robust skeleton where the sensors can be properly accommodate in order to give reliable readings. Woon (Yeo et al., 2007) and Gan (gan, 1998) use fabric as the primary material for their DMIs (Stringball and Sqeezables, respectively) but they do not seem to present the robustness and stability we were looking for Intonaspacio. Also, we decided to use the fabric cover as an extra sensitive part of the instrument, providing a number of extra possibilities to the performer which can, at the end, enhance the expressive qualities of the instrument.

With few exceptions (Hermann et al., 2002) (Aimi and Young, 2004), we used a more complex combination of sensors in Intonaspacio because we wanted to ensure a great flexibility in mapping and a higher level of expressivity (through the design of complex mappings as suggested by Hunt (Hunt et al., 2000). Several ball-shape DMIs use a very simple mapping (the MIDI ball (Cutler and Robair, 2008), the Soundstone (Bowen, 2005) or the Arcade Fire's ball (Milk, 2011) are a few examples) which interest in a long-term usage or even expert performance is yet to be studied. Intonaspacio intends to be a musical instrument for expert performance and thus we searched to combine several sensing possibilities (with the implementation of different sensors to measure specific gestures at different ranges that complement each other, e.g. the piezo and the accelerometer to measure impact on the surface) with one-to-many and many-to-many mapping [4]. In this sense, projects such as the BeatBug (Aimi and

[4]The strategies designed for mapping are explained in detail in chapter 4.

Young, 2004) or the Haptic Ball (Hermann et al., 2002) proved to be more interesting in terms of mapping and sensor technology.

Finally, a characteristic very important in a ball-shaped instrument is the possibility of transmitting data without wires, especially if the interface is thought to be shared or played by more than one person at a time. Two main solutions are used in the presented projects: bluetooth (Yeo, 2006) and radio frequency transmission (Yamaguchi et al., 2010), (Milk, 2011) and (Aimi and Young, 2004). Intonspacio uses the second method - radio frequency transmission, this provided a very interesting range (about 100 m, which cover the majority of the performance rooms), and it does not show interference when other wirelless systems that are present in the same room (we tested the xbee sensor on Intonaspacio with the FM microphone and both worked correctly).

Common to all these DMIs is the use of a 3-axis accelerometer to calculate orientation, tilt and shock (when the instrument is thrown away). A ball does not have necessarily a visual clue to distinguish top and bottom, front and back. Concerning orientation this can become a tricky question. In Intonaspacio, this identification is easy since the top of the instrument is slightly different from the bottom, Also, in order to play it correctly the performer must hold the instrument with the IR sensor facing him. Orientation is usually mapped to control continuous parameters of the sound.

Piezzoelectric sensors are also widely used to calculate percussive gestures. These are commonly mapped to trigger sound files (Broson, 2011) (Yeo et al., 2007). Sometimes this sensors are coupled with an FSR (Force Sensitive Resistor) that measures surface deformation (gan, 1998), (Hermann et al., 2002). Two of the DMIs use haptic feedback (Hermann et al., 2002), (Bowen, 2005) using devices that produce small vibrations that are sensed by the skin of the performer.

Some examples use Infrared (IR) sensing to calculate distance (Yamaguchi et al., 2010), (Milk, 2011) but only one of them uses the distance between the body and the instrument as in Intonaspacio.

Intonaspacio has different goals from these DMis, and looks for a different combination of gestures. First, it is a musical instrument to be played by one performer. The combination of sensors used in our design gives more complexity and expressivity to the instrument, because the interface has more sensitive areas and a larger number of freedom degrees. Also, none of this DMIs looks for the integration of place as a extra parameter for composition, they rely on the desire of having a playful instrument, and that is the main reason they have chosen to design a DMI ball. Finally, in Intonaspacio we have integrated the whole structure as part of the instrument, i. e., the whole instrument is sensitive to the performers gestures. We achieved this not only by implementing textile sensors on the fabric that covers the surface of Intonaspacio, but also by trying to place sensors on specific locations where we could had a wider range of sensed area.

The sensors implemented in Intonaspacio were chosen based on two conditions. First, the structure of the instrument, the material used to construct the frame of Intonaspacio presented some characteristics that inspired some gestures. Second, the idiomatic gestures of a ball, i.e., the gestures suggested by the shape itself. We will divide the next section according to the type of actions we were interested in capture: orientation, impact, distance and pressure.

3.3.1. The conception of the structure

One of our main concerns in this research was to have an actual tangible physical object that the performer could play with. Therefore the structure of the object played a major role on the design of the musical instrument. Since the beginning of this research we had envisioned Intonaspacio with a ball shape, first because it's a very versatile object, and second because it is a somehow known shape and thus the introduction to the instrument would be easier This design however presented a number of constraints such as: portability, robustness and easiness of access to sensors.

Portability was actually one of the main issues we were concerned of. Accordingly, we decided to design a pliable object. With this in mind, and inspired by the cage skirts worn by women in the XVIII century, Fig. 3.2, we built a frame of eight arcs attached at two points (up and down) which could be mounted as a sphere when the instrument was in use. Based on the previous research of DMIs that used the same

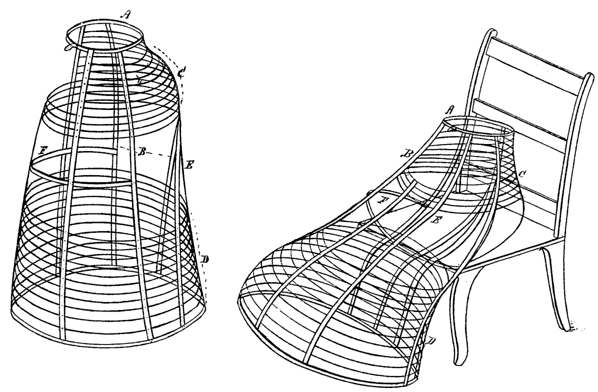
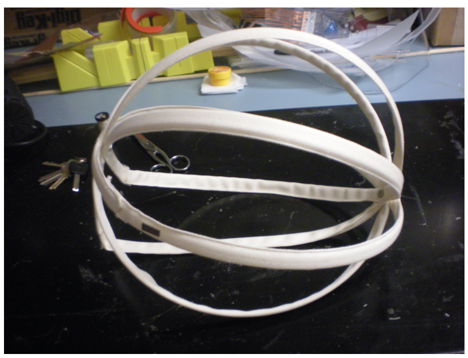
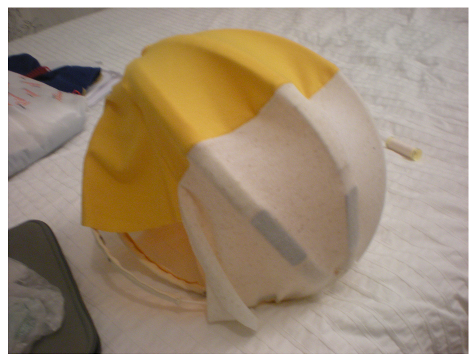


Figure 3.2.: Cage skirt model.
Source: Wikipedia



(a) Intonaspacio without the fabric cover



(b) Intonaspacio with the fabric cover

Figure 3.3.: Version 1 Intonaspacio.
Source: Mailis Rodrigues

ball-shape as Intonaspacio, we observed that other materials such as foam or plastic presented some problems that we wanted to avoid.

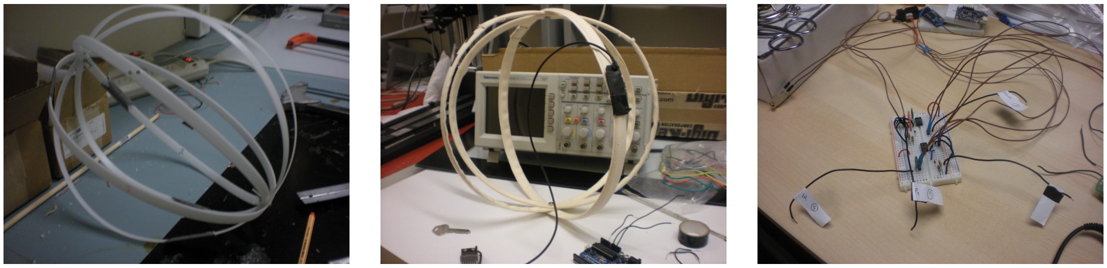
To build the frame we used the same material as these skirts - strips of a very bendable plastic. They were connected to each other and covered by strips of twill. The first version of Intonaspacio Fig. 3.3 was made in a way that the performer could ply the sphere until it formed a circumference, thus easily portable.

The frame had to be robust since some of the sensors are fragile. Also, they had to be in a stable position in order to, ideally, be accurate and repeatable. For that reason our concern was to have a central base that would support all the electronic

apparatus. This base is mounted in the middle of the sphere. The initial idea, taken mostly because of aesthetically reasons, was to have a platform made of acrylic. This, however, proved to be impossible since the height of the acrylic would bend the plastic structure and prevent it to have a ball shape. Also, due to the need of making stable and strong electronic connections we had to change it to a PC board in order to solder all the sensors to it. Finally the structure had to give easy access to this central board. Easy access is indispensable in situations where batteries need to be changed, sensors or wires need to be removed, connections need to be corrected. This is particularly important in a performance situation where one must be able to quickly solve any technical problem. Whence the use of fabric to cover the instrument that works as a removable skin with an opening who granted direct access to the main electronic area in Intonaspacio.
The plastic arcs however, showed very little rigidity which prevented the instrument of having a stable shape. We thus opted for a different material to build this structure - Commercially Pure Titanium. This material presented a number of characteristics that were relevant for our work, namely lightness and robustness, also aesthetically the titanium was more interesting.
At the moment we are designing a new version of the instrument, with a slightly different structure and a different material. This version is the result of a collaboration with the visual artist Mario Ângelo. It will be made using rapid prototyping materials - 3D printing. The new version will correct some of the problems encountered on the second version - the electronic is not visible and thus is not so easily accessible (to others than the performer or the designer), the instrument will be more robust, and it will be easily reproducible.

3.3.2. Version 1

To build the frame of Intonaspacio we connected 4 strips of plastic that are attached to each other in two points, forming arcs and enabling the structure to be pliable. This way Intonaspacio can have two positions, one in a sphere shape when is being played and another one as a circumference when is being carried from one place to another. Each arc was covered with fabric in order to be easier to cover all the surface of the instrument with a fabric skin. The plastic we used is very bendable and at the



(a) Frame (b) Testing sensors (c) Sensors

Figure 3.4.: Version 1 Intonaspacio.
Source: Mailis Rodrigues

same time is stable enough to maintain the shape. Each arc as a size of 94 cm to obtain a sphere with a diameter of 30 cm. The diameter of the sphere reflected the size of the ensemble of electronics, and the intention of making a ball that was easily handled with two hands. We added to each arc a hook that keeps the spherical shape, without it the height of the arcs would tend to form an ellipse. At the center of this structure is a platform that support the sensors. This provides a solid base, that is essential for having good measurements from the sensors, especially in orientation. The structure was then covered with fabric. Fig. 3.4 shows some of the stages of the design of Intonaspacio.

In the first version of Intonaspacio we used the following sensors: IMU (Inertial Measurement Unit), Piezoelectric, IR (Infrared) and a bend sensor.

Orientation

To calculate orientation of Intonaspacio we used the Mongoose 9 Dof (Degrees of Freedom), an IMU board developed by CkDevices [5]. An IMU is a device that combines several inertial sensors, usually accelerometers, magnetometers and gyroscopes. Combining them prevents drift errors that appear when just one sensor is used; and allow the measurement of orientation in three axis - Pitch, Yaw and Roll. The Mongoose board has embedded a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis

[5] http://store.ckdevices.com/products/Mongoose-9DoF-IMU-with-Barometric-Pressure-Sensor-.html

magnetometer. The output values are already scaled by the firmware included on the board.

According to Newton's second law of motion, a linear accelerometer (Fraden, 2004) (Sen, 2014) measures a force that is proportional to the acceleration applied to a mass in one axis. Accelerometers are useful for calculating inertial measurement of velocity and position, as well as vibration or shock. Its output can vary from +/- 1g to many gs. At low-frequency an accelerometer can inform us about the static acceleration (gravity) and at high frequency about dynamic acceleration (vibration). To measure a position the sensor calculates the displacement of a mass that has been subjected to a force. The position of this mass is calculated in reference to the housing of the sensor itself, thus a position measured by an accelerometer is always relative. To have information about the absolute position of an object in a certain place it is necessary a fixed reference point inside the room. The accelerometer used at the Mongoose is a digital accelerometer with an output of +/- 16g.

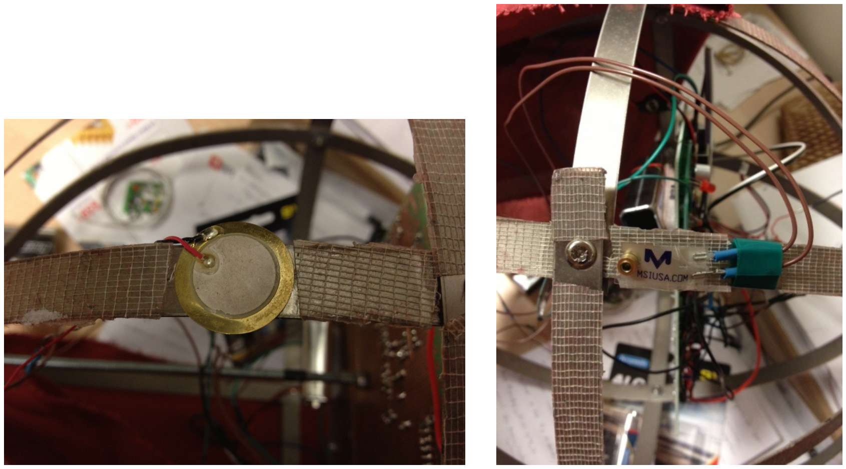
The gyroscope measures the angular velocity (degrees per second) of an object, it is normally used together with the accelerometer to correct drift errors that the accelerometer can present when integrated to calculate position. There are different gyroscopes available in the market, the one we used in our musical instrument is a digital gyroscope with an output of +/- 2000º/s.

Finally the magnetometer measures the strength and/or force of a magnetic field (depending on the type of magnetometer used). It can be used to detect motion, position or displacement. In combination with the accelerometer and the gyroscope prevents the IMU from calculation errors. The one mounted in the Mongoose board is a vector magnetometer. It measures both strength and force of the magnetic field. It is a digital compass, therefore calculates direction in relation to the magnetic field of the earth.

We have performed some tests with the IMU in order to perceive its response to gesture. We started by defining a set of gestures - moving up, down, left and right; and analyzed its range of values on the three angles - Pitch, Yaw, Roll, We repeated this sequence of gestures both standing still and walking. The sensors presented some errors with abrupt or very fast movements, especially in the Yaw and Roll angles. This is a fault of the Mongoose itself, either way is important to be aware of this problems to prevent complications when mapping. We observed some similarities on the graphical representation of a number of these gestures - moving up (standing still), and moving up (walking), but these were cont conclusive. Nevertheless, we searched to implement a gesture classification, in which the computer could recognize what was the direction the performer was pointing Intonaspacio - up, down, left, and right. Following the methodology proposed by Figo (Figo et al., 2010) and Veltink (Veltink et al., 1996) we started by calculating the magnitude of the signal outputted from the accelerometer on its three axis for every recorded movement, and then perform cross-correlations to look for similarities, particular qualities of the signal for each movement that could help to characterize it. Our results did not showed the existence of distinct characteristics of the signal to differentiate the different gestures. One of the reasons can be the necessity of having a larger library of recorded movements to analyze in order to start having some interesting results. We implemented a very rough gesture classification in Intonaspacio but it was not very accurate and we decided to remove it. We do perform other calculations with the accelerometer signal that help us to characterize some of the gestures made with Intonaspacio, namely gesture amplitude, variation rate of the movements, among others (calculations are explained in chapter 4). Gesture segmentation is out of the scope of this work, once the core feature of Intonaspacio is the interaction between sound and place. The others sensors used on the instrument provide an extra layer of signal processing and contribute for a large set of features extracted and consequently the possibility of designing complex mappings.

Impact

Percussive gestures bring great possibilities in the design of a musical instrument. To sense impact, shock or vibration several methods could be used. One of them is briefly exposed in the previous subsection, by using an accelerometer we can calculate impact or vibration. Another technique is the use of piezoelectric sensors. A piezoelectric sensor (Fraden, 2004) (Sen, 2014) uses the piezoelectric effect that is based on the



(a) P1 (b) P2

Figure 3.5.: Piezoelectric sensors used in Intonaspacio. Piezo D is P1, and piezo M is P2. The vertical lines indicate the moment of the stimulus.
Source: Mailis Rodrigues

properties of certain crystals that produce electrical charges when stressed. The electrical charge generated is proportional to the applied force. These sensors convert mechanical action in electrical signal and work better with AC currents, i.e., changing or transients currents. Sometimes the piezoelectric sensors produce high voltages, consequently a limiting circuit is needed in order to prevent voltages above the 5 volts which will damage the board that interfaces the sensors with the computer (Arduino or similar), that commonly work at 5 volts.

Intonaspacio has two different piezoelectric sensors, which differ in the shape and sensitivity. This way we intended to create several sensitive zones introducing more degrees of freedom in the manipulation of the instrument. Each sensor has a complementary limiting circuit proposed by Malloch [6] for the T-stick (Malloch, 2008) . One of the piezos, which we will mention as Piezo 1 (P1), is a disc shape sensor, the other one, Piezo 2 (P2) is a film with a small mass at the end, this characteristic make it more responsive than P1 to small vibrations, Fig. 3.5, Fig. 3.6.

The graphic clearly shows that P2 is more sensitive on-axis (when the strike is made

[6]https://josephmalloch.wordpress.com/projects/mumt619/

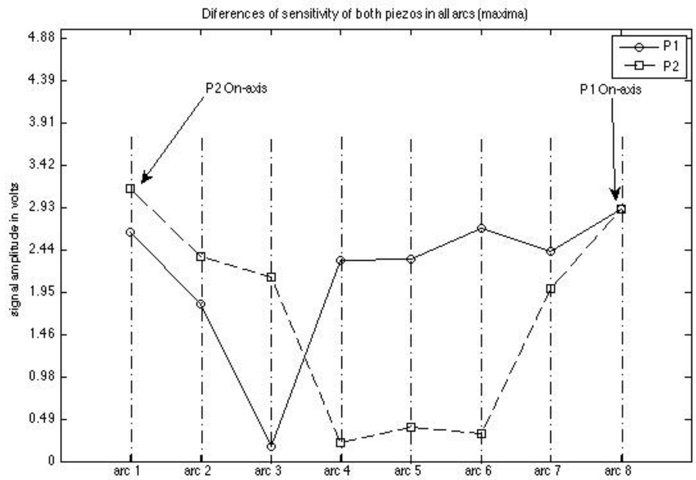


Figure 3.6.: Piezoelectric sensors: Differences of sensitivity of the two sensors, when plucking the 8 arcs of the structure. The measurements were made with the peak amplitude of each arc of the frame.

on the arc the piezo is placed on) than P1, the peak amplitude of P2 is 3.17V while P1 is 2.93V. Despite that, P1 shows a greater sensitivity to off-axis measurement (when the strike is made on the arc where there is no sensor), namely on the opposite arc (arc 6 with a signal amplitude of around 2.69V) and on the neighbor arcs (arc 7 and arc 5 with a signal amplitude of 2.44V and 2.34V, respectively). These differences in amplitude according to location allow us to have several zones of sensitivity in the ensemble of the skeleton of Intonaspacio. Both piezos are glued to the structure of Intonaspacio, each in a different arc. We tried to place them as far as possible aiming greater sensible zones, since we realized that the sensors were still able to sense impacts on neighbor arcs, Fig. 3.7. The performer can either pluck or tap both piezos.

In the graphic we identified the arcs where the piezos reached higher amplitudes when plucked. We observe here that similar to the previous graphic, P1 is more sensitive on off-axis situations than P2 (that presents no important amplitudes rather than when stroke on-axis). On the other side, in this measurement P2 shows a slightly lower amplitude in relation to P1 (contrary to the previous graphic). We believe this is due to the force applied by the user when stroking both piezos that varies from

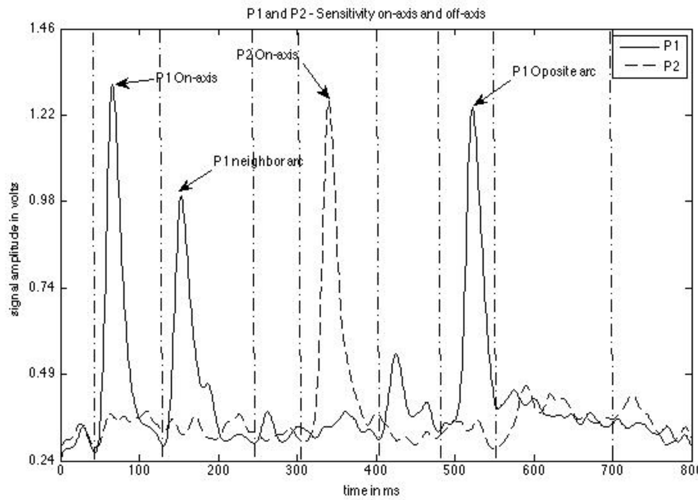


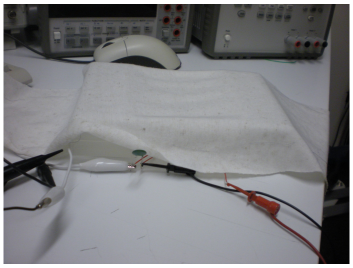
Figure 3.7.: Piezoelectric disk: Sensitivity on all 8 arcs of Intonaspacio.The vertical lines indicate the moment of the stimulus.

moment to moment.

