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**Sound response to physicality**

Artistic expressions of movement sonification

Skriftlig reflektion inom självständigt, konstnärligt arbete

Till dokumentationen hör även följande inspelning:

*Hypercycle*
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Terminology

Accelerometer – ‘an instrument for measuring acceleration or for detecting and measuring vibrations.’

Ambisonics – ‘a system of sound reproduction that uses a combination of channels and speakers to produce an effect of surrounding the listener with the sound.’

Gyroscope – ‘a device which contains a heavy spinning mass or wheel mounted in such a way that only one point, its centre of gravity, is in a fixed position; the wheel being free to change orientation of its axis around center of Gravity. […] It is used to sense the angular motion of a body.’

Human-computer interaction (HCI) – ‘the study of how people interact with computers and to what extent computers are or are not developed for successful interaction with human beings. […] HCI consists of three parts: the user, the computer itself, and the ways they work together.’

Hyper-interactive work – a work in which, regardless of whether the work is designed to involve one or more individuals simultaneously, interaction may be executed by anyone from its environment.

Hypo-interactive work – a work in which interaction is executed by specific person or group of people, but it is not designed to be created by anyone from the work’s


environment. Usually it takes the form of a performative situation. Presence of the spectators is necessary.

IMU (Inertial measurement unit) – an electronic device that combines a collection of measurement tools (e.g. accelerometers, gyroscopes and magnetometers).\(^5\)

Magnetometer – ‘an instrument for measuring the intensity of a magnetic field, especially the Earth’s magnetic field.’\(^6\)

OSC – Open Sound Control is a protocol for