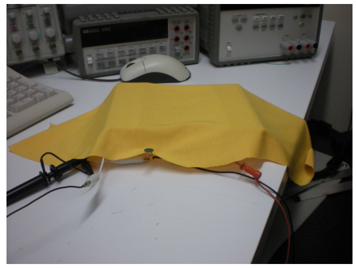
Distance

To calculate distance we used a PSD (Position-Sensitive detector). A PSD (Fraden, 2004) or an infrared sensor (IR) (Sen, 2014) is an optical sensor with a LED (Light-Emitting Diode) that emits a beam of infrared light and a photoreceptor that receives the reflected beam. When an object is within the sensor range, the beam is reflected by the object and a triangulation calculation is used to calculate the distance at which the object is from the sensor. The intensity at which the beam is received depends on the reflective properties of the object. The angle of the object in relation to the emitted light can also alter the measurements. This sensor only measures the distance in one axis.

Intonaspacio uses a Sharp GP2D120 mounted at the center of the sphere facing the performer. Our initial idea was to completely cover the surface of the instrument with fabric, however the IR sensor presents some sensibility to changes in opacity. We decided to test it with several fabrics. The fabric had to have some characteristics: height, it had to have some height in order to be rigid enough as to not deform when



(a) IR: fabric 1



(b) IR: fabric 2

(c) IR: both fabrics

Figure 3.8.: Testing different fabrics with the IR sensor.
Source: Mailis Rodrigues

hit by the performer; and opacity, it had to be translucent in order to enable a wide dynamic range in the IR sensor.

We chose two cotton fabrics for the first version of intonaspacio. One white, very translucent, and one yellow, somewhat translucent. Both of the fabrics were placed at the same distance from the IR sensor, first one by one and then the two fabrics together, one on top of the other, Fig. 3.8.

We observed how different were the responses of the sensor for each situation - white fabric, yellow fabric, and both combined. In Fig. 3.9 is possible to see that the response is quite similar between the two fabrics, but in the third condition there is a small difference in the response of the IR sensor, that can be used to map different situations.

These results led us to decide using both fabrics together, interpolating them - white, yellow, both, and so on, as a beach ball, Fig. 3.10.

This way we could create different zones of sensitivity on the instrument. This idea however was not easy to implement, the frame of Intonaspacio due to its pliable characteristic is not stable enough, which makes it very hard to sew fabric into it. Instead we chose to separate the instrument in two distinct zones, the top with the yellow fabric and the bottom with the white one, shaping the fabric as two doughnuts, Fig. 3.3b. This also enabled an easier access to the center of the sphere and therefore to the sensors. Nevertheless the fabric created a lot of “pits” in the surface of Intonaspacio, which revealed to be a problem, since we were looking for a

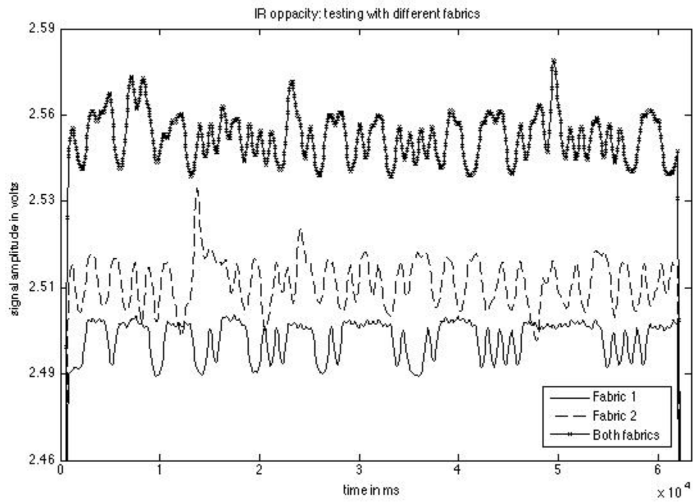


Figure 3.9.: Testing different fabrics with the IR sensor - results.The stimulus is continuous.

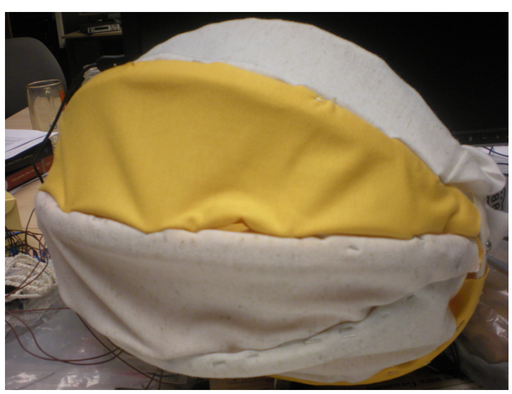


Figure 3.10.: Fabric covering Intonaspacio. Different zones of sensitivity.
Source: Mailis Rodrigues

stiff “skin”.

The IR sensor we are using has a 30 cm range and detects any body at a distance of 15 cm from the instrument. Initially we thought about detecting changes in the surface - when the performer bent the surface with his hand, the distance between the fabric and the sensor would decrease, causing a change in the output of the sensor. This was the method used in version 1 of Intonaspacio.
The IR sensor introduces a lot of noise in the signal, to smooth it we use a capacitor in series. In addition the sensor also presents a non linear and non monotonic response (Medeiros and Wanderley, 2011) and (Medeiros and Wanderley, 2013), as we can observe in Fig. 3.11. A non monotonic response gives the same output for different inputs, creating zones of ambiguity on the reading. These can be corrected either by calibration or through software (Medeiros and Wanderley, 2011), (Medeiros and Wanderley, 2013), (Erdem, 2010) and (Khan et al., 2008). In the figure we can see that the same continuous movement - changing the distance of Intonaspacio to the user's body, in opposite directions, over a 15 cm distance, the sensor outputs the same non monotonic response. In the figure we clearly notice that different distances output the same value. It is also observable that the signal will change direction even if the movement continues in the same sense For example on the top figure the amplitude of the signal starts to increase again (around 160 ms) even if the distance is still decreasing. These are characteristics that we must be aware when mapping the values extracted from the IR sensor. [7]

Surface deformation

The first version of Intonaspacio has an extra feature that is no longer present in the following versions - the measurement of surface deformation. This is due to the characteristics of the material we used to build the frame of the instrument, which is very bendable. To calculate the deformation we use a bend sensor. These sensors use conductive ink with a certain resistance that varies when it is bent. It is widely used in gloves to detect the flexion of the fingers. We are using the Flexpoint PAT.5.157.372.

[7] We worked in collaboration with Carolina Medeiros to perform several tests where we compared the response of the IR with a motion capture system to measure position. The results will be presented in the PhD thesis of Carolina Medeiros, manuscript not published yet.

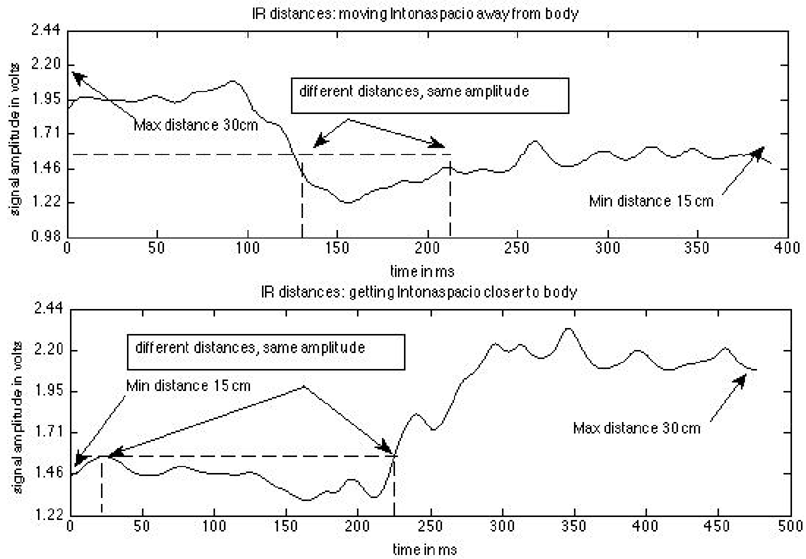


Figure 3.11.: IR: non-monotonic response.The stimulus is continuous.

which is unidirectional, it only measures flexion in one direction, from 0º to 180º. We tested three different sizes and chose the one with approximately 5 cm, because it was the one that adapted better to the curvature of the instrument. The sensor is used within a voltage divider circuit with a resistance of 47KΩin order to get a better range of outputted values. We placed it in one of the arcs of the instrument, Fig. 3.12.

Since we changed the material in version 2, this sensor is no longer used once the new structure is not very flexible, as we can observe in Fig. 3.13. The signal amplitude of the bend sensor when placed on the Ticp arc is very low when compared to the same sensor placed on the plastic arc. Also the Ticp shows a very small dynamic range which is not desirable to our work.

3.3.3. Version 2

The second version of Intonaspacio used Commercially Pure Titanium (Ticp) to built the frame. This material gives a greater stability to the structure but decreases drastically the flexibility of each arc. Nevertheless it seems more adequate to support the sensors and it is aesthetically more interesting, Fig. 3.14.

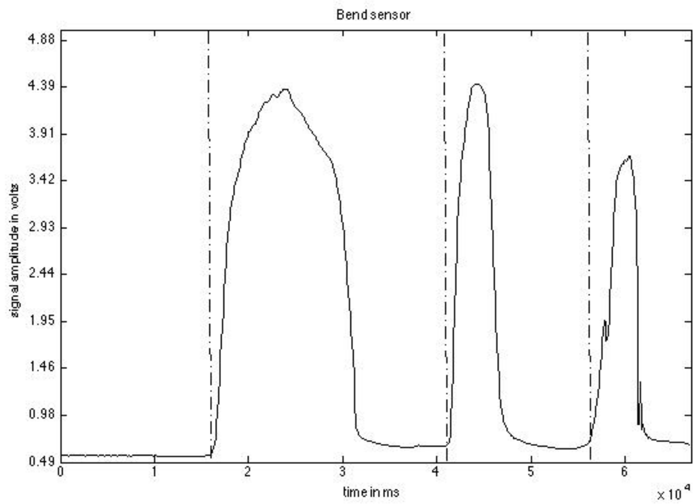


Figure 3.12.: Bend sensor. The vertical lines indicate the moment of the stimulus.

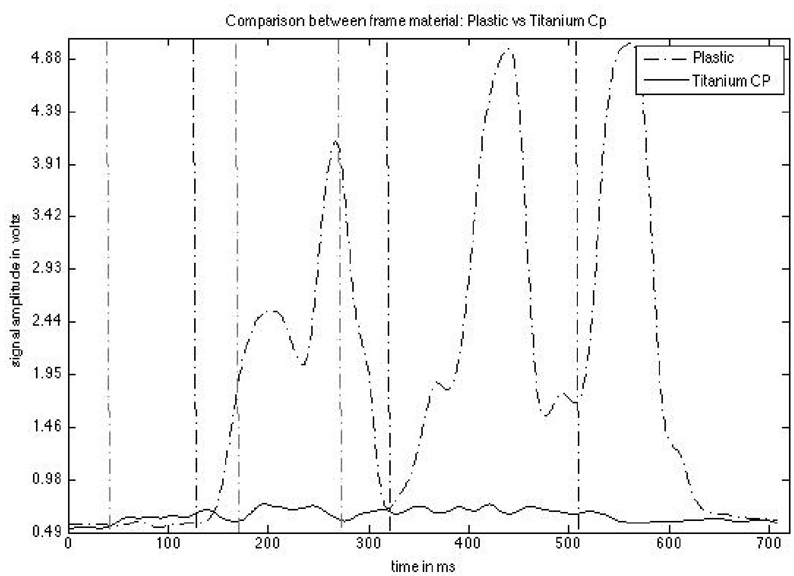


Figure 3.13.: Bend sensor placed in two different materials. Plastic and Ticp. The vertical lines indicate the moment of the stimulus. The grey lines indicate the Ticp stimulus.

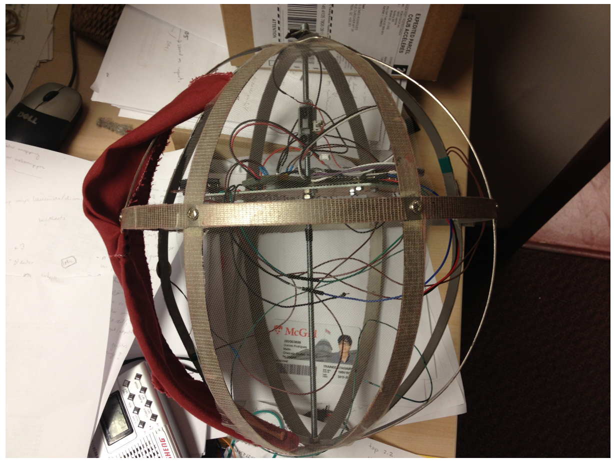


Figure 3.14.: Intonaspacio version 2.
Source: Mailis Rodrigues

We also changed the cover of the instrument opting for a linen fabric which is heavier and consequently more rigid, enabling to keep the sphere shape. At first we applied a very translucent fabric but we noticed that the dynamic range of the IR sensor was not very wide, hence we decided to leave the front of the sensor without any cover. This decision led to new ways of holding the instrument, different from the one we had initially thought, Fig. 3.15. Examples of these are presented on chapter 5.

The fabric in this version was not sewed but glued to the arcs using adhesive tape suitable for fabric. We added visual clues to the surface to facilitate the location of the piezos. On a learning stage this clues are extremely useful, as we perceived by the comments gave by the participants of our experiment (presented on chapter 4).

With a new material for the structure some of the sensors we used in the previous work were not adequate anymore, mainly because they did not had enough sensitivity to measure the gestures this new version called for. We added as well a new sensor, a textil FSR that is explained in detail below.
We will present the modifications of version 2 of Intonaspacio, using the same subsections as in version 1, excluding the ones where there was no change (Orientation and Impact).

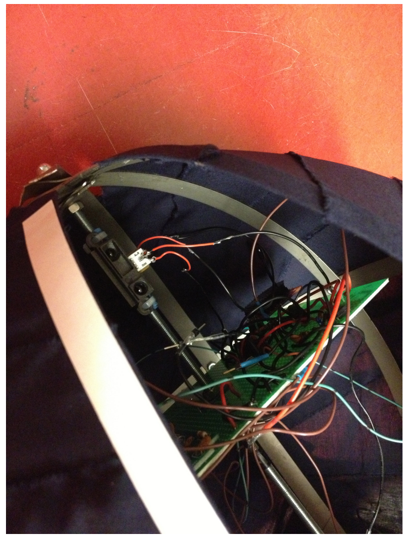


Figure 3.15.: Intonaspacio version 2. Detail.
Source: Mailis Rodrigues

Distance

As it was stated before, we no longer use the bend sensor since the new material (Titanium cp) does not present a great flexibility. Another modification is that the IR sensor do not have fabric in front of the sensor anymore, which enables a greater dynamic range. Also, after analyzing the sensor's response we decided to start considering the distance from the instrument to the performer's body and not his hand only. This decision was made because we have noticed the sensor responds better when it has a bigger surface in front of it than with a surface with a smaller area like the hand. Besides, the hand must be quite away from the body or else it will not be detected as a separate 'entity.

Pressure

The decision of covering the frame of Intonasapcio with fabric was based in two important motivations in our research work. First, e-textiles is a research area that is still in its beginning, especially when related to sound issues, with interesting exceptions (the work of Adrian Freed (Schmeder and Freed, 2010)). Second, we wanted to create a skin for the instrument that could work the same way as a membrane in a percussion instrument. One outcome of this option was the idea of having the possibility to change the stiffness of the skin, enabling the creation of a tunable instrument. We then decided to have a pressure sensor embedded on the fabric, so we designed a Force-sensitive Resistor (FSR) textile sensor.

A force (Fraden, 2004) (Sen, 2014) sensor is a sensor that measures force applied to a certain spot. Fraden (Fraden, 2004) differentiates two types of force sensors: a quantitative and a qualitative. Quantitative sensors are the ones that measure force and translate it in an electrical signal, a strain gage (Window, 1992) (Neubert, 1967) (Fraden, 2004) (Sen, 2014) is a good example. Whereas qualitative sensors just measure force when a certain threshold is exceeded, their reference force. For example in a typical FSR sensor, the sensor only reacts when the performer applies enough pressure for his resistance to change, so they do not measure force accurately. For our work, and for several musical applications, an accurate measurement of force is not fundamental thus FSRs are widely used.

E-textiles(Paradiso and Rossi, 2006), (Coyle et al., 2009), (Berzowska and Bromley, 2007) are fabrics that have conductive characteristics. A new branch of digital interfaces related to this technology, called wearable technology (Fontecave-Jallon et al., 2013), (Seymour and Belloff, 2008),(Thorpe, 1998) has been growing, especially with the introduction of micro-controllers like LilyPad (Buechley and Eisenberg, 2008). The e-textiles and all their possibilities are not yet very explored especially in music (most of their applications are in medicine (Patel et al., 2012), (Fontecave-Jallon et al., 2013), (Dosinas et al., 2006)(Edmison et al., 2004) and sports(Scilingo et al., 2003)(Ermes et al., 2008). In arts there are some interesting projects but mainly focus on visuals (Perner-Wilson, 2007), (Berzowska, 2007), (Berzowska and Coelho, 2006a), (Berzowska, 2005), (Berzowska and Coelho, 2006b), (Seymour and Belloff, 2008) and (Ugur, 2012)). For personal motivations we decided to explore this area of research and designed an homemade pressure sensor, Fig. 3.16.

Based in Wilson (Perner-Wilson and Buechley, 2010) we designed our textile sensor with homemade conductive ink, combining graphite and nail polish. The sensor was very responsive and robust. We wanted this sensor to be the size of a finger pulp, thus we designed smaller sensors and glued them to some of the arcs of the instrument. When installed, however, they revealed several weaknesses, namely they were not

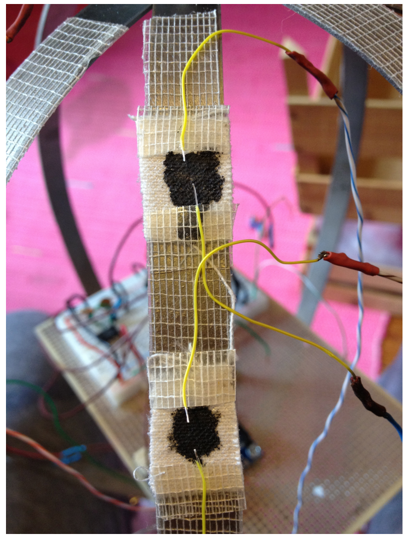


Figure 3.16.: Fabric sensor.
Source: Mailis Rodrigues

very robust.

To overcome this problem, we decided to use, instead of a FSR, a textile home-made strain gage sensor. A strain gage (Window, 1992) (Neubert, 1967) (Fraden, 2004) (Sen, 2014) is an extremely precise sensor (when installed in good conditions) to measure deformation of an object. Its operating principle is very simple. Knowing that any conductive material has a resistivity than changes with extension and compression, it is possible to measure deformation by applying a conductive wire in a non-conductive surface glued to the measured solid. This way when the object is deformed the sensor deforms in the same proportion and translates it into an electrical signal. The problem with strain gauges however is the installation that is quite laborious, the sensor needs to be perfectly glued to the object, and since it has very small dimensions it needs a complementary circuit in order to raise the output voltage and prevent errors due to temperature changes.

To design a strain gage using fabric we had two options: using conductive ink directly on the fabric that covers Intonaspacio, which was non-conductive; or sewing conductive fabric on top of Intonaspacio's cover. However, this task revealed to be much more simple, since the amplitude range was greater than we initially though

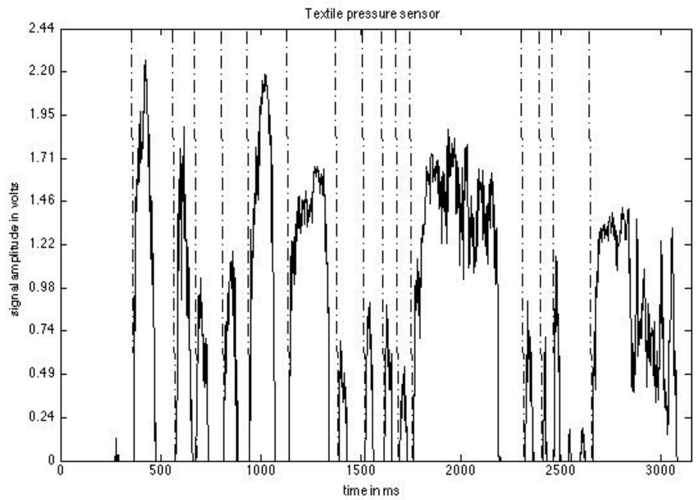


Figure 3.17.: Fabric sensor response when pressed. The vertical lines indicate the moment of the stimulus.

and a simple FSR was able to detect the deformations in a satisfactory range. The sensor is made with conductive fabric - ESD Static Fabric, glued on a non-conductive fabric that is in turn glued at one of the arcs. It is mounted at the top of the arc, close to the junction with the other arcs. The goal is to detect only the small changes that are produced by the performer's finger pressure. The sensor has two conductive wires at each end, that are placed between the non-conductive and the conductive fabric, this way it only allows current to pass when it is pressed. Tests showed that the sensor is very stable, presents good results in accuracy, repeatability and sensitivity, Fig. 3.17.

3.4. Conclusion

Intonaspacio is a DMI designed in order to integrate place in the generation and control of sound. It is an interface that creates place-specific sound. Inspired by the approached presented on chapter 1, we decided to give the performer the possibility of recording the background noise of the place and use it to excite the structural sounds of that place. Thus we use a microphone to capture the sound present in the room (sound generated by the performer itself, sound from other players in the room, other sounds present in the room or the resonant frequencies generated by the room). We have opted for a wireless mic that uses an FM transmitter to communicate from Intonaspacio to the computer. Previously we had tested a pair of binaural microphones but this solution brought enormous constraints - these microphones need a supply of 3V to work and this situation prevents the instrument of being wireless. Our interest was always to have a wireless DMI that the performer could displace around the room, searching for responsive areas, create layers of randomness that were generated by the place's acoustical behavior. The wireless microphone is not, however, the best solution. It introduces noise in the signal and its frequency of emission has to be adjusted every time Intonaspacio is moved to another room.

Intonaspacio has a ball shape which has specific characteristics that brought some questions related with stability, robustness and lightness of the structure. At the same time this shape inspires a set of gestures that comes from the experience of playing with balls. We can use this previous knowledge to facilitate the first approach of a performer to the instrument. This situation also help us to predict a set of actions that the instrument has to sense, as well as what are the most suitable sensors to measure them. From this point of departure we designed a first version of the instrument, where the frame was made with very bendable plastic stripes. These enabled the structure to be pliable and thus easier to carry from one place to another. The structure however presented several problems and we had to change the material of the frame to Ticp. From version one to version two some of the sensors had to be different since the characteristics of the material were not the same.

The choice of the sensors was made based in the set of actions we wanted to capture - orientation of the instrument, impacts on the surface, distance from the instrument to the performer, deformation of the surface (in version 1) or pressure applied by the performer on the surface of Intonaspacio. Our DMI has implemented a set of 5 sensors - an IMU with an accelerometer, gyroscope and magnetometer (all with 3-axis); two piezoelectric sensors (one is a ceramic disc and the other is a film with a small mass at the end); an IR sensor and finally a textile pressure sensor. For each we performed several test to understand their behavior and their dynamic ranges. Based on these tests we chose the best position to place the sensor and what kind of features we could extract from them. The change of material also prevented us to use the same sensors in both structures - see for example the bend sensor used in version 1 where the structure was much more flexible than structure of version 2 that almost did not presented any ability to deform.

4. Mapping and validation of Intonaspacio

In this chapter we purpose three different ways to integrate place on sound using Intonaspacio. Each mapping reflects a method where the resonant frequencies of the room are excited. The first two mappings are evaluated in a users test. Then, we present a third mapping as a result of the analysis of the experiment.

4.1. Mappings

As we have seen on the previous chapter, the DMI convey a disconnection between sound generation and sound control, thus introducing a new element in the instrumental interaction - the mapping. The mapping is the element where gesture and sound parameters are combined in different relations, Fig. 4.1.

The associations between both layers - control and sound generation, are arbitrary, and dependent only on the intention of the DMI's designer. Some researchers associate mapping with composition, the distinction between both perspectives relies on their position when discussing time. Mapping in DMIs always relates to real-time questions (the action/reaction must be enclosed in the smallest frame of time possible in order to be understood as an immediate behavior of the interface). While composition deals with non real-time processes. In our work we will opt for the first perspective since we believe mapping is an essential key of the design of DMIs, it defines the behavior of the instrument and contributes to the development of an unique instrumental technique.

The literature proposes two types of mapping approaches: generative mapping and "explicit mapping techniques" (Hunt et al., 2000) . The former has a learning and training period where the system acquires knowledge on how to react to certain

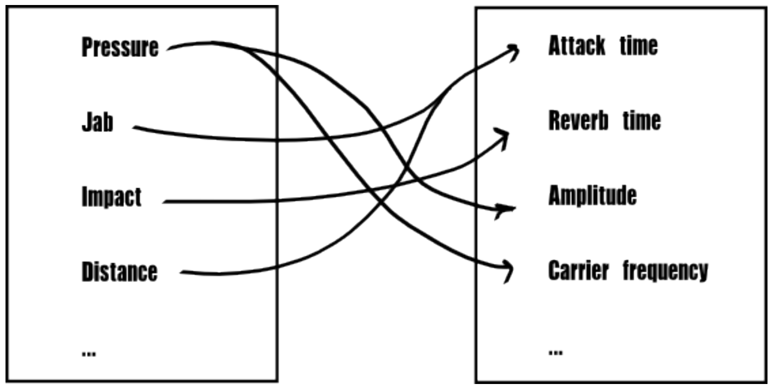


Figure 4.1.: Mapping. Several strategies are used: one-to-one, many-to-one and one-to-many)

inputs from the performer. Some common used techniques of this approach are neural networks and some statistical procedures such as standard deviation, covariance and so on (Modler, 2000),(Smith and Garnett, 2012), (Kerlleñevich et al., 2011).
Explicit mapping techniques are relations created by the designer of the instrument that relates control gestures to sound generation and modulation parameters. These can be of several types:

- **One-to-one** One feature controls one parameter on the sound.
- **One-to-many or divergent mapping (Rovan et al., 1997a),(Rudraraju, 2011)** One features controls one or more parameters on the sound,
- **Many-to-one or Convergent mapping (Rovan et al., 1997a),(Rudraraju, 2011)** Several features control one parameter on the sound.
- **Many-to-many** Several features control several parameters on the sound.

A clear trend of the design of digital musical instruments is to opt for simple mappings, where one-to-one strategies are used. Designers tend to establish simple connections where the effect of the gesture is immediately perceived by the performer. However, this strategy presents several weaknesses. The most obvious is the lack of expressivity. When we observe the links established between gesture and sound in an acoustic instrument, we easily understand that complex mappings are, generally, the most present (Hunt et al., 2000), (Rovan et al., 1997a), (Rudraraju, 2011), (Marshall,

2008). In an acoustic musical instrument several parameters contribute to a change in the sound - convergent techniques are the most common. Bongers (Bongers, 2000) exemplifies with the violin where the speed of the bow, the pressure, the string played and the position of the finger, all together contribute to control the intensity of the sound. Similarly, several studies (Hunt et al., 2000), (Rudraraju, 2011) demonstrate that complex mappings are more expressive than simple mappings. Thus performers are more inclined to explore these DMIs and feel more engaged and interested in it (Hunt et al., 2000). Comprehensibly this situation leads to a longer learning time and possible to an increased frustration since the player cannot simply relate gesture with sound, but learning an acoustic instrument also requires a lot of time of dedication and learning.
One possible solution to design complex mappings, suggested by Goudeseune (Goudeseune, 2002) is the use of relations (between gesture and sound) where parameters are not exclusively connected in a direct proportion (x = ky). One can establish derivative relations, where the rate of change in the input controls the output, or a integration relation, where the history of the input controls the output. Combining these three options (PID theory - proportional-integral-derivative) creates greater complexity with a greater number of available options of control.

Mappings can balance expressivity and complexity with a simpler approach which enables the performer to understand, without further difficulty, the behavior of the instrument. Some DMIs, especially the instrument-like DMIs (see chapter 2), take advantage from the performer's previous knowledge on how to manipulate these instruments. Some others, as Intonaspacio, suggest a combination of gestures because the shape is familiar. Goudeseune also (Goudeseune, 2002) suggest the utilization of a metaphor on the mapping design. This brings transparency to the process. A metaphor, in this situation stands for the creation of an association between a know manual task and the action of playing a DMI. For example, the authors suggest the activity of sculpting. The DMI, to be played, would make use of the same gestures that a sculptor needs to use when working. Goudeseune (Goudeseune, 2002) defends that transparency is an essential feature for achieving expressivity on DMIs.
Complex mappings also benefit from the use of high level language. Instead of controlling frequency and amplitude, for example, the mapping can enable the control

of timbre (Malloch, 2008), the DMI would result in a interface that could control and modulate timbral spaces (Wessel, 1979). Malloch (Malloch, 2008) also suggests the subdivision of mapping in several layers where the gestural acquisition would be separated from the sound synthesis parameters, and in-between would exist a semantic layer where these abstractions would take place. [1] If we have generic features that are sensed by the instrument, and at the same time generic parameters in the synthesis algorithm, it is simpler to create dynamic mappings. It also facilitates the use of different synthesis algorithms controlled by one DMI and vice-versa.

4.2. Mapping Intonaspacio

When designing the mapping for Intonaspacio we had two main concerns: one, the integration of place on the sound process, and the creation of a musically expressive instrument. Due to it, the process was time consuming and in need of constant improvement. In our research we present three possibilities of combining place and sound with Intonaspacio. Our goal in the several approaches was to excite the resonant frequencies of the room. Two methods are proposed: one is direct and the second is indirect.

In Intonaspacio we have a layer for the gestural interface and a second for the sound synthesis algorithm. For each, different people are in charge, the former is the one that defines the way the instrument will be played and how it will react to the gestures of the performer, therefore it is part of the DMI designer's work and should be, in our perspective, fixed. This way the DMI have a certain coherence over time. Hunt (Hunt and Wanderley, 2002) alludes to this situation when he notes that is the designer of the DMI that has to decide how the physical interface will connect to the sound source. The second part is much more relied to composition techniques and this one can be dwelt by the composer or performer and can be changeable from piece to piece. Our work relies exclusively on the first layer of the mapping, we have

[1] By abstractions Malloch means the transformation of the extracted features on meaningful actions. For example if the signal of an accelerometer presents high frequencies and high amplitude, one can associate it to jerky gestures. By creating these abstractions it is easier for others than the designer to create mappings with the DMI.

worked in collaboration with composers that have created different solutions for the second layer (we present some of it in chapter 6). The design of the DMI should rely on a gestural approach where the sensors are chosen based on the set of gestures we are interested to capture, enabling the creation of an individual technique of the instrument, that aggregates control and expressivity.

In Intonaspacio most of the signals extracted from the sensors were extremely noisy. Hence, the first step was to smooth the output signal [2], pulling out an average signal. Except for the IR, all signals outputted from the sensors were somehow "cooked" - they had to be transposed to values more suitable to work with [3]. The IMU had already installed an option to output the calculated euler angles (Pitch, Yaw and Roll), thus we did not performed any transformation on these. We used Maxmsp to process the signals and to design the sound synthesis algorithms, and Libmaper (Malloch et al., 2013b) to create the mappings. Libmapper is an application that allows to create dynamic mappings between the DMIs and the synthesis algorithms. Thus we can combine the same interface with different sound synthesis algorithms very easily. The advantage to our work is that we can test all the mappings we propose on this work together with no time constraints. There are other options to create dynamic mappings but for time constraints we did not test them, also although the evaluation of mapping tools is out of the scope of this thesis.

The interaction process in Intonaspacio was somehow inspired by the same mechanisms that underlie the experience with an acoustic instrument - a transmission of energy from the performer to the musical instrument is simulated and this energy must be is some way reflected in the generated sound. These relations in Intonaspacio were establish based on the analysis of the incoming signal (rate of variation, amplitude of the signal, integration and so on). We also attributed functions of excitation and damping to specific gestures - strike one of the piezos would initiate a sound with the same amplitude as the piezo reported, the stronger the impact the louder the

[2] We mention output instead of input because we are speaking of the signals that are sent from the sensors.

[3] For instance in Maxmsp the amplitude of sound must be between 0. and 1. else it will cause distortion.

sound. Obstruct the IR will damp the sound, and eventually stop it, depending on the time the performer remains with the instrument in the same position.

4.2.1. Direct approach

Different strategies can be used to integrate the sound present in place into the sound work, Ascher, Lucier and Cage to name three, all presented different solutions. The direct approach is inspired by the idea of Lucier's constant loop. We use the microphone installed in Intonaspacio to record samples of sound ambiance of the room (background noise). The sample is played on a continuous loop. This process of feeding back the sound in the room will excite the resonant frequencies of the room (structural sound)- each iteration is the result of the combination of the previous recorded sound and the acoustical response of the room to the emitted sound.
At this point two options are available for the performer. He/she can immediately create enough iterations to produce a noisy sound file where the resonance of the room is combined with the sound ambiance. This is achieved by initiating a new record every time the sound file is reproduced. Otherwise the performer can play with every layer of the process, taking some time before starting a new recording. It is possible to start the process all over again at any time. Fig. 4.2 shows a diagram where this process is represented.
The performer can produce sounds with its own body (tapping, voice) and create loops of sound with them. By displacing Intonaspacio inside the place, the performer can create different responses of the place to the initial recorded sound.

We have applied this method on mapping 1 of an experiment with users (we will introduce this experiment in the next section).

4.2.2. Indirect approach

The indirect method consists in the analysis of the input signal of the microphone. We use a FFT to extract the fifteen most amplified frequencies in the room. We have chosen to extract fifteen frequencies because it creates an ensemble of partials that can represent a rough spectral image of the room acoustical response.

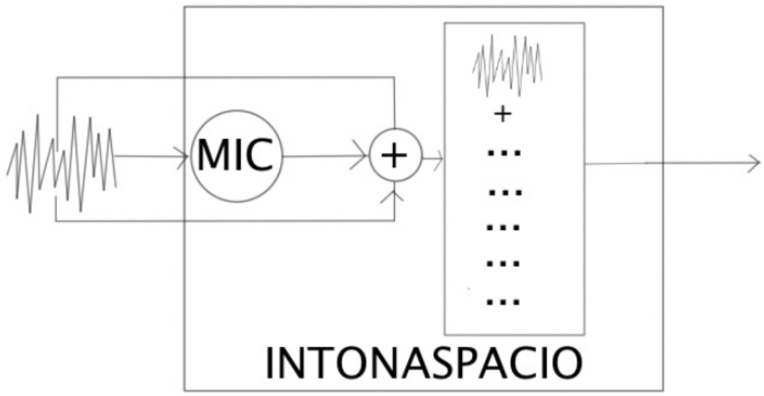


Figure 4.2.: Direct approach. The sound is recorded and reproduced on loop capturing all the sounds present in the room. Resonant frequencies are excited and combined with the other sounds.

This mapping also allow us to have a process that is performed in real-time with an inexpensive computation. This set of frequencies is dependent, first on the sounds produced by the performer and second, over time, on the response of the room. The goal is to have a very simple room analysis, where we are aware of the filtering effect of the room as well as the frequencies that excite this behavior. The retrieved information is used to control several parameters in the synthesis algorithm. The performer can create smooth changes on certain sound effects (reverberation, harmonizer, chorus and so on) with the variation of the readings. This process is performed in real-time too.

Mapping 2 of the user's experiment (presented in detail in the next section) uses this approach. The performer no longer can record samples of sound ambiance, instead by its displacement along the room he will change the readings extracted from the FFT. This will affect the parameters of a reverberation and tremolo effect. This changes are very subtle. We believe from room to room the differences could be more pronounced. Fig. 4.3 presents a diagram with the indirect approach.

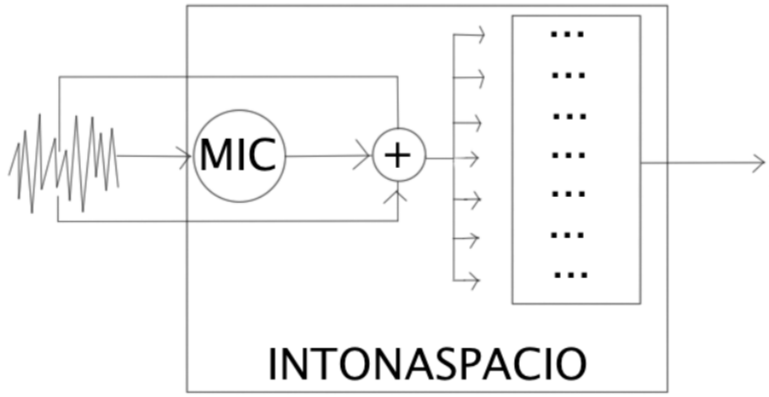


Figure 4.3.: Indirect approach. The sound input is analyzed and a list of the 15 most amplified frequencies in the room is outputted.

Other sensors

As we have presented on the previous chapter , Intonaspacio as four other sensors beside the microphone. These contribute to modulate the generated sound, and are either directly controlled by the performer (in the first proposed approach for example) or indirectly by the displacement of the performer in the place (as proposed in the second approach). Next we will present the extracted features of both piezoelectric sensors, the IMU and the IR.

Piezoelectric sensors

The same features were extracted from both piezos. They exhibit some differences in behavior but these are somehow lost in the signal acquisition.
The analyzed signal from the piezoelectric sensors informed us if a sensor was struck and how intensely. This information is used to initiate a sound with an amplitude which is proportional to the amplitude of the output of the piezo. Additionally, we also extracted the number of times both piezos were struck and finally the velocity of the strike, i.e., how fast the piezo reached it's maximum amplitude. These features were combined with the amplitude to tell us the intensity of the strike.

Accelerometer

The accelerometer signal is used to detect impact, namely jab and regular taping on the surface of the instrument. To perceive jab we add up the signal of the three-axes acceleromenter (x, y and z) and analyzed the amplitude of the signal. If a certain threshold is exceeded, the system reports a jab. This detection method is, however, not completely reliable. In order for this detection to be robust, we would need an algorithm to separate the accelerometer signal in two strings - low frequency and high frequency. These would prevent misrepresentations of jab gestures such as when the performer tilt Intonaspacio reaching high amplitudes of the combined signal (the three axes together).
The accelerometer also enables us to sense regular tap in the surface of Intonspacio. Jab gestures can be mapped to trigger sound effects.

Pitch, roll and yaw

The output of the IMU unit also allows us to extract the three euler angles - pitch, roll and yaw. These are used to control different parameters such as sound spatialisation. We can also define regions of values where certain effects are turned on or off.

Infra Red

The IR signal give us information about distance to the body or hand of the performer. We separated the signal in three zones that corresponded to far, close and covered. Then we integrated the values collected at each zone. From this information we were able to know how much time the instrument was kept in the same zone. This helps us to attribute to IR the damping function. When the performer holds Intonaspacio close to his body, covering the IR sensor for more than five seconds, the instrument is turned off.
IR is also responsible for controlling the overall amplitude of the sound. By changing the distance towards the body or the hand the performer can alter the intensity of the sound played.

4.3. Experiment 1: User's test

We have performed an experiment at McGill University in order to understand the amount of control users had over Intonaspacio, as well as the most common gestures and their perception of place presence in the generated sound. The study involved seven participants, all with musical background, and six with previous knowledge on performing with digital musical instruments. The test included three trials where the user could play freely with Intonaspacio, around the room. Each trial had a correspondent mapping. At the end all subjects were asked to answer a questionnaire about the experience. The questions centered on two particular points: the usability of Intonaspacio - sensation of control, easiness of manipulation, repeatability of behavior; and the perception and interest of integration of place in sound, according to different strategies. The complete questionnaire is presented in appendix II.
We understand that statistically the number of participants is very reduced, and because of that we combine several methods of analysis, namely we analyze video and sensors' data; we analyze the comments of every participant and we combine the information from the participants in groups. This procedure we believe will give us an ensemble of hints that need to be further explored, eventually by repeating a similar experiment with more participants or extending the experiment on time (given more time to each user to explore Intonaspacio).

We present three different mappings to the users. They could play with each mapping for around 5 to 10 minutes. Mappings 1 and 2 correspond to the direct and indirect approach, respectively. Mapping 3 does not have any active participation of place in sound in order to understand if participants would feel place as an essential feature when playing with Intonaspacio.
The mappings were made with Libmapper, which facilitated the exchange between the three mappings. Mappings were selected one after another, sequentially (same order to every participant). [4]

[4] We did not think it was important to exchange the order of the mappings between participants, since the necessary steps in every mapping are clearly different, thus the participant always knows what mapping he/she is working with.

The questionnaire is divided in two modules, preceded by a first section where a group of questions helped us to characterize the subject and understand what his/her knowledge in music was, and if he/she had past experience with DMIs. The first module of the questionnaire examines the interface design. Here, we pose questions about control, robustness and repeatability of events. Finally, the second section analyses questions of place-specificity and compares the three mappings. We insist particularly in the comparison between mapping 1 and 2 in order to understand which method for place integration in sound users prefer or feel more comfortable with. We also tried to discern if participants felt the instrument as place-specific and what were the level of engagement this feature conveyed.
The questions are of two types: closed questions with a 5 points Likert Scale (Gavin, 2008) or a yes or no answer; and open questions where the user comments the experience. In the Likert Scale we used a rate scale where 1 corresponded to extremely difficult and 5 to very easy. Some of the questions had different terminology according to the nature of the characteristic we were evaluating (see for example Part1:Question6 in appendix II).

For each user, we recorded the values outputted from the different sensors, in every mapping. This information help us to understand which where the most common gestures used by each participant at each mapping, if there were gestures commonly repeated by all of the users, or if there was a set of gestures repeated by a participant. The goal is to extract a gestural grammar that could be the basis for a musical notation system for Intonaspacio (presented in chapter 5). We also recorded a video for each participant.
As we had a small number of participants in our study, we combined different analysis techniques in order to extract the maximum information from it.

Based on the information we gathered from the users we divided them in three groups:

- **Group A** graduated musicians - 3 people
- **Group B** amateurs - 4 people
- **Group C** users with previous experience with DMIs - 6 people

- **Group D** users without previous experience with DMIs - 1 person
- **Group E** users with previous knowledge of place-specific practices - 2 people
- **Group F** users without previous knowledge of place-specific practices - 5 people

4.4. Results

As proposed earlier, and in order to have more expressive results, we analyzed the answers of each group in the various themes (interface, place-specificity and mapping), rather than the individual choices of each participant. We also separated the results according to the type of questions. Thus, for questions related to interface and site-specific, we have two sets of results corresponding to the Likert scale questions and the yes and no. Questions about mapping were handled differently since they were mainly multiple choice questions, where the participants were asked to choose between mappings.

4.4.1. Interface

In the conception of a new musical instrument is of paramount importance to understand how users, namely musicians, adapt to the interface and how its behavior will be over time. In these section we focus mostly in trying to understand how robust participants felt the instrument, if they were able to repeat the same gestures and generate the same sound, if the interface inspired them to perform some gestures, or on the contrary they felt their actions constrained in some way, and finally how hard was to learn how to play Intonaspacio.

To each answer was attributed a numeric value, 1 to 5 in the Likert scale questions and 1 or 2 in the yes and no questions (1 corresponding to yes and 2 to no). For each question we summed the answers and performed a calculation on the percentage of each value both by group and subject (Interface, Mapping and Site-specific). We then calculated the mean for each group of participants in the three main subjects [5]. Fig. 4.4 present the average of responses related to Interface, comparing Group A with

[5] Since we did not have a large number of participants, we did not consider standard deviation.

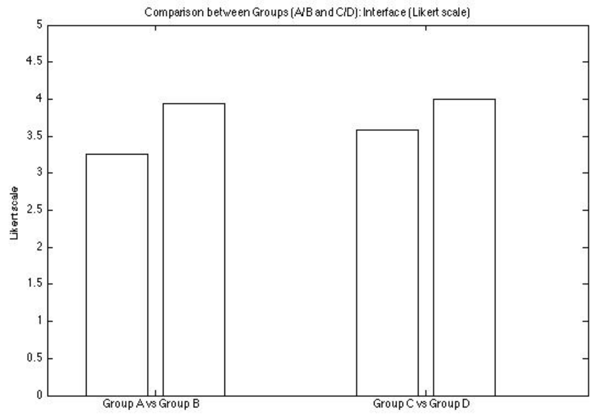


Figure 4.4.: Likert scale - comparison between groups A/B and C/D)

B and Group C with D, respectively. We can observe that graduated musicians are more critic of the interface than non graduated musicians (with around 0.75 points of difference). However comparing both graphics we understand that the overall opinion is very satisfactory, it stands above 3.5 (3.64) as we can observe in Fig. 4.5 which compares the total of answers with the answers within each group.
We should notice that participants from Group E, give a lower evaluation to the interface (2.88). However, it must be observed that Group E shares subjects with Group A, thus the results from Group E are not particularly relevant. They are, nonetheless, accentuated by the fact that there are fewer participants to answer (2 instead of 3).

The second set of questions (the yes and no questions) related mostly to how the interface felt to subjects - the need for other clues than the audio ones, for instance visual and haptic feedback; inspired or constrained gestures by the interface; and how much control participants felt while playing with Intonaspacio. Somehow, we have the same repetition of the previous results (Fig. 4.6), once more professional musicians are more critic to the interface than amateurs. Although this time we can see that Group D is much more negative (the average of answers is 1.13 against 0.96). This can be viewed as a consequence of the lack of experience with DMIs. The participant showed a great enthusiasm (greater than the participants that already had contact with these instruments) but at the same time it is more difficult to him to interact with (we will assume that other participants have a previous knowledge on how to

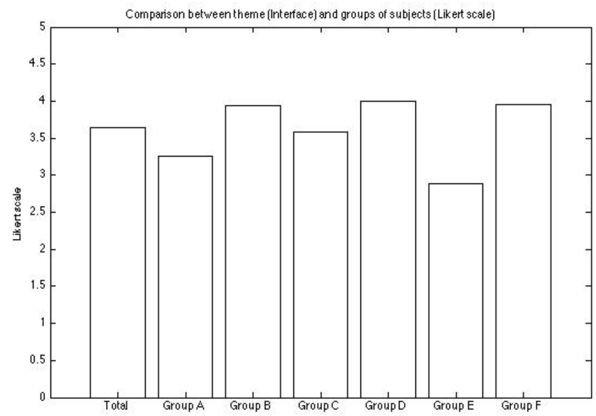


Figure 4.5.: Interface: comparison between groups (Likert scale)

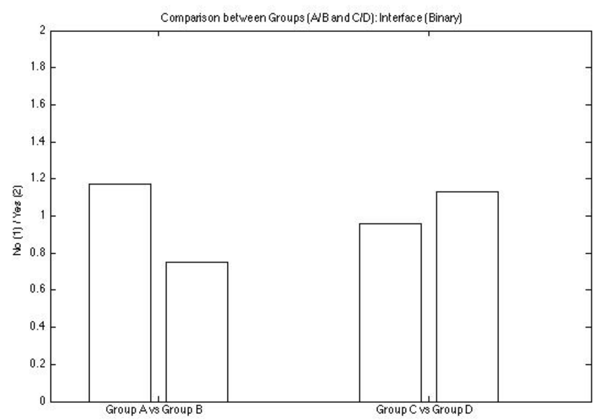


Figure 4.6.: Yes and No questions - comparison between groups A/B and C/D)

play with a DMI).

According to most users the shape of Intonaspacio was very easy to rely with, first because it is a known shape - a ball, and that leads participants to perform certain gestures. Participant 5 describes it as "It made me think about a ball, so I felt like I could throw it on air and make it rotate on my hands.". The same idea is present in the comment of Participant 4 "It was really neat how it invited these kind of smooth, rolling gestures (from the shape of the instrument and it's size)." Later, Participant 4 also mention that he thinks it is interesting because "it invites to a lot of weird performance gestures". The relation created between actions and sound also helps

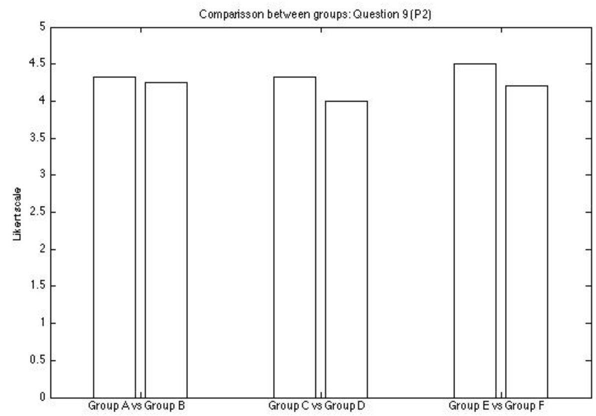


Figure 4.7.: Comparison between groups: Question 9 (Part 2)

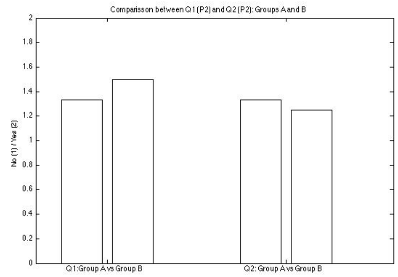
to perform some particular gestures, Participant 6 mentions that he “did some crazy gunshot gestures, and the accelerometer inspires to weird ball positions”. Although, some participants notice that this relation is not always clear “rotation was difficult to associate to action/sound relations” as states Participant 7.
Some participants showed some concerns regarding the strength of the structure, mainly regarding abrupt gestures, as Participant 4, explains “I didn’t feel like i could throw it or drop it; the gestures were mostly orientation manipulation and jabbing and tapping”.

The overall evaluation nonetheless is quite good. Fig. 4.7 represents the answers to the question “How interesting do you think this interface is?” (Q9 part2), where we observe that the minimum answer value was 4.

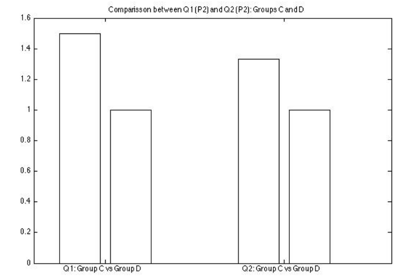
4.4.2. Mapping and Place-specific

The second section of the questionnaire help us to understand if participants felt the influence of space in the sound they generated with Intonaspacio, as well as to understand what was the preferable method - direct or indirect, represented by mapping 1 and 2 respectively.

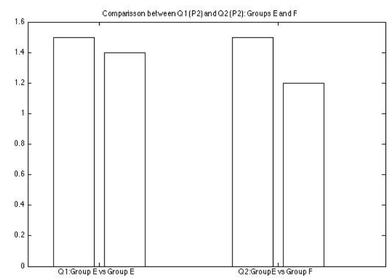
The first two questions of this section look on how much contribution the participants felt both in mapping 1 and 2. We decided to plot them together for a better



(a) Groups A and B (Part 2)



(b) Groups C and D (Part 2)



(c) Groups E and F

Figure 4.8.: Comparison between Q1 and Q2 (Part 2)

understanding of the results. Fig. 4.8a, Fig. 4.8b and Fig. 4.8c show the different results by group. In both questions users would have to say if they felt or not the contribution of space in mapping 1 and mapping 2. The results were calculated based on the attribution of value 1 to yes answers, and 2 to no answers. Therefore the furthest the mean is from 1 the most negative answers it contains.

What we observe is that participants felt the influence of space in both mappings, although there is not a clear trend between mapping 1 or 2 regarding place presence. Even so mapping 2 (strangely since the integration is indirect and more subtle) has more positive answers. However when we look at the comments, we understand that most of the participants did not felt a great level of contribution. Participant 7 affirms that “It was possible to feel changes only in extreme conditions”, and Participant 6 when alluding to mapping 2 explains“Heard it, but didn’t understand that it’s the room that was causing the effect”. Likewise, Participant 5 mention that “it was not easy to change the sound significantly”, still the same participant alluding to mapping 1 explains “it was difficult to understand the contribution of the space as

Table 4.1.: *Question 3, 4 and 5: Overall results*

	Mapping 1		Mapping 2		Mapping 3	
	cnt	pct	cnt	pct	cnt	pct
Q3	5	71.43	2	28.57		
Q4	3	42.86	3	42.86		
Q5	5	71.43	1	14.29	1	14.29

soon as there is a noise, but this noise could contribute to the specificity of sound". We should underline this last affirmation, since it approaches of our initial idea of designing place-specific sound based on the integration of the found sounds present in the room. [6]

Following this idea, we asked participants to decide in which mapping they felt there was a greater contribution of place in the sound. The results shows that around 71% of the participants choose mapping 1 over mapping 2. However if we ask which one they prefer, the answer is not so clear, we do not find a clear tendency in the answers, on the contrary, both mappings have the same number of choices. The real difference appears on question 5, when participants are asked to choose between the three mappings, and once again we have a clear preference for mapping 1 (probably because it is clear for participants the presence of place). We should notice however that only one of the participants chose mapping 3. He justifies his choice based on a clearer causality between sound and gesture "The control of the instrument and the associations between action/sound were more clear". Table 4.1 [7] [8] presents the results for question 3, 4 and 5 of part 2.

When we take a look at the comments made by the users, we understand that mapping 1 was the one that offered, according to participants, the largest range in

[6] Found sounds here relates to the same idea we encounter in visual arts when we talk about found objects, *objets trouv ès* and *assemblage*.

[7] One of the participants did not answered to Question 4, thus only six valid questions were analyzed. That is the reason why there are some disparity between the percentage from question 4 to question 3 and 5.

[8] In the table cnt refers to count (the number of times the option is selected by the participant. Pct refers to percentage.

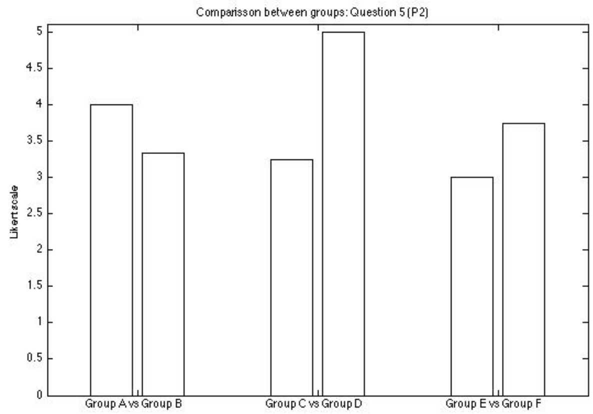


Figure 4.9.: Comparison between groups: Question 5 (Part 2)

timbre. Participant 1 mentions that "it seemed like the sounds were richer in the first mapping". Accordingly, Participant 3 justifies his choice based on the "more accurate response and more variables acting together", Participant 6 mentions that mapping 1 gives a "Better control over the sound, I prefer mic input", which goes along with what Participant 5 also suggests "we can record anything we want and thus we have greater sound diversity".

When asked how place-specific the instrument felt to participants, most of the participants are quite neutral (the average of responses lies in 3.33). However if we look at the groups individually, Fig. 4.7, we clearly see that the participants that declare to have previous experience with place-specific practices are the most critic about it. [9] Some of the comments of the participants show, however, a great confusion about the concept of place-specific, for example when Participant 4 says "uses the room but not specific to this room". One of the participants who did not answered the question justified that he needed to compare the sound in several rooms. This suggestion is closer to our initial proposal, where the same piece played with Intonaspacio in different places would result in a different sound. Time constrains, however, did not allow us to test this hypothesis while conducting this test.

[9] We should note that two of the participants did not answered to these questions.

4.4.3. Fusing information

We have recorded the data from each sensor of Intonaspacio from every participant, as well as a video of their performance. This information allow us to understand how users played with Intonaspacio - would they, individually, have a consistency of gestures through the three mappings? Does several participants share the same type of gestures, independently of the mapping? Is it possible to perceive an instrumental technique that is common to all participants?, Is it possible to define a set of gestures to build a vocabulary to Intonaspacio?

In order to analyze the data recovered from the accelerometer, we used a low pass filter [10] to clean the data from the high frequency spikes that introduce noise on the signal, and calculated the FFT of each axis (x, y and z) as well as the position. For the FFT analysis we started by perform a reference. We recorded three different signals, where three different actions were made. In the first one, the instrument was still, in the second one Intonaspacio is smoothly and subtlety moved (tilt), and in the third one it was actively shaken. This way we could have a comparison method with the gestures of the users. Predominance of low frequency activity would mean that the participant used mostly soft gestures when playing Intonspacio, predominance of high frequency components would show that the user used jerky movements more often. We then compare this information with the videos, in order to visually confirm our assumptions.

From the analysis of our reference model, we arrived at a threshold of 1.5 Hz to differentiate tilt movements from jerky movements. Activity under 1.5 Hz would reveal that participants mostly used smooth gestures such as roll and tilt. Activity above 1.5 Hz would mean that participants used a lot of jerky movements.

As stated before, we observed the data from each participant in the three mappings. We calculated the FFT of the accelerometer data in the three axes x, y and z, and position by integrating twice the recorded signal of the accelerometer. However, and since we do not had a reference position, this only informs us of the changes of velocity in time. The calculation of position shows some patterns of movement that appear repeatably either in the same mapping or for the same user. However we cannot

[10] Butterworth filter of second order in Matlab, with a cutoff frequency at 17Hz

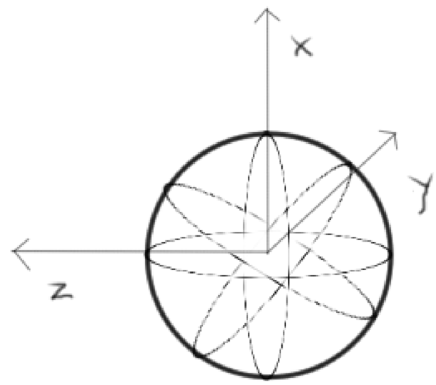


Figure 4.10.: Axis of IMU installed on Intonaspacio

assume significant conclusions based on it, we would need a point of reference and compare position over time in relation to that starting point. This could be performed using a motion capture system for example.

An initial analysis show us that most of the participants used gentle gestures, mostly by rolling the instrument. From the seven participants, only two have considerable activity on the high frequency region, even so this activity is still lower than the one at low frequency. From these two participants, one had previous knowledge of the instrument, which suggests that fast and shaky movements are not intuitive. We believe this kind of gestures is mostly used as punctuation rather than in a continuous fashion. On the other hand, if we observe some of the comments of the participants to the question Part1:Q8, we noticed that some of them mentioned that the instrument had a fragile look which prevent them from using abrupt gestures.

Most of participants hold Intonaspacio whether facing them with the top pointing to the ceiling (x axis), whether lying with the top facing the wall (z axis). Nevertheless there is more activity in the x axis, which makes us believe that participants have tendency to position Intonaspacio facing them, probably because of the IR sensor, and the opening that enables them to grab the instrument using only one hand.

Based on direct observation during the test and after on video recordings, we can affirm that from mapping to mapping most of the participants tend to not alter their gestures. We believe this is due to the fact that the relations between sound and action are kept along the three. Some users present different gestures at different moments of the three mappings but we believe this is due, mostly, to adaptation and exploration of the gesture than a clear difference between mappings.

From the video analysis we are able to observe some gestures that are common to all users, although they all have their personal approach to the instrument. Some users explore it more than others. We noticed that participants that affirmed they felt they had control over the instrument show a greater tendency to explore different movements than the others. Their strategy reflect an orientated exploration - they repeat the same gestures in search of the same sound, and they try variations of the same gestures. It is clear with the videos that the gestures do not change from mapping to mapping, generally they are quite consistent. Participant 1 and Participant 6 who claimed they did not felt control over Intonaspacio, present more erratic movements and especially Participant 1 whose movements are very repetitive. In the video we can clearly observe that he is more interested in exploring the possibilities with the microphone that the gestures themselves. One of the reasons that could explain the lack of control of both participants, is the low correlation between sound and gesture that we observed with these two participants. By observing the video is quite hard to understand the sound result of their gestures, thus it can explain their frustration with the instrument.
With the exception of Participant 4, all others grab the instrument with both hands unless they perform some jab movements, for example Participant 3, Fig. 4.11 and Fig. 4.12. Participant 4 uses the opening in front of the IR sensor to grab the instrument. This situation enable him to perform larger gestures, where the whole body is introduced and not only the upper body as the other players. Still, Participant 4 performs gestures that are common to every participant, namely subtle tilt movements, Fig. 4.13.

The analysis of this data allow us to understand what kind of gestures were most used when playing Intonaspacio, but also to understand the problems of the interface and mapping. We believe that a simpler approach to mapping, where the actions

(a) holding with 2 hands (b) triggering sounds

Figure 4.11.: Participant 3 playing with Intonaspacio.
Source: Mailis Rodrigues

Figure 4.12.: Participant 3 playing with Intonaspacio: jab.
Source: Mailis Rodrigues

Figure 4.13.: Participant 4 playing with Intonaspacio: holding with one hand.
Source: Mailis Rodrigues

of the performer would be easily translated by sound, could improve the feeling of control. Also, starting with simple controls can give the performer enough tools to perform complex sound compositions. Nevertheless, is not our goal to simplify Intonaspacio as much as a toy, it could frustrate performers on a long term usage. Intonaspacio as any other musical instrument needs time to be learned and explored. Even so, our user test showed us that participants have a great amount of possibilities of creation, from seven participants only two showed lack of control, leading us to believe that the instrument in the overall works but it needs a few changes in order to became more robust (hardware and mapping).

4.5. Rethinking mapping in Intonaspacio

Precedent mappings presented some problems in a long term usage of Intonaspacio, namely on control and repeatability (as we observe from the user's test presented in the previous section). Consequently, we decided to rethink the features extracted from the gestures of the performer, although maintaining the previous idea of having the energy of the performer transferred somehow, to the sound generated by Intonaspacio. For that reason we decided to extract features that would characterize the gesture of the performer: What is the amplitude of the gesture? How distant is the instrument from the performer? Is the performer moving Intonaspacio or not? How fast? etc.. Other gestures, such as taping in the structure of Intonaspacio or shaking the instrument were kept.

We have simplified the number of features extracted and organized it by groups - Piezos, Jab, Orientation, Gesture amplitude, Time spent, IR, Variation rate, Signal; as Fig. 4.2 presents. This procedure was made in order to facilitate the visualization of the several output signals coming from Intonaspacio. We kept the piezoelectric information but simplified, preserving just the detection of a strike and its amplitude - P1/trigger, P2/trigger and P1/stramp, P2/stramp, respectively. We added the feature introduced by Clayton Mamedes for his composition, Entoa (presented in chapter 6) a sequential detection of strikes in both sensors - P2/P1.
Some other features were kept such as orientation in the three euler angles - yaw, pitch and roll; detection of jab gestures and the amplitude of the IR sensor, and the

Table 4.2.: *Extracted features from Intonaspacio*

Extracted Features (Intonaspacio)							
Piezos	**Jab**	**Orientation**	**Gestural amp.**	**T. spent**	**IR**	**Var.rate**	**Signal**
P1/trigger	jab	yaw	ampx	ty	Ir	racx	freq
P1/stramp		pitch		tp			
P2/trigger		roll		tr			
P2/stramp				tir			
P2/P1							

analysis of the input sound of the microphone.

We have created three different sets of data that indicate different actions from the user: amplitude of the gesture, time spent in the same position and variation rate. For calculating gesture amplitude, the performer can record an initial value of acceleration in the x axis (a0). This value is then used to calculate the difference between the current value and the initial recorded value (Δ a_0 - a_x), every 1000 miliseconds. We use a simple Pythagoras' theorem to calculate the angle between the cathetus and the hypotenuse θ, by using a time interval of 1 second as a constant distance from the origin, Fig. 4.14. The results are converted to degrees and we obtain for gestures with a small amplitude values around 7º and 10º, and for gestures with large amplitudes we obtain values around 20º. All the calculus are performed in Max/MSP 6. Below we present a pseudocode description of the algorithm used to perform the calculation:

Step 1:Record a_0
accx = accelerometer x axis
a_0 = Record an initial value of accx
Calculate the absolute value of a_0

Step 2: Smooth the incoming signal
Store the last 10 values of accx
Sum them and divide the total by ten
Calculate the absolute value of a_x
a_x = incoming accx value

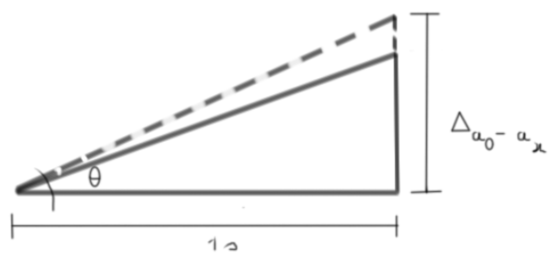


Figure 4.14.: Calculation of the gesture amplitude

Step 3: Calculate Δ a_0 - a_x
Every 1000 milliseconds calculate the difference between a_x and a0

Step 4: Calculate θ using Pythagoras' theorem
Divide Δ a_0 - a_x by 1000 [11]
Calculate the arctangent of θ

Step 5: Convert to degrees
Multiply θ by 57.29578
ampx = θ in degrees

To determine how much time the performer hold the instrument in the same position, we simply calculate the average of the signal to smooth it, and then define a certain threshold. If this value is not exceeded then the clocker object in maxmsp is set on. The performer can control how much time he holds the instrument without moving (time spent in yaw, roll and pitch) or how much time he holds Intonaspacio at the same distance from the body (time spent in IR) - close or distant. This information is useful for controlling the damping of the sound using the IR sensor, after a certain threshold defined by the user, the sounds is turned off. Below we present a

[11] 1000 represents the dimension of the side of the triangle that composes the square angle together with Δ a_0 - a_x. The value corresponds to 1000 miliseconds (1 second in Fig. 4.14), the moment at which each calculation is performed.

pseudocode description of the algorithm [12] :

Step 1: Smooth the incoming signal
yaw = yaw angle
pitch = pitch angle
roll = roll angle
Ir = IR signal amplitude
Store the last 10 values of yaw, pitch, roll and Ir
Sum the 10 values for each variable
Divide the total by 10 for each value
Calculate the absolute value of yaw, pitch and roll

Step 2: Detect when Intonaspacio was moved (yaw, pitch and roll)
If the abs values of yaw, pitch and roll are greater than 2, then start the clock (in milliseconds) else turn off the clock
Store the clock value for each variable
ty = Time spent without moving Intonaspacio (yaw angle)
tp = Time spent without moving Intonaspacio (pitch angle)
tr = Time spent without moving Intonaspacio (roll angle)

Step 3: Detect how long Intonaspacio stays at the same distance from the performer's body
If the abs value of Ir is greater than or equal to 22, then start the clock (in milliseconds) else turn off the clock
Store the time spent
tir = Time spent with Intonaspacio at the same distance from the body.

Finally, the variation rate is calculated using a simple function to detect a change in the current state of the instrument, where at every second the system counts the amount of changes in the signal (using the change maxmsp object coupled with the

[12]Direct observation of the behavior of the incoming signal lead us to chose 2 (yaw, pitch and roll) and 22 (Ir) as the values to detect a change on the current condition of the instrument (the performer moved Intonaspacio/the performer did not moved Intonaspacio)

counter object). The output is then divided by the sampling frequency and the result represents the variation rate of the gesture. Whit this calculation we want to know how fast is the performer moving Intonaspacio. When this movement is very fast we obtain values that are higher than 0.2 Hz. Direct observation allowed us to perceive that we could obtain this information using only the amplitude of the accelerometer on the x-axis, reducing the need for extra calculation. Below we present a pseudocode description of the algorithm:

Step 1: Smooth the incoming signal
accx = accelerometer x axis
Calculate the absolute value of accx
Store the last 10 values of accx
Subtract the first value stored and the last one (1 and 10)

Step 2: Detect a change
If the difference between the two stored values is greater than 10 then send 1 and store it, else send 0

Step 3: Calculate the variation rate
For every 1000 milliseconds sum the number of detected changes (e.g. 1+1+1+1)
Divide the total by the sample rate of the IMU - 50Hz (for the Mongoose 9DoF)
racx = variation rate of the accelerometer on the x angle.

4.5.1. Combining both approaches - a third possibility for place integration

Both direct and indirect approaches to place integration revealed certain problems, detected by the participants of our experiment. The direct approach was sensed as more present, and had more timber possibilities, although it was not easy to control the feedback and the sound could became extremely noisy very fast. The indirect approach although more easy to control, it is much more subtle and participants did not related it explicitly with the place interaction. Based on these conclusions, we decided to purpose a different possibility for place integration, where we combined both approaches. In this mapping, we still extract the same ensemble of the fifteen most amplified frequencies of the input sound. These, however, instead of controlling certain parameters of sound effects (tremollo and reverb), are used in an additive synthesis algorithm. The frequencies are combined together and we build an amplitude envelope for each. The performer can control the variables of the ADSR envelope of each frequency by changing the orientation of Intonaspacio - pitch, roll and yaw trigger presets of combinations for the attack, decay, sustain and release parameters. Fig. 4.15 shows a diagram that represents the process. The analysis is performed in real-time and the output is continuously changing. This situation creates a natural frequency modulation in the generated sound. The process is once more developed over time, any interference will cause the sound to change - the performer can subtly modulate the sound either by producing sounds with his/her body, interacting with other instruments on stage or displace the instrument around the room.

This approach results on a combination of the previous two, the input sound is analyzed but it is also used as the sound material for the composition. We believe this gives the performer a greater feeling of control, although randomness is still an important and desirable component - randomness reflects the interactivity with place. Agostino Di Scipio (Scipio, 2003) purposes a similar approach to sound place-specificity in his own work. Di Scipio uses a set of microphones that he disposes in the room at specific locations, where he believes the acoustical response of the space is more interesting. The sound input of these microphones is then summed together and reproduced, creating a continuously loop between the incoming sound and the reproduced sound. Each work stays in the same room for a large period of time, the composition evolves along time. However the solution Di Scipio presents does not give the performer/composer in this particular case, the possibility of interfering in the place behavior. With Intonaspacio we are looking for an interaction between place, performer and instrument (as discussed on chapter 1), thus it's important that both place and performer could have the chance to respond to each other actions.

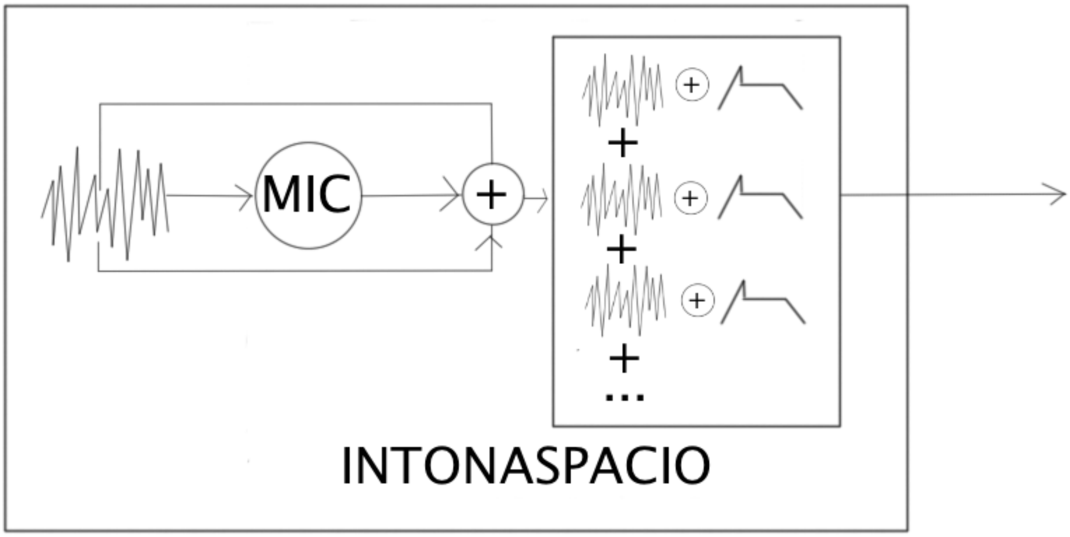


Figure 4.15.: Combining both processes. The sound input is analyzed and a list of 15 frequencies is extracted and used as the parameters of an additive synthesis algorithm.

4.6. Conclusion

Mapping is an extremely important layer of the DMI design. Mostly because it is where the designer connects the performer's gestures to the parameters that generate and control the sound. Thus, this is the main stage of the design process that characterizes the interaction with the DMI.
Intonaspacio is a musical instrument that facilitates the access to the acoustical behavior of the place, integrating these features on the reproduced sound and enabling the performer or composer to easily modulate them (through their gestures). At the chapter 3 (section 2) we raised some questions on how to create the conditions to have a place-specific sound. Based on the hypothesis of having an input sound that would trigger an acoustic response of the place we started by suggesting two possible mappings where this response was integrated in two different ways.

The first one started by recording small samples of sound that were then reproduced in loop and re-recorded again (in several iterations). An approach similar to the one

Lucier used on his work *I'm sitting in a room*, with the difference that the performer can start a new record every time he/she wants, and can modulate the sound with several effects (tremollo, reverb, speed of reproduction) while this recording loop is having effect. This process results in a very textured sound where several layers of sound ambiance are glued together.

On the second mapping we decided to experiment an indirect method to introduce place's acoustical behavior in the composition. This time the sound input was not reproduced, the performer could not listen to what he/she recorded, instead the sound was analyzed and extracted a set of frequencies. These frequencies were the ones that had strongest amplitude over time, i.e. the frequencies that were amplified by the filtering of the place (acoustically the room can boost and cut certain frequencies according to its spectral response). The ensemble of frequencies were then mapped to control several parameters of certain sound effects (tremollo and reverb). The performer no longer could control these effects, the results was more or less random. Alternatively the performer could either generate certain sounds or displace the instrument to create a new set of frequencies.

Both these mappings were tested by users with musical experience (graduated musicians and amateurs) and the results showed that there were no explicit preference for one or other method. Based on that we decided to suggest a new mapping where both previous approaches are combined. This mapping uses the ensemble of frequencies extracted through the analysis of the sound input, as the material for an additive synthesis algorithm. The frequencies are summed together and the performer can control several aspects of the timbre (ADSR envelope) by interacting with Intonaspacio. This method keeps the same randomness of the previous mapping allowing, however, a finer control of the sound by the performer. He/she can, not only displace the object to find "sweet spots" on the room, but also control the main characteristics of the amplitude envelope. To validate Intonaspacio, we conducted an experiment with participants, all musicians and most of them with previous experience with DMIs. This test help us to understand two main things: the interest and functionality of the interface; and the interaction method used in Intonaspacio. At the end of the experiment we asked participants to answer to a questionnaire. The questionnaire was divided in two sections, one for the interface and its usability and a second one for the place-specific issue. In this section we suggested three different mappings to the user, mapping 1 (direct approach) and mapping 2 (indirect approach) gave the user two different possibilities of generating place-specific sound; and mapping 3 did not have any influence from place. This third mapping was useful to understand the interest or not of the users in an musical instrument with the characteristics of Intonaspacio.

We can tell for the interface, that the overall evaluation was rather positive. Users considered the instrument very responsive and repeatable. They also mentioned that the shape of the Instrument helped to have an easier approach, although some of them note that they would need some time to learn how to play Intonaspacio in order to have full control. The ball shape also suggested more subtle and smooth gestures, rather than abrupt movements like throwing the ball in the air, for instance. We noticed that to some participants it was easier to interact with Intonaspacio than others. Some of them would clearly define a gesture strategy and would then mostly concentrate on exploring the sound of the instrument, while others took a lot of time exploring different gestures without a particular musical goal.

The second section of our survey focused on mapping and site-specific questions. The evaluation of the users helped us to understand the problems of the concept behind Intonaspacio, and search for solutions. All users demonstrated a great interest in the possibility of creating place-specific sound with a musical instrument, and from the seven participants only one choose a mapping where there was not any presence of place.

Besides the questionnaire, we also recorded video and data from the sensors which help us to perceive some common gestures to all participants. These gestures were independent of the mapping. This gave us some hints of the ensemble of idiomatic gestures of Intonaspacio.

5. Searching for an instrumental technique

As we previous suggested (refer to chapter 2), a distinct instrumental technique and a repertoire are two important aspects to assure a long life of a DMI. Musical notation can be a useful tool to guarantee both these aspects, because it facilitates the transmission of information on the technique between performers, it gives the composer a support to preserve and record his/her work and to facilitate the communication between performers and composers. Intonaspacio as a large number of DMIs generates a sound that cannot be represented by pitch and duration (as common musical notation does). Accordingly we searched for a musical notation more suitable for Intonaspacio. Gestural notation seems especially interesting to our work since it provides an easier way of addressing the instrument. To design this notation we looked for the idiomatic gestures of Intonaspacio (Stewart, 2009), (Rocha and Stewart, 2014), the gestures that are dependent of the shape of the instrument. These gestures were identified during the several trials of the participants on experiment 1 (presented on the previous chapter) and experiment 2 (presented bellow (section 2)).

5.1. Extracting a gestural vocabulary for Intonaspacio

From the observation of the videos of the participants of our experiment, we were able to propose a common vocabulary of gestures. These constitute the starting point for the creation of a gestural notation for Intonaspacio. We noticed that several gestures are common to all users. The two factors that most influence the way a performer plays with Intonaspacio are, on one side its shape and placement of sensors; and on the other side, the mapping used. Our gestural vocabulary will focus on those which are independent of the mapping. We do not want to narrow in some way the gestural possibilities the instrument proposes, but rather give some directions to an initial exploration.

5.1.1. The importance of musical notation

Musical notation in western music has several functions, including, communication, transmission, analysis and preservation. [1]. It is a symbolic language that expresses the musical idea of a composer, based on signs and the relations between them, that carry information. Through the history of western music, musical notation started with the introduction of neumes (McLean, 1981), (Young, 2014), (Cole, 1974). As Mclean (McLean, 1981) explains: "the neume did not attempt to make out what we now have come to regard as individual pitches and units of rhythm, but only shapes and contours of melodic lines customary in current practice". This symbols were not completely external to its context, instead in order to read the music represented, the performer had to be familiar with the practices of the epoch. Through the history of western music, we assist to a greater detachment of symbol and musical practices. McLean alludes to this situation as a symbolic extension (McLean, 1981). This evolution is driven by a lack of ability to represent complex musical ideas. Eventually neumes were replaced by staff notation when composers started to use polyphony (Cole, 1974), (Psimikakis-Chalkokondylis, 2010), and latter as Laonikos (Psimikakis-Chalkokondylis, 2010) describes: "The emergence of functional, chordal harmony around 1600 C.E. resulted in the use of scores as opposed to partbooks, which allowed for much more complex music to be composed, and notation began to become to a certain degree standardized". Which meets what Roads (cited by (Lassfolk, 2004)) defines as Common Music Notation, "the standard music notation system originating in Europe in the early seventeenth century".

[1]Several authors defend that musical notation also has a function of limiting and constraining the musical idea. This is manly due to the need of translating and filter the idea of the composer with the rules that underline musical notation. (McLean, 1981), (Young, 2014),(Psimikakis-Chalkokondylis, 2010)

In the beginning of the twentieth century, traditional musical notation experienced some criticism. Several characteristics contributed to it. Cole (Cole, 1974) mentions same, namely the rise of electronic music that considered the vocabulary of traditional musical notation insufficient to express all the musical ideas of the composer, but also the contribution of ethno-musicologists with studies about non-western music where traditional notation would not be able to represent it. Some authors (McLean, 1981), (Young, 2014) point as a major problem of traditional musical notation the incapacity of representing variables other than pitch and duration. Mclean (McLean, 1981) notes that it is impossible to reduce everything to discrete pitches, organized by octaves, and that this notation is "restrictive in the inability to express (for example) gesture". Likewise, several instruments are not tuned accordingly to this scale. Cole affirms that this notation limits once you try to describe something that is not within the traditional western music theory, "Our notation could never serve for a music in which interest centered on mode of attach, or in which the expressive force lay in the way in which each note joined to the next, or in which a mechanically divide scale was used.".

In the twentieth century several composers introduce new ways of representing their musical ideas, types of notation that are more suitable to transmit the sort of information composers are interested in. Laonikos (Psimikakis-Chalkokondylis, 2010) mentions two main trends, one where composers would use a very detailed score where little or no space for the performers' interpretation were given; and another one where scores were particularly open and indeterminate. In this later, scores would eventually be more graphically, resembling drawings, to represent improvisation. One example is the score of John Cage's Fontana Mix, or the Five Piano Pieces for David Tudor from Sylvano Bussoti (Stone, nd). Eventually traditional notation ended up being expanded with the introduction of more symbols and indications. Nevertheless, traditional notation is still very limiting and quite fixed. It is not easy to adapt it to new forms of musical expression, especially with new musical instruments that are not designed to follow the traditional tuning. Therefore, new forms of notation are desirable, ones that are more suitable for these musical instruments. We loose on universality but we achieve a wider range of possible ways to represent musical ideas.

Nonetheless, authors such as Toeplitz (Toeplitz, 2002) support the idea that no notation is needed, when we deal with DMIs. Toeplitz states that the computer already uses a symbolic language, which makes musical notation pointless. The function of music sharing and preservation would then be performed by the computer itself. Still, this introduces some problems, especially with obsolete or discontinued software, which arrive quite fast with the constant evolution of computers. Digital conservation is currently one of the main issues of digital art (Serexhe, 2012) [2]. Thus, musical notation still has a reason to exist, since it can be a general system of preservation and sharing of music. Therefore, we can envisage new ways of notation, far from the traditional one, that are more apt to composing music with DMIs. We believe that gestural notation, where the score would include the sequence of gestures the performer has to do in order to achieve a certain musical idea, presents a lot of advantages to Intonaspacio.

Intonaspacio is not designed to fit traditional tuning, the way it is played is not easily described by discrete pitch and duration indications. Also, we have noticed that users adapt their gestures to search for a specific sound. Though the shape has great influence on the type of gestures made by performers - the way performers hold Intonaspacio or the way they manipulate it. When participants get a certain knowledge of the shape of the instrument, they tend to focus more on the type of gestures suggested by mapping itself relegating shape to a second level. This suggests that performers embody the instrument and are concentrated in generating sound.
We believe a gestural notation will be an easier way for composers to transmit their musical ideas, by conveying information about the gestures needed to reach the desired sounds. This gestural notation, however, must rely in a previous gestural vocabulary extracted from the manipulation of the musical instrument. The existence of a gestural vocabulary can contribute to the creation of an instrumental technique that is particular to Intonaspacio and can be shared between performers. It also makes it easy to learn the instrument, and allows the establishment of a community of performers and composers around Intonaspacio.

[2] An example of this problematic in music is presented here (Boutard et al., 2013) and here (Ransbeeck et al., 2012)

5.1.2. Gestural notation

Gestural notation is commonly associated with dance, several notations were proposed since 1455 (de Laban, 1954), to Labanotation (Knust, 1959) and Benesh Movement Notation (Ben, nd), the two most known and studied nowadays, according to Evans (Herbison-Evans, 1980) [3]. Both the Labanotation and the Benesh Movement use a number of descriptors to characterize the movement, namely direction, area of the body implied in the movement, duration and dynamics. However the Benesh Movement Notation (Ben, nd) has a lot of similarities with musical notation, it uses the same score design, with performers represented vertically on the score (like several musical instruments) and the same tempo signatures and dynamics - Fig. 5.1 is an example of the Benesh movement notation. Notice the *allegreto* annotation at the beginning of the score. Symbols also represent duration (similar to musical notes) and thus this movement notation is easily combined with traditional musical notation.
These movement notations however do not represent situations where the performer plays with an external object like a musical instrument, thus apart from the possible adaptation of some of the descriptors of movement (dynamic, direction and duration of the movement) these did not seem useful to represent the ensemble of idiomatic gestures of Intonaspacio.

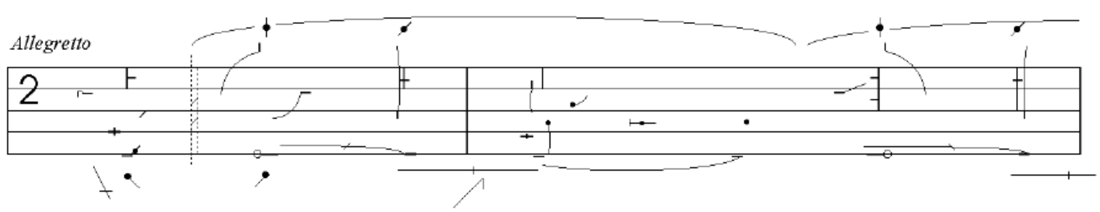
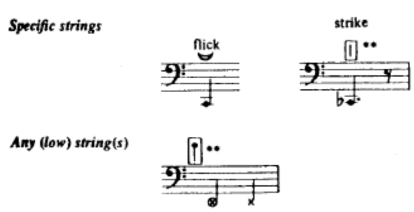


Figure 5.1.: Benesh Movement Notation.

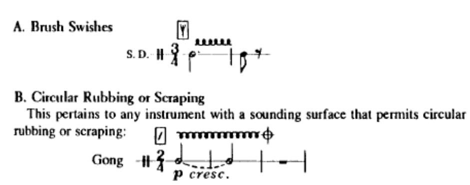
In music, gestural notation unlike traditional notation represents the input parameters rather that the desired output sound. Since Intonaspacio has a changeable voice,

[3]For reference here are some of the other existing movement notations - Arbeau from 1589 (Hutchinson, 1968), Feuillet notation for the Baroque European dances(Savage and Officer, 1978), Zoru from 1905 (Hutchinson, 1968) and Eshkol-Watchman Movement Notation from 1958 (Kleinman, 1975)

i.e., does not have a stable and fixed sound and gesture relation (we deliver that task to each composer with whom we collaborate with), it is more suitable to use a notation focused on the input parameters. An interesting proposition was made by Tormey (Tormey, 2011) who suggested the use of hybrid scores, where gestural notation could be combined with more traditional ways of musical notation. This combination of both sides of the musical chain (input and output) would eventually allow for a more detached notation and consequently the possible representation of a wider range of situations (create scores for different instruments that use the same gestural approach as Intonaspacio, for example). Contemporary notation presents some examples where gestural indications are introduced in the score, namely notation for percussion instruments. Musical notation for percussion usually indicates the type of mallets the performer should use, as well as the hand that should be used. Gestures such as rubbing in the surface of the instrument are directly represented by figurative drawing on the score, see for example Fig. 5.2b. Similarly, some of the symbols used for Harp musical scores allude to gestural actions in combination with the sound output, for example indications on how to strike the string, Fig. 5.2a.



(a) Indications to strike a string in the harp.
Source: (Stone, nd).



(b) Indications to circular rubbing or scrapping on percussive instruments.
Source (Stone, nd).

Figure 5.2.: Gestural indications on traditional notation scores.

5.2. Experiment 2: Analyzing gestures from a non-musician performer

While working with Intonaspacio, we realized its performance could demand for a great involvement of the body of the performer and not exclusively its hands and arms. Therefore, we decided to ask an actor, with experience in movement improvisation, to play Intonaspacio. The experiment took place at the School of Arts at UCP. The participant was asked to come in two different days, with a 24 hour separation between them. In the first day, he would play freely with Intonaspacio, and no indication of the placement of the sensors or the mapping was given to him. His performance was recorded - video and audio. He played for 10 minutes and at the end he answered some questions about the experience. The participant was left alone. We did not wanted our presence to constraint him in any way. On the second day, the protocol was very similar, but this time he would know previously where the sensors were and what was the mapping. For both days, the mapping we used was the same. The goal was to understand if his gestural performance would change if he knew what gestures to perform to achieve a certain sound. Another intention was to see what kind of gestures a performer from another discipline than music could suggest when playing with Intonaspacio.

5.2.1. Day one

In day one our participant was more concentrated on exploring movements with the object itself, than on achieving a particular sound. He used a lot of uncommon gestures (uncommon compared to the gestures other performers had used so far), where his whole body was implicated. He explains his approach when playing with Intonaspacio for the first time: "At the beginning you gave me that stuff and I try like, Ok. The sound is like this. Let's try to change it. And with every movement, the sound changed. (...) I tried to understand how different was the sound if I was faster with the arm or with the body or if I was slower. If I shook the object, it would play dedededed or not. (...) I was trying to understand how the object worked". [4] Examples of this gestures are for example, when we places Intonaspacio above his head

[4]Translated by the author.

Figure 5.3.: Participant placing Intonaspacio on the back of his head.
Source: Mailis Rodrigues

Fig. 5.3, on the back of his body or takes the instrument close to the floor. During the interview, the participant explains that he tried to interact with Intonaspacio as if it had different functions. “the polysemy of an object (...) the different uses an object can have. That’s why I placed Intonaspacio on the top of my head, like it was a soccer ball. To try other things”. [5] We observed that he was not concerned with having Intonaspacio facing him, he does not uses the IR sensor at all, nor even the piezoelectric sensors, unlike the participants of our previous experiment.

He also tried different ways of grabbing the object, and similarly to Participant 4 of our previous experiment, he holds Intonaspacio with one hand. Still he shares some common gestures with the other participants, especially when he performs subtle gestures on orientation. From the video analysis we can clearly perceive that the participant understands the correlation between sound and gesture, although he does not understands the mapping in its totality. Several times he repeats specific movements, when he understands this correlation, it is clear that he tries to achieve the same sound. Yet, through the 10 minutes of the experiment his main concern is to explore the gestures he can do with Intonaspacio more than the sound. We could say that in the first day the participant is more in relation with the object itself than with a musical instrument, in a functional point of view of sound production. At the end he recognizes that he had some evolution in his learning process, mainly by saying that at a certain moment he changed the focus of attention to the visual display rather

[5]Translated by the author.

than the interaction with the object, "At the beginning I was trying to see what that was, put my hands on the instrument and understand how that worked. Then, at the end, I started to look more at the computer, and see that the closer I was [with the instrument in relation to the computer] the more it moved [the sliders of the GUI, see Fig. 5.4] and the sound changed, and then Ah! So yes, it's like this! Exactly! And the movement of getting closer and further, shaking the instrument, raising it, moving it down, doing an eight". [6] This close relation between sound and gesture was of extreme importance to interact with Intonaspacio, as he noticed "You understand that one plus one is two, that making this gesture you get a sound like this, that make that gesture you have a sound like that". [7] The participant even compares the mapping to a motion capture system where the sound would reflect every action of the performer in the same proportion. This is, indeed, one of the points where he says he felt some frustration, when this direct relation was not present. "At the first essays when I tried to move my arm, up and down, I was expecting the sound to be more aggressive (...) I felt frustrated in that sense, when, for example, I would do a movement like this [At this point of the interview the participant makes the gesture instead of describing it. In the context of its speech we believe he performs a gesture with a large amplitude and very strong.] the instrument would react, right? A little bit like us." [8]

It was interesting to notice that at same point during the interview, the participant alludes to the embodiment of the object as an important factor for playing it correctly. Revealing how important it is in a learning process of an instrument, to feel that it is part of the body (Jordá, 2005), (Cadoz, 1999). As the participant explains: "As an actor and since I had some movement classes, every time we would work with an object, we would try to embody the object. (...) the first time it's always a little bit difficult even because we don't know what we are going to do with it. But, from the moment we rehearsal a certain choreography with a certain object, and this object is part of ourselves and we are part of the object, things become more fluid. (...) If I had rehearsed [with Intonaspacio] I don't know, for a weak or something, the result

[6]Translated by the author.
[7]Translated by the author.
[8]Translated by the author.

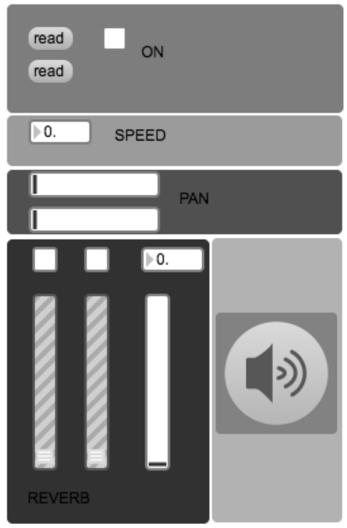


Figure 5.4.: GUI mapping experiment

would probably be better”. [9]

5.2.2. Day two

On the second day of our experiment we started by explaining to our participant where were the sensors placed and what was the mapping between sound and gesture. The data shows a clear difference on the approach the participant follows. The focus of his interaction changes radically, on day one he is clearly on an interaction gesture - instrument, while on day two he is on a relation gesture - sound. His whole conduct is towards the exploration of the sound. His gestures change considerably, especially in amplitude and velocity. As the participant notices: “As for the movements, I think yesterday it was better. Today I was really tied to the object, I was also more concerned, I knew already how it worked and I was much more concerned with making sound”. [10] He repeats some of the gestures he made in day one, but in overall his actions are more restrained, the amplitude of its movements is much smaller, and he stays for longer periods of time in the same position. The gestures are closer to the ones performed by the participants of our previous experiment, although he still introduce gestures where his whole body is implicated, Fig. 5.5. He adds some

[9]Translated by the author.
[10]Translated by the author.

Figure 5.5.: Participant using his body to play Intonaspacio.
Source: Mailis Rodrigues

Figure 5.6.: Triggering sounds using one of the piezos.
Source: Mailis Rodrigues

new gestures that include the sensors he did not used the day before (IR and both piezoelectric sensors) Fig. 5.6 “I played a lot the Tibetan bowl [alluding to the sample triggered by one of the piezoelectric sensors]”. [11] We also observe that he tries new ways of holding Intonaspacio in an attempt to include the IR sensor, Fig. 5.7. He also plays a lot with the speed of his movement, testing slower and very subtle movements, Fig. 5.8. His action is directed to an exploration of the sensors and the sound.

Even if this changes are clearly observable in the video, the participant itself recognizes them: “I changed, I was much more tied to my hands and the movements with my hands (...) and I was also tied to this thing of the slow motion, and the hands”.

[11]Translated by the author.

Figure 5.7.: Controlling volume with IR.
Source: Mailis Rodrigues

Figure 5.8.: Using slow and smooth movements to play Intonaspacio. [Both images were captured seconds apart from each other].
Source: Mailis Rodrigues

And in another moment of the interview "I guess yesterday I tried to use the whole body, today I used mostly the upper body". [12]
Once again he mentions the question of embodiment of the musical instrument in a long term interaction, "the performer should have the object since the beginning of the process, with the instrument, to embody it and then conjugate his movements with the sound he wants to produce" [13] Although when asked if he would prefer to know since the beginning how Intonaspacio worked, his answer his not clear. In a first moment he explains that he had preferred to explore it freely (with no constraints for sound production) as in the first day, "Maybe it was better to know it today because yesterday it was more an exploration, today it was also an exploration of course but an **oriented exploration** if we can call it that way" [14] Still, immediately after he explains that for the embodiment of the instrument this knowledge is important.

We underlined the expression oriented exploration because we think it clearly reflects the difference of approach between day one and day two. The first day was characterized by an open exploration of the object and its possibilities, with no particular intention of the participant in the production of sound. Consequently, gestures were wider, involved the whole body and the participant searched for uncommon ways of holding the instrument. The interaction could be described as one where gesture and object were the main subjects. It is the shape that conducts the interaction. Differently, on day two and after an explanation on how Intonaspacio worked, the gestures of the participant were much more restrained, involved mostly his hands, arms and upper body. Gestures were slower, closer to the body and smoother. The participant repeats the same gesture more often than in day one, and clearly searches for a specific sound when playing with the instrument. In the second day the interaction could be described as an interaction between gesture and sound. It is mostly the mapping that conducts the interaction.

[12] Translated by the author.
[13] Translated by the author.
[14] Translated by the author.

5.3. Gestural vocabulary for Intonaspacio

After the two experiments we carried with users playing with Intonaspacio, we observed that several users used a large number of common gestures. Based on this observation we decided to propose a vocabulary of gestures, specific to Intonaspacio, i.e., highly dependent on his shape and sensitive areas (placement of the sensors). Andrews (Stewart, 2009) and Malloch (Malloch and Wanderley, 2007) note that these are the idiomatic gestures of the instrument, those that are suggested to performers by the shape and behavior of the instrument.

In these experiments we also noticed that the exploration of the instrument is not exclusively dependent on the shape of instrument, on the contrary, the way the mapping is designed has great influence on the way performers play Intonaspacio. This assumption was confirmed by the several comments made by the participants throughout the experiments. For that reason we are excluding from this vocabulary all the gestures who were not suggested by the ball-shape of Intonaspacio and the placement of the sensors (users adapted their hands position to reach more easily certain sensors such as the piezos e.g. the possibility of striking both piezos at the same time).

This vocabulary, we believe will facilitate the learning process of Intonaspacio, as well as to establish the base of a future gestural notation for Intonaspacio. We believe that the existence of a gestural notation could promote the development of an instrumental technique as well as the creation of a repertoire dedicated to Intonaspacio. Both would contribute to the preservation and use of Intonaspacio over time.

We will divide the gestural vocabulary in two groups:

- **Group 1** gestures oriented by the placement of the sensors (especially the IR and both piezos)

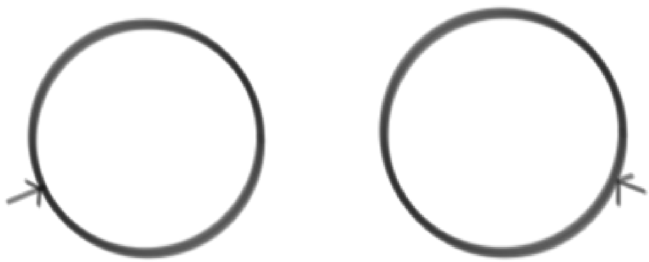
- **Group 2** gestures oriented by the ball-shape of the instrument

Needless to say that this gestures are simply suggestions to guide an initial approach of Intonaspacio. What we present here is not an exhaustive vocabulary, we believe there are much more possible gestures than these, and more complex (we envision combinations between them, or gestures related with the place-specific characteristic of the instrument - indications on how to explore place for example). We made an effort to keep the symbols as simple as possible, while preserving its intelligibility.

5.3.1. Gestures oriented by sensors placement

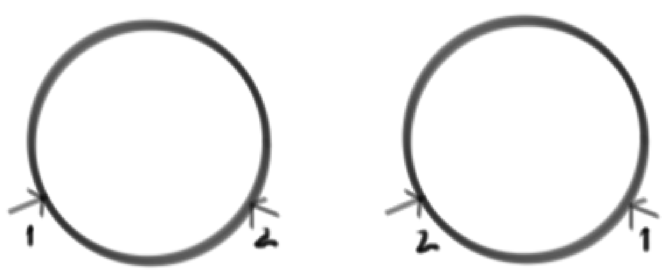
Piezos

Fig. 5.9 and Fig. 5.10 show some of the possible gestures with both piezos.



(a) Strike on Piezo 1 (b) Strike on Piezo 2

Figure 5.9.: Gestural indications to strike on Piezos 1 and 2, respectively



(a) Strike sequentially on both piezos. First strike on Piezo 1 and then on Piezo 2.

(b) Strike sequentially on both piezos. First strike on Piezo 2 and then on Piezo 1.

Figure 5.10.: Gestural indications to strike sequentially on both Piezos.

IR

Fig. 5.11 show both ways of controlling the IR signal.

(a) Controlling the IR signal with the hand.

(b) Controlling the IR with the distance to body.

Figure 5.11.: Gestural indications to control distance (hand and body, respectively) to the IR sensor.

Other gestures

Shaking the instrument can be another possible gesture to interact with the instrument, Fig. 5.12 shows the movement.

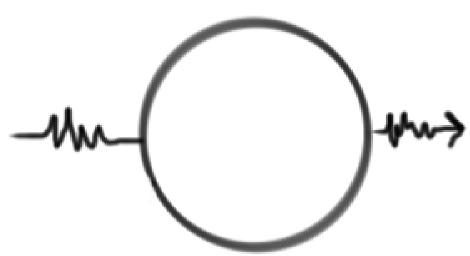
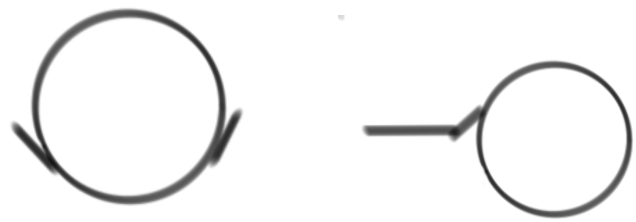


Figure 5.12.: Gestural indications for jerky movements - jab

5.3.2. Gestures oriented by the shape

Hold Intonaspacio

We have noticed two different ways of holding Intonaspacio. There are others, that some participants have used but these are the most common. One uses both hands and is better when the performer needs to reach both piezos, Fig. 5.13a. The second one uses only one hand and is very useful when controlling the IR with the hand, it also allows for a greater involvement of the body in the performance, Fig. 5.13b.



(a) Holding Intonaspacio with two hands. (b) Holding Intonaspacio with one hand.

Figure 5.13.: Gestural indications to hold Intonaspacio.

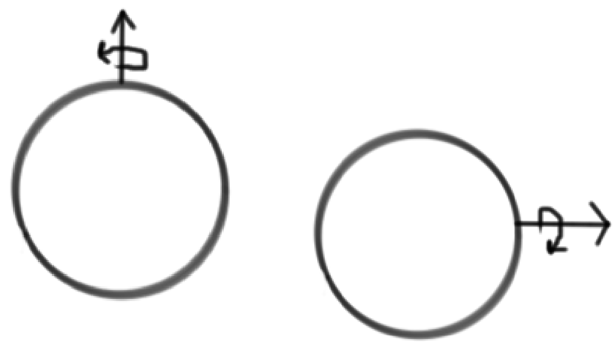
Rotate around one axis

[15] We can rotate Intonaspacio around its three axis - x, y and z. Commonly users use the x and z axis, Fig. 5.14.

Balance

Another common gesture that we observed was a gentle sway around the x and z axis, Fig. 5.15.

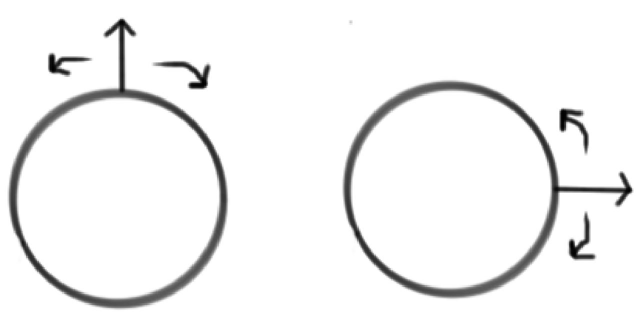
[15]The axis are defined by the IMU that is implement in Intonaspacio.



(a) Rotate Intonaspacio around the x axis.

(b) Rotate Intonaspacio around the z axis.

Figure 5.14.: Gestural indications for rotation of Intonaspacio around the x and z axis, respectively.



(a) Swing Intonaspacio around x axis.

(b) Swing Intonaspacio around z axis

Figure 5.15.: Gestural indications to swing Intonaspacio around x axis and z axis, respectively.

Rolling

Performers whom interact mostly with their torso when playing Intonaspacio have tendency to roll it. We defined two movements, roll in and roll out. The former consists on rolling Intonspacio in the direction of the body, Fig. 5.16a; and the second is the opposite movement, rolling the instrument away from the body, Fig. 5.16a.

(a) Rolling Intonaspacio in the opposite direction of the body - Roll out

(b) Rolling Intonaspacio in the direction of the body - Roll in.

Figure 5.16.: Gestural indications to roll Intonaspacio in different directions.

Eight or infinite

This is a very common gesture made by most of the users when playing Intonaspacio, to draw an eight on air. This gesture is made at different velocities. Eventually the composer can add some notes about the dynamics of the gesture.

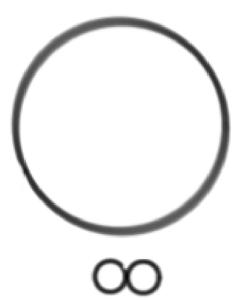


Figure 5.17.: Gestural indications to explore orientation - drawing an eight on the air.

5.4. Conclusion

Musical notation is an important feature to transmit, analyze and learn a new instrumental technique. History shows that traditional musical notation has undergo some changes to adapt to the musical instruments and ideas of each epoch. The beginning of the twentieth century brought a strong debate over the utility of notation, namely because of its demonstrated inability to represent other musical ideas where pitch and duration were not the main concern. We assist to an adaptation of the scores to these new ideas. On one side composers fill the scores with indications other that the common symbols, and on the other side composers deny the traditional symbols and create new ones. The same inability exists when trying to write music for certain DMIs who by their characteristics prevent traditional musical notation to be suitable for them. We believe gestural notation is a possible option, since gestural interaction is of utmost importance in these musical instruments.

Several gestural notations had been proposed through out the literature, but these are mostly directed to dancers and do not necessarily include an external object (like a musical instrument) in the representation and description of body movements. For this reason and after observing several participants playing with Intonaspacio on the first experiment we conducted, we noticed that several gestures were common between users and independent of the mapping used. To analyze deeper this idea we invited an actor with movement experience to play Intonaspacio. The experiment was divided in two sessions on two separate days. The goal was to understand if the participant would change his gestures from day one to day two. The results show that he changed the type of exploration, more than the gesture itself. Two reasons explain this change, first the learning period he had on day one enable him to concentrate on sound on day two. Second, on day two he was aware of the mapping and the placement of the sensors, thus his exploration is oriented to sound production. Clearly this conclusions must be validated with a second experiment whit more participants and more time for each one to explore Intonaspacio.

Both experiments gave us clues of a set of gestures that are not dependent on the mapping but rather on the interface and the shape of Intonaspacio, its idiomatic gestures. We purpose a graphical gestural vocabulary to represent these gestures that we divided in two groups - gestures that are dependent of the shape of Intonaspacio, and gestures that are dependent of the sensors' placement.

6. Building a repertoire for Intonaspacio

In this chapter we analyze some of the causes for the short-life cycle of the majority of DMIs. We also present some of the advantages of creating a repertoire for DMIs and the major role of the collaboration between composers, performers and instrument designers. Finally we present both pieces that were written for Intonaspacio: Entoa and Intonéspacio.

6.1. Challenges of DMIs

Over the last few years we have witnessed a flourishing of new musical interfaces, reflected in the continuous presentation of new musical instruments every year in conferences such as as NIME [1], SMC [2] and ICMC [3], to name a few. However, only a small number of these DMIs establish themselves, i.e., a few number of these DMIs remain in use (by a group of people). Several characteristics of the DMIs can explain this reality, namely the idiosyncrasy of a great number of instruments or the hybrid situation DMIs face (they fall in-between musical toys and musical instruments). Another aspect of this lack of historical continuity is, as Malloch (Malloch and Wanderley, 2007) notes, the great dependency some DMIs have to its designer. A number of DMIs require the constant presence of designers, either for reasons of lack of robustness, or because their are technically demanding and performers cannot simply plug an play them. This prevents the musical instrument from being total independent of its creator, reducing its possibilities of establish itself in the music

[1] www.nime.org
[2] http://smcnetwork.org/conferences
[3] http://www.computermusic.org/page/23

community.

In the following subsection, we will briefly talk about these characteristics. However, we will insist mainly in three points that we believe are important factors on the quick fade of most of the DMIs (which we previously pointed out on chapter 2 and chapter 5): the lack of an instrumental technique dedicated to the musical instrument, the necessity of a new form of musical notation more suitable for DMIs, and the non-existence of a repertoire. All these three factors, we believe, are connected between them.

6.1.1. Hybridism

DMIs present an ensemble of characteristics that bring new considerations in music. We will not focus on the separation between the sound control and the sound generation system, since this subject has already been treated by other authors (Cadoz and Wanderley, 2000),(Wanderley, 2010),(Cadoz, 1999), and in this document (chapter 2). Yet, we realize that DMIs have an hybrid classification, leading even to an absence of a comprehensive definition [4]. From an overall review on the literature on this subject, we understand that a DMI is presented, frequently, as an ambivalent concept. DMIs can be an interface in a sound installation (D'Arcangelo, 2001), (Bökesoy and Adler, 2011), (Teles and Boyle, 2008), (Follmer et al., 2008); a musical toy (Tomitsch et al., 2006), (Mase and Yonezawa, 2001), (Robson, 2001); or a complex interface with expressive competences (Waisvisz, 1985), (Malloch and Wanderley, 2007), (Jordá, 2005). Within the latter, Magnusson (Magnusson, 2010) suggests that the physical interface can be disregarded in the definition of DMI. He states that the core of the musical instrument consists in the mapping layer in conjunction with the sound synthesis algorithm. Consequently, using a different physical interface to control the same combination mapping + sound synthesis would be considered as the same musical instrument, although the gestural interface was not identical. This assumption includes in the notion of DMI situations where no dedicated gestural interface is used, such as live coding (Magnusson, 2010). Thus, combining composition and musical instrument in the same pot. Topetliz (Toeplitz, 2002) had already suggested it when consider-

[4] Most of the times, DMIs are defined within the framework of a specific research topic.

ing traditional musical notation as irrelevant for contemporary music. Although, we consider mapping as one the core elements of a DMI, (our user tests demonstrated that performers tend to direct their gestures according to the mapping it is used) we can not discard the gestural interface from the concept of DMI. The interface of the musical instrument is paramount in the first approach of the performer to it. When observing our participant in our second experiment (chapter 5), it is clear that when the performer has no clue on the mapping, his gestures are mostly conducted by the interface itself. We classify it as an interaction gesture - object. Additionally, as some authors suggests (Malloch and Wanderley, 2007), (Rocha and Stewart, 2014) and (Stewart, 2009), the gestural interface is responsible for the idiomatic gestures, the gestures that are naturally suggested by the shape of the instrument.

Each of these concepts of DMI has different consequences in the complexity of the instrument. Usually musical toys and musical interfaces for interactive installations need to be simple enough to be played by everyone (Chadabe, 2002), (Jordá, 2001). The goal is not so much the expressive characteristics of the instrument but rather the simplicity and easiness of play. This characteristic does not need to be negative per se, since it opens the spectrum of music to unsuspected performers (music amateurs, public in general). A large number of these interfaces outputs combinations of sounds that necessarily work together, enabling anyone to “compose” music without a big effort (D’Arcangelo, 2001). Nevertheless, we consider these interfaces should have a different classification, other than DMI, since in our point of view, a musical instrument should gather a number of characteristics that these interfaces do not. A possible classification could be musical gadgets.

In the framework of this research, we consider a DMI as the ensemble of gestural interface, mapping and sound synthesis algorithm, that achieves a balance between complexity and expressivity, in order to produce a musical outcome. DMIs demand a learning period (Chadabe, 2002), (Jorda, 2004) where the performer must acquire an instrumental technique that would be the basis of a notation system suitable for it (Stewart, 2009),(Rocha and Stewart, 2014),(Malloch and Wanderley, 2007), (Oore, 2005), (Mamedes et al., 2014). Once, DMIs do not have an historical framework that provide performers with hints on how to play them, an instrumental technique should result from the collaboration between the three main actors in this relationship - designer, performer and composer.

Performance and improvisation

This status of hybridism is supported by a tendency to define DMIs towards performative music, rather than composition. DMIs are presented as instruments where improvisation is the main feature. The number of compositions written for DMIs, is considerably small, and the ones where improvisation has not a key presence, is even smaller (Tormey, 2011).
Chadabe (Chadabe, 2002) notes that an interactive instrument[5] combines performance and composition. Both instrument and performer would have equal responsibility in music composition. In the same line of thought Jordá (Jordá, 2001) notes that computers allow control over macro (notes) and micro ("sound within these notes") level. This can be combined in the DMI, generating what he defines as intelligent instruments (Jordá, 2005), musical instruments that are responsible for the low level language, freeing the performer to concentrate on timbre control and other high level parameters, enabling musicians to compose in a high level of complexity within a simplified symbolic environment.

6.1.2. Idiosyncrasy

Another common characteristic of DMIs, is that usually the designer of the musical instrument is also the performer and sometimes the composer. In addition to create a confusion on the roles of performers, instrument designers and music composers, this situation also contributes to the design of idiosyncratic musical instruments (Magnusson, 2010), (Jordá, 2001), (Wanderley, 2010), (Orio et al., 2001), (Rovan et al., 1997b). The designer has a certain interaction idea that he/she wants to explore and the DMI is build to answer it. This idea, however, is commonly very personal and not

[5] The idea of interactive instrument for Chadabe relies on the mutual reaction of the instrument to the performers actions and vice-versa. The performer does not have the total control over the instrument. Not all DMIs can be included in this classification. Interactive instruments would represent a particular case in the universe of the DMIs. This definition is similar to the one Chadabe presents of interactive composition (Chadabe, 1984).

necessarily interesting for other musicians. Consequently the DMI would mostly be the object of a specific designer instead of a community of performers and composers, which could grant it a longer-life cycle.

6.2. Creation of a repertoire

As we stated earlier, the reasons that could explain the short-life cycle of DMIs relate to the lack of an instrumental technique, the lack of a musical notation suitable for these musical instruments who are not exclusively pitch directed, and finally the lack of a repertoire. These three aspects are connected between them, they are consequence of one another. We have already discussed the first two elements of this list in the previous chapter, we will know focus on the creation of a repertoire for DMIs.

Despite the increasing number of DMIs, the amount of written music for these instruments is very small. Several reasons could explain this situation. The majority of these musical instruments is associated to an idea of improvisation and real-time performance, rather than non real-time experiences as composition. At CITAR (Centro de Investigação em Ciência e Tecnologia das Artes [6], we present every year at Christmas an ensemble of Laptopts and DMIs, where although we use a written score, this score is normally very open, containing only temporal hints for the entrance of each performer. Likewise, other laptop orchestras (Tormey, 2011) and DMIs concerts operate similarly.
Additionally, it is very common to find out that the designer is the one that performs the instrument as well. This situation contributes to a blurring of the distinction between composition and instrument (Magnusson, 2010). It also prevents the sharing between other performers and composers. There are exceptions, Waisvisz (Wai, 1999) composed several pieces for his instruments, namely The Hands (Dykstra-Erickson and Arnowitz, 2005) and The Web (Krefeld, 1990). As he explains on a round table about gesture: "At present I enjoy not modifying The Hands too much, and concentrate as much as possible on the creation of music in various collaboration or solo-projects" (Wai, 1999). The same idea of the necessity of fixing the technological

[6] Research Center on Science and Technology of Arts

side of the gestural interface, appears later: “The only solution that worked for me is to freeze tech development for a period of sometimes nearly two years, and than exclusively compose, perform, and explore/exploit its limits” (Wai, 1999). What Waisvisz explains in this statement is of major importance for the establishment of a DMI. Designers have a natural tendency to improve their musical instruments with better technology, the addition of sensors, change of shape, and so on. However, a stable version of the DMI is essential for its establishment through the contribution of composers and performers.

Another example that helps explaining this lack of repertoire is the situation where a DMI is designed for a particular musical piece (Pérez et al., 2007). In these situations the DMI is so full of particularities that it is almost impossible to adapt it to other musical idea.

Finally, through literature we notice that there are few collaborations between composers, performers and designers of DMIs in order to create a repertoire and an instrumental technique of the instrument. Collaboration that we think is critical to the development of a community of interest around a certain instrument. As Medeiros suggests ”Often, DMIs requires some adaptation after performer’s practice sessions, through technical and player’s evaluation” (Medeiros and Wanderley, 2011).

6.2.1. Collaborations performer - designer - composer

The CIRMMT/McGill Digital Orchestra Project (Pestova et al., 2009) is a good example of collaboration between the three main actors of this relationship - designer, performance and composer. The project included several DMIs designed at IDMIL such as the T-stick (Malloch, 2008), the FM Gloves (Fortier et al., 2008) or the Rulers (Birnbaum et al., 2014), several performers and composers. Stewart (Stewart, 2009) explains that this collaboration was important in order to define what were the idiomatic gestures of each DMI. Idiomatic gestures are the base for the development of an instrumental technique and of a more suitable notation for each DMI (Stewart, 2009), (Malloch and Wanderley, 2007), (Rocha and Stewart, 2014). This notation will be the tool composers can use to write a repertoire. Another important point of these collaboration projects is that DMIs are in constant adaptation to better meet the needs of both the performers and the composers. Contributions of both parts help the designer to adapt the mapping of the instrument.

Another example of a close collaboration between instruments designers, performers and composers is the project Le Geste (Malloch et al., 2013a). Malloch and Hatwick designed a series of prosthetic musical instruments that were attached to the body of two contemporary dancers. The design process included several workshops were the dancers, the composers, the choreographer and the designers were present. In result of this collaboration a contemporary dance performance was created.

The creation of a repertoire does not necessarily needs a period of collaboration like the previous ones. A number of other examples exist of DMIs which have written music. The Hands from Waisvisz, as we exemplified earlier, some of the interactive compositions of Chabade are written for DMIs (Solo for example), Max Mathews composed for the Radio Baton, and so on. Yet we do believe that collaborations where the three actor are present - designer, performer and composer, are more likely to contribute to the establishment of a community around the instrument and a longer life spam.

6.3. A repertoire for Intonaspacio

In order to create a repertoire for Intonaspacio, we followed a similar approach of collaboration. So far, we worked with two composers that wrote two pieces [7]. The two compositions are called Entoa and Intonéspacio, respectively, and both present different interaction proposals, where the performer has different degrees of freedom.

6.3.1. Entoa

Entoa (2013) is a musical work composed by Clayton Mamedes for Intonaspacio [8]. The piece explores the shape of the instrument as well as its interaction potential. The goal was to create an intuitive and expressive performance where the correlation

[7] At the moment we are preparing three more collaborations, this time with performers from different musical backgrounds (free jazz, contemporary music and experimental electronic music).

[8] A demo of this work is available here: https://vimeo.com/78300123

between sound and gesture was perceivable by the audience. To achieve it, gestures were clustered and associated to sound events, and then distributed among the various sections of the music. The characteristics of the gestures (amplitude, speed and so on) were mapped to control several sound parameters such as "amplitude, superposition of sound layers, variation of spectral content through sound processing and displacement of sound sources in spatial diffusion" (Mamedes et al., 2014). The ensemble of sounds of Entoa consists on percussive sounds with a metallic timbre profile.

Conceptually, Entoa is grounded on a finite-state machine model (Gill, 1962), "each state on the music progression corresponds to a new section. As a state machine, each section has an independent group of procedural rules, which in our case comprises a different multi-layered mapping relation (different mapping designs for each section) between the extracted information from sensors and the sound processing parameters." (Mamedes et al., 2014). The piece has five sections in total, progression from one section to another is based on this model. The transition is based on established rules that help to smooth its effect. The performer can move from section to section, caused by sequentially taping on both piezos (P2 followed by P1) within a certain time span.
Sound spatialisation is implemented across all sections of Entoa, using the SPAT library developed at IRCAM. The position of the sound sources is controlled by the rotation of Intonaspacio on both angles of pitch (elevation) and yaw (azimuth). The distance of the sound sources depends on the distance of the performer's body to the IR sensor. This sensor measures a distance from 0 to 30 cm that is translated to a spatial distance of 0 to 5 meters. The established connection is inversely proportional, the further the performer is from the sensor, the closer the sound is perceived.

Entoa has a set of rules that direct the practice of the performer. Nevertheless, the performer has a great level of freedom within the piece to control certain parameters, such as the time duration of several sections (sections 1, 3 and 4), the intensity and expressiveness of his/her gesture or the amplitude of several sound effects along the piece.
Entoa as any other composition for acoustic instruments demands a period of rehearsal to allow the performer to achieve the control and mastery over Intonaspacio

as well as over the score.

Section 1

In this section the composer uses sounds of singing bowls that were processed with ring modulation. There are eight different sound files that the performer can trigger with both piezos. The files are played sequentially. For each sound triggered the amplitude is defined based on the calculation of the velocity of the strike - we calculate the velocity of the strike until it reaches its maximum amplitude. This characteristic combined with the distance from the IR sensor to the performer's body changes the dynamics of each sound, "the performer can continuously control presence, direction and intensity of sounds combining rotation and distance of the instrument to his body." (Mamedes et al., 2014). The performer is also able to control spatialisation of sound through changes on the orientation of Intonaspacio .

Section 2

In section 2 a sound track is played continuously. An harmonizer effect is added to this file and the performer can control the intensity of it with the Roll values extracted from Intonaspacio, "any rotational movement of the instrument will cause the sound to change, supporting a combination of different movements. For each sound channel we have defined a different configuration for the harmonizer, increasing perception of space and preserving musical appeal by response to movement." (Mamedes et al., 2014). The singing bowls from the previous section are still available in this section. The transition for section 3 is automatic once the track ends.

Section 3

This section is the core of the work, the composer wanted to build a strong detachment of this section from the previous two. The intention is that the performer can have a very intense and dynamic performance. In this section sound is triggered by movement, "an envelope controls the dynamics of the sound according to the information retrieved from the gyroscope" (Mamedes et al., 2014). When the amplitude of the retrieved signal is greater than a specific threshold, sound starts at a certain amplitude. Two samples of "beaten and scratched knife sounds" (Mamedes et al.,

2014) are played, each associated to an axis (x and y). To avoid clips when the performer moves very fast, there is a fade in and fade out of 10 milliseconds for each sample. The gestures of the performer control amplitude and duration of sound. The greater the expressivity of the performer, the more enhanced is this relation gesture - sound.

Section 4

Section 4 retrieve the singing bowls from section 1 and 2, and adds a sound track composed mostly by percussive sounds. The interaction model is very similar to section 2, although this time, the harmonizer is replaced by a chorus effect that is controlled by the Pitch angle. The composer notes that a reduction on amount and intensity of gestures is expected on this section.

Section 5

The final section of Entoa comprises a blend of all the gestures explored on the previous sections along with the introduction of jab gestures. These triggers "brief inharmonic sounds with low pitch, high amplitude and a sharp closed attack-decay morphology" (Mamedes et al., 2014) [9]. The singing bowls were kept as well as the sound track. At this moment, the performer had already explored all the features of Intonaspacio individually, thus in this section he should not have great difficulty in combining all. Section 5 "conducts a large *crescendo* that concludes the work in a *sforzando* climax followed by a short coda" (Mamedes et al., 2014).

6.3.2. Intonéspacio

Intonéspacio (2014) was composed by José Alberto Gomes, for the presentation of Intonaspacio at the Margaret Guthman Competition 2014. The piece explores Intonaspacio as an interface for triggering sound events. The composer uses continuous signals to initiate discrete events, opposing to a more or less natural association of discrete events with discrete signals. Intonéspacio is divided in two movements, A and B. In each, different sensors are in use - IMU and IR on section A, IMU, IR and P1

[9]For more information on the described morphology please refer to (Smalley, 1986).

on section B. The function of each sensor changes from A to B [10]. Both movements can be understood as separate entities, where a *crescendo*, climax and *diminuindo* arrives sequentially. Also, the sound content of each is remarkably different, making it perfectly clear for the audience the different moments of the composition. The duration and progression from movement A to B is controlled by the performer, the composer provides hints on the development of the piece but timing decisions are more or less left to the performer.

A

The first movement of Intonéspacio comprises an additive synthesis where each frequency has an independent envelope that is linked to a list of values that progressively modulate the amplitude of each one. To trigger each element of the list, the performer has to rotate Intonaspacio in order to attain certain values of both angles Roll and Yaw, stipulated by the composer on the score. At the same time, the performer should modulate the overall pitch of the piece with the Pitch angle, according to the indications present in the score. Finally, the overall amplitude of the music is controlled by the distance from the performer's hand to the IR sensor. Since Intonaspacio has a complex behavior, it is not easy to act over a single sensor, this combination of envelope, pitch modulation and volume control is rather difficult to achieve and demands several hours of rehearsal to obtain complete mastery over it.
Transition to movement B is made by a jerky movement - jab gesture.

B

In Movement B an FM synthesis is playing continuously. The overall pitch is modulated using both Pitch and gestural amplitude, extracted from the interaction with Intonaspacio (stronger gestures would result on bigger changes on pitch). IR is still mapped to control the overall amplitude, it is one of the few features that has the same function as on section A[11] Two samples of sound are added to the sound content

[10]This is a very different approach from the one used in Entoa, where from section to section, different parameters are made available for the performer but the sensors kept more or less the same mapping across sections.

[11]The other is the Pitch angle.

of this movement, one of the sound of a razor and another one of the sound of several clicks. The former is controlled using the Roll values, these are directly proportional to the amplitude level of the sample. Clicks are triggered by one of the piezos (P1). Modulation of each sound parameters are indicated by the composer on the score, although these do not consist on fixed values, rather the performer is free to interpret them as he/she wishes.
The piece ends with an indication to hold Intonaspacio still, these action initiates a fade out that silences all the sound.

6.3.3. FLVC

Intonaspacio has also been used on an improvisational context, namely as part of the FVLC (Formação Variável de Laptops do CITAR) [12] group, a laptot/new music instruments ensemble at CITAR, Porto. We have played with Intonaspacio in one of our Christmas presentations - December 2012.
For each performance the group invites a composer who writes a graphical score. The score is used mainly as a guidance tool, where time hints are given, as well as indications on the entrance of each performer. Besides these clues, the performer is free to choose the sound content of the performance. In this concert we have used a simple record function that captured the sounds produced by the other musicians and modulate it according to changes in orientation of Intonaspacio.

6.3.4. Future collaborations

The creation of a repertoire and the beginning of a community of both performers and composers around Intonaspacio is of utmost importance for us. We aspire to give a continuity to Intonaspacio after the completion of this work. This goal motivate us to contact a number of performers that could be interested in playing the instrument. The feedback was very positive, and at the time we have around 5 performers willing to explore the interactive possibilities of Intonaspacio. Due to time and geographic reasons (two of the musicians live in New York and another one in Montreal) we are still trying to find the best time to work together. When the new version of

[12] Variable ensemble of Laptops from CITAR

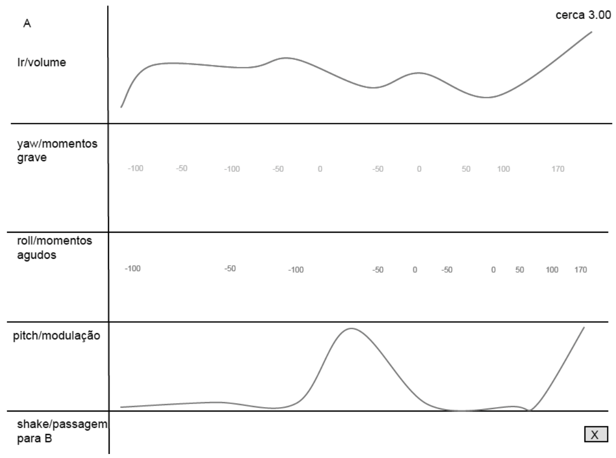


Figure 6.1.: Intonespacio: A (graphical score)

Intonaspacio will be ready, it will be easier to distribute Intonaspacio through all the interested performers.

At the moment, we are collaborating with Michal Seta who will compose a new piece to be presented on March 1st at Montréal Nouvelles Musiques 2015. This new composition will integrate place on the composition, thus we could test Intonaspacio in a real performance situation.

6.4. Applying the proposed gestural vocabulary to our repertoire

Both music pieces, Entoa and Intonespacio, had a previous score provided by the composers. The former had a textual score, where textual hints are given to the performer, and Intonéspacio had a graphical score (Fig. 6.1 is the score of movement A).

The two scores give a certain degree of freedom to performers, they can make decisions mostly on time interval and gesture intensity. Once both compositions were written before the creation of Intonaspacio's gestural vocabulary, we decided to do an hybrid version of the scores by adding gestural hints. We believe this will facilitate the understanding of the pieces in future performances. For time constraints the vocabulary was not yet evaluated. We intend to do it on the future, namely by

comparing the learning curve of groups of performers who have access to scores with gestural notation and a group of performers who rely exclusively on the written score (for Entoa) or graphical (for Intonéspacio).
Bellow we present a suggestion on how to apply the purposed gestural vocabulary to excerpts of both pieces written for Intonaspacio. Gestures are separated in lines. They are sequential if they succeed one another on time (horizontal progression), or consecutive if they are at the same location (vertical progression). Before the beginning of each section is given an indication on how to hold Intonaspacio (one or two hands).

6.4.1. Entoa

The score for Entoa includes notes on how to perform with the instrument on each section of the piece, it is similar to an instructions list. These, however, do not include fixed rules on time cues. The performer can freely do any possible gesture of the section within that time. Thus, a notation would constraint his freedom of decision, if not all at least some. Nevertheless, we will suggest a gestural notation for some of the sections of the piece, to serve as an example.

Section 1 - hybrid notation

"The first movement of the piece associates the piezoelectric sensors to the triggering of pre-recorded sounds of Tibetan singing bowls. Sound amplitude corresponds to the intensity of the strike on the piezos.
Spatialisation is controlled by rotation of Intonaspacio. Sound recordings were processed and edited to enrich its sustain period, allowing the performer to explore this characteristic of the sound material. Attack on percussive sounds tend to be well located by the public, the performer must choose how to use this property expressively. The conceptual idea of the work foresees a *piano* dynamic. The density and intensity of sounds played in this section are chosen by the performer. [13]"

[13]Translated by the author.

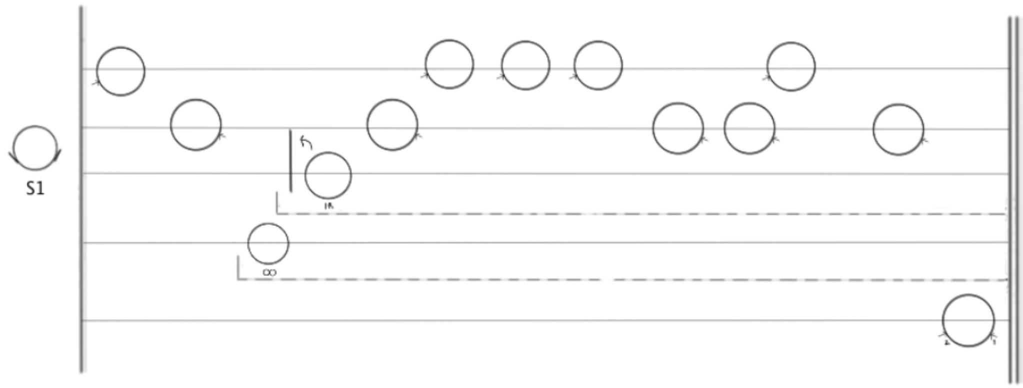


Figure 6.2.: Entoa section 1 gestural score

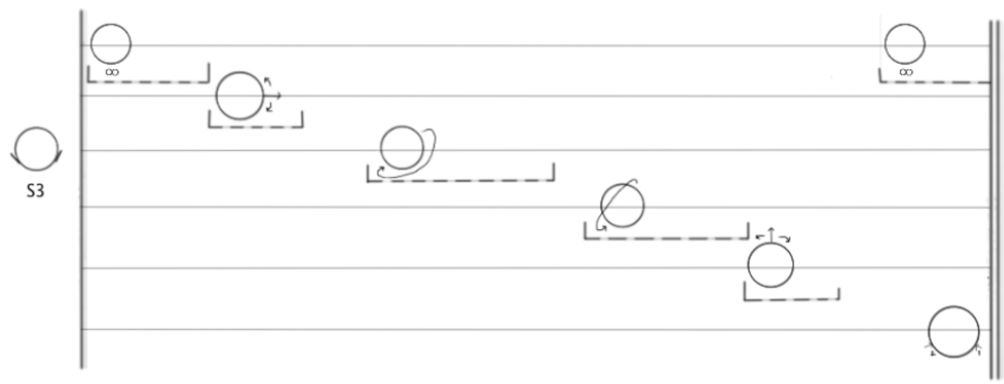


Figure 6.3.: Entoa section 3 gestural score

Section 3 - hybrid notation

"The section associates rotation at the azimuth and elevation axis with sound production. The idea of the work expects an opposition in relation to the previous section, including gestures with wide amplitude, resulting in *mezzo-forte* and *fortissimo* dynamics. Speed of rotation is linked to sound amplitude of the sound file played. Progression for next section is selected by the performer by playing sequentially both piezoelectric sensors. This control is the only mapped activity for both piezos on this section. [14]"

[14] Translated by the author.

Section 5 - hybrid notation

“In this movement the Tibetan singing bowls of the previous sections are kept and a new sound file is superposed. This was processed with a chorus effect which intensity is controlled in a similar way of the previous section. Abrupt movements or sudden shake of the instrument triggers percussive sounds.
When the sound file ends the sound is automatically stopped. The end of the performance can also be selected by the performer with the same sequence of the piezos that is used to progress from section to section.
The clues of the end of the piece are the end of the layers of sound material and the progressively emptiness of its spectral content. This formal structure works as a formal coda. [15]”

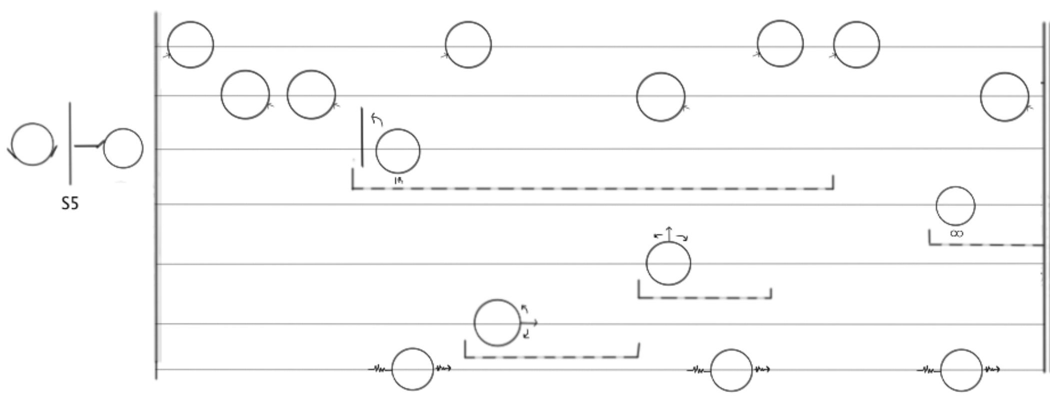


Figure 6.4.: Entoa section 5 gestural score

6.4.2. Intonéspacio

The score of Intonéspacio is a graphical score that in some way indicates the way the performer must control the sensors used on the composition. The way the performer manipulates Intonaspacio is constrained by the indicated amplitudes he/she has to achieve. In this gestural score we introduced some gestures that would help the performer to play Intonéspacio correctly. Still, these are neither the only ones nor mandatory but a simple suggestion.

[15]Translated by the author.

B

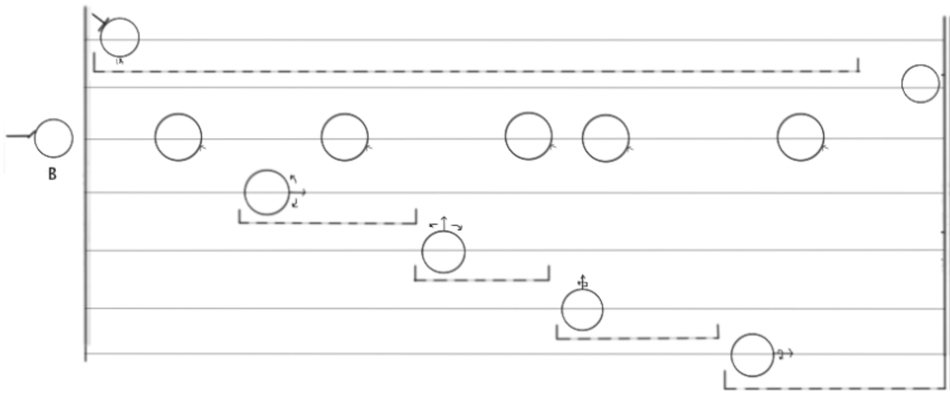


Figure 6.5.: Intonéspacio B gestural score

6.5. Conclusion

DMIs face several challenges that can prevent them to have an historical continuity. Among them are the hybridism of classification (in-between musical toys, musical gadgets, interfaces on sound installations and musical instruments), and their idiosyncrasy. However there are three characteristics that we believe can give DMIs longer-life cycles, namely the existence of an instrumental technique dedicated to the musical instrument, a gestural notation adapted to the instrument and finally the creation of a repertoire that is shared between performers and composers.
The previous chapter looked over notation and instrumental technique. This chapter concentrate on the question of the repertoire. In spite of the large number of new DMIs that are presented every year, the number of written compositions for them is still very small. One of the reasons that explains this situation is the tendency of DMIs to be used mostly in performative music where improvisation is a very strong component. Similarly, there is a lack of collaborative work between the three main actors of this process - designers, composers and performers. We collaborated with two composers that wrote two very different pieces for Intonaspacio.
Clayton Mamedes wrote Entoa, a piece divided in five sections that correspond to different states of a machine. Entoa has a dynamic mapping, where different gestures

relate to different sound parameters along the five movements of the music. Clayton Mamedes created several conditions for each movement on the music that are mutable along time. The same gesture can control different parameters at different moments of the piece. The action-sound relation, however is always very clear. The performer has to learn the exact gestures that trigger the sound the composer has described in the score. In spite of this aspect, the performer still has some freedom and he/she his responsible for some important choices in the music, such as the duration of each movement (with some exceptions), and the weight of the sound effects (harmonizer, spatialisation control and so on).
Intonespácio was written by José Alberto Gomes. The piece is divided in two movements. In each one we have a crescendo in intensity. The time of each movement is controlled by the performer's manipulation of the instrument. The composer established very interesting relations between continuous gestures and discrete actions, for example, changes in orientation will trigger specific changes in timbre. They will also trigger the reproduction of sound samples. Once more there are some gestures that are not common to both movements.
We intend to continue these collaborations with composers in order to develop a repertoire for Intonaspacio, in an attempt to give a long life spam to Intonaspacio. We also have to insist on compositions where place is an important ingredient of the composition.

7. Discussion, conclusion and future work

7.1. Discussion

We started this research work by posing a question on how to integrate space in sound composition as a creative parameter, i.e, **how to create site-specific sound?** Before formulating an hypotheses to answer this question, we started by framing the question of space and to understand what site-specificity implies as artistic discipline.

Space suggests, according to several authors (please refer to chapter 1), vast and infinite dimensions where place and site are normally contained. Site, on its turn, carries an idea of anonymity that reflects the notion of non-place (Augé, 1995). It is hard to create relations of intimacy with site, instead site reflects a more functional and utilitarian view of space. At the end of the nineteen century we assist to a reconstruction of the importance of place in relation to space, where place slowly gains a greater importance. This change is due mostly to an orientation towards the human body and its perceptions and limitations (especially with the inputs of phenomenology). Place then gathers this possibility of having fluctuate dimensions that are exclusively dependent of the human and especially the body perception of it. More, discovering the place and establishing its boundaries rely on human action (as Deleuze and Guattari (Deleuze and Guattari, 1987) suggest with the Nomad Space, and Merleau-Ponty (Merleau-Ponty, 1962) with the construction of the body image) contributing to associate an image of intimacy that is closely linked with the idea of place (Bachelard, 2008).

Accordingly site-specific art (in broadly terms [1]) searches for this intimacy, this strong bound between the artwork and the place. They are conceptually inseparable from each other. The artwork looses its purpose and meaning once it is relocated (Serra, 1994).
We suggested then, in the framework of our research, a new denomination of the discipline, instead of site-specific sound, we believe place-specific sound is a much more accurate term since it reflects this search for intimacy. Accordingly, we reformulated our initial question - **How to create inherently place-specific sound?**
Inherently precisely to insist on this idea of bounding and intimate connection between place and the sound artwork. Thus we established the premises to consider a sound artwork as inherently place-specific. They are:

Sound has to influence place response,
Place has to change our perception of sound

Acoustically, there is a natural connection between place and sound. When we produce sound, what we hear is a combination of several parameters - direct sound, early reflections of the room and the reverberation of the room with the reflections of the room (Henrique, 2007). Thus it is impossible to completely dissociate sound perception from the place where the sound is generated.
We have an acoustic response of place almost naturally, but that does not necessarily mean we have access to it and more importantly it does not grant us control over it, which is of undeniably importance if we want to create an interaction between place and sound artwork.
Based on this assumptions we reformulated once more our question - **How to create and control inherently place-specific sound?**

To answer this question, we state as a possible hypothesis the design of a musical instrument. We believe that a musical instrument give to its performer control over sound and facilitates the access to the sound present on place and generated by it. Mostly because it extends the human body, bridging its limitations. Moreover, DMIs,

[1] We are not making a distinction here on site-specific sound art and other domains (visual arts, theater, performance).

by its characteristics (separation between sound generation and sound control) open the range of possibilities that were impossible to traditional musical instruments to achieve (either due to mechanical constraints or the human physical constraints). We can then have access to new spatial and temporal dimensions (a discussion about DMIs and its characteristics is carried on chapter 2).

Intonaspacio is then an possible answer to materialize our initial question. The core feature of Intonaspacio is precisely the access to sound present in place (Background noise as Labelle (Labelle, 2006) names it - please refer to chapter 1 and 3) and the sound generated by the place (due to the physical characteristics of the place - dimensions, materials). To combine both we purpose a method where the performer can use the sound present in the room as a trigger to create the acoustic response of this same room. Hence the emergence of two sub-questions (refer to chapter 3): **How to integrate the background noise on the art work on real-time?** and **How to allow these sounds to trigger the responsiveness of place?**
To answer these questions we designed three different mappings that present different solutions to integrate place in the sound artwork. The first mapping suggests the use of the sound ambiance of the room that is continuously reproduced and recorded in approach similar to the one Lucier proposes in his work *I'm sitting in a room*. Although the performer is allowed to choose when to start the recording, as well as to introduce new elements in the interaction (namely sound effects). Mapping 2 starts from an analysis of the incoming sound and extracts a spectral analysis of the room that is changeable over time, i.e., as the performer displaces Intonaspacio around the room, introduces new sounds in the room or interact with other instruments, the resultant frequencies (extracted from the analysis) will change. These are mapped to control several parameters of sound effects like tremollo and reverb. Finally the third mapping combines the analysis with an additive synthesis. Generating sound with the information recovered from the incoming sound. Once more this process is very dynamic and depends on the displacement and action of the performer.
With these mappings we gave performer access to place, however and according to the experiments we carried with users during this research, control is still an issue. This can be due to technical questions - the microphone and wireless systems need to be improved and the mapping must be further developed.

These thesis can be divided in two main parts, one dedicated to the place-sound relation that comprises chapter 1 to 4, and a second one where we introduce some of the challenges DMIs face currently, chapters 5 and 6. The reason why we chose to include this second section relates to our desire of having Intonaspacio used and played by performers.

In chapter 2 we separate DMIs from musical gadgets or toys based on the assumption that a musical instrument relies on two main conditions to be considered as such: the existence of an instrumental technique dedicated to the instrument and the existence of a devoted repertoire. These are also, in our belief, two main points to proportionate a longer longevity to the DMI (we present a few others briefly on chapter 6) since they contribute to the establishment of a community of composers and performers around the instrument.

Therefore we not only collaborate with two composers that created two pieces for Intonaspacio (presented on chapter 6), but also based on direct observation of the participants of both experiments we carried during this research work, we suggested an ensemble of idiomatic gesture of Intonaspacio. We compiled these on a vocabulary (chapter 5) that can be the basis of a future gestural notation for Intonaspacio and other DMIs that share the same shape.

On the account of technical problems (Entoa) and time constraints (Intonéspacio) none of the composed musics for Intonaspacio integrates place directly on their original version. However, they could be both adapted to do it. We are currently collaborating with a performer who will use Intonaspacio as a place-specific musical instrument.

7.2. Contributions

This thesis is highly interdisciplinary, with this work we introduced questions from philosophy, visual and sound art, sound acoustics and design of DMIs. Therefore our contributions span over more than one domain.

The starting point of this research was a philosophical premise where we related sound and place and the notion of place- specificity. We suggested a new terminology to the field, namely place-specific, instead of site-specific. We also delineate the two conditions necessary to consider a sound artwork as place-specific.

In the domain of the design of DMIs, we presented a new musical instrument oriented towards an interaction with the place of performance. A DMI that grants the access and control of sound present in and generated by place. Intonaspacio presents also a combination of sensors rather complex, specially when compared with similar instruments, providing greater flexibility and mapping complexity that contributes to a greater expressivity. We proposed three different possibilities to integrate place on sound creation: one where the performer uses the sound present in the room (background noise), another where the analysis of the incoming sound generates a spectral image of the room that is mapped to control parameters on pre-recorded sound, and a third one where the same analysis is made and the extracted information is used to feed an additive synthesis algorithm.
Intonaspacio seems to be an effective tool to integrate place on sound artwork. It gives the possibility to generate place-specific sounds, with three different approaches that are easily interchangeable. We noticed, after the experiments we carried during this research that these present some problems that need to be deal with in a future work. Namely the direct approach although providing wider timbre possibilities and a greater feeling of place integration, is not easily controllable, thus introducing some undesired sounds and noise. The indirect approach, it is easier to control but the integration of place is felt as almost nonexistent since the contribution of place is more subtle and not directly controlled by the performer. We intended to surpass these problems by proposing a third mapping where both approaches are combined. This seems to give more interesting results. However, we still have to evaluate it with a larger group of performers.

Moreover we suggested two main requirements to guarantee a longer life to DMIs (a challenge the DMIs face currently): the development of an instrumental technique dedicated to the instrument as well as the construction of a repertoire. Finally we proposed a gestural vocabulary for Intonaspacio with idiomatic gestures, that can be the basis of a future gestural notation more suitable for instruments that present the same characteristics of Intonaspacio.
We understand the possibility of having place as a creative parameter for sound

composition reflects a conceptual and artistic thought, composers and sound artist may or may not which for it, but it exists as a new possibility and increases the possibilities of artistic creation.

7.3. Future work

Our work was centered on several points (place-specificity on sound creation, design of DMIs, gestural notation and creation of repertoire) which opened multiples lines of future research work. On the integration of place on sound we proposed three different ways of integration acoustical properties of the room. These need to be further explored, individually or combined between them. An interesting experiment would be one where we could perceive the way the audience notices this interaction between place, sound and performer, and what is the level of interest and engagement. Another area of research may be the analysis of gestural interaction with DMIs. For time constrains we were not able to perform more experiments with a large number of participants. One future experiment could analyze how several performers use or not different gestures to play Intonaspacio in different places (using the same composition as reference).
The vocabulary we suggest on this thesis can be further developed and in the future we can evaluate the impact this gestural notation has on the learning curve of future performers and on the work of composers. An interesting experiment could be to have a group of performers where half of it would have a gestural score and the other half a textual or graphical score, and evaluate their processes of learning using qualitative methods, by interviewing the performers and record their evolution on time.

At the moment we are preparing a third version of the instrument, more robust. This version will be given to performers to explore Intonaspacio during a certain time, and create music works with it. We could then have participants with a longer experience with the instrument, allowing us to get more accurate conclusions on the expressiveness and musical interest of Intonasapcio. We want to collaborate with musicians from musical genres other than electroacoustic music; and other performers such as dancers or actors. Each of them can introduce new gestures to the gestural vocabulary we started in this work, and contribute to the repertoire.

Finally, we want to promote more live performances for Intonaspacio, solo or in ensemble.

With our work we tried to give performers and composers an instrument to add an extra parameter to sound and music composition - place. Although we do not defend this parameter as a mandatory feature of the sound composition, we do believe this is an important asset. As any other musical instrument Intonaspacio is dependent on the intention of composers and performers that are willing to play with it. It is not supposed to be a comprehensive instrument that is played in every song, rather it is an instrument with a specific feature - the possibility of creating place-specific sound works.

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A. Appendix II

Participant Information

Date:

Age:

Gender:

Question 1: Did you play an instrument?

Yes No

If yes:
Name of the instrument(s):
Years played:

Are you a graduated musician (do you have university training in music?)
Yes No

If yes, which instrument and how many years have you been professionally playing with the given instrument?

Question 2: Do you have any previous experience with digital controllers?

Yes No

If yes, what have you played, for how long and at what level (beginner, intermediate, expert)?

Question 3: Are you familiar with site-specific practices?

Yes No

If yes, in which context?

User Experience Questionnaire - Intonaspacio

Date:

User:

Part 1: Interface design

Question 1: How easy was to understand what kind of gestures were producing sound?

1	2	3	4	5
extremely difficult				very easy

Question 2: Did you felt you controlled the instrument?

Yes No

If no, did you felt your gestures gave random musical results (no repeatability)?

Yes No

Question 3: Did you felt that any area of the instrument less responsive than others?

Yes No

If yes, which one?

Question 4: Did you easily found the parts of the instrument that are contributing to produce sound?

Yes No

If no, do you think more visual clues are needed?

Yes No

Or tactile clues?

Yes No

Question 5: How was your adaptation to the interface?

1 2 3 4 5 extremely difficult very easy

Question 6: How responsive was the instrument?

1 2 3 4 5 extremely dificult very easy

Question 7: How repeatable you felt the instrument?

1 2 3 4 5 extremely dificult very easy

Question 8: Did you felt the instrument constrained your gestures in any way?

Yes No

If yes, in which one?

Question 9: Did you felt the interface inspired some of your gestures?

Yes No

If yes, explain briefly how?

Part 2: Site-specific, comparison between mappings

Question 1: Did you felt the contribution of space in mapping 1?

Yes No

Question 2: Did you felt the contribution of space in mapping 2?

Yes No

Question 3: In which mapping, 1 or 2, did you felt space were more present?

1 2

Why?

Question 4: Between mapping 1 and 2, which one you consider more interesting in terms of musical results?

1 2

Question 5: Which mapping you liked better?

1 2 3

Why?

Question 6: Did you think space added an extra layer to the sounds, when you compare mapping 3 to mapping 1 and 2 do they seem more or less interesting?

Yes No

Question 7: Do you think is important to add this other layer (space as parameter of composition)?

Yes No

Question 8: How site-specific you felt the instrument was?

1 2 3 4 5 not at all
tremely site-specific

Question 9: How interesting you think this interface is?

1 2 3 4 5 not interesting
very interesting

Thank you!
Any suggestions, comments and so, please send an email to mailisr@gmail.com or just talk to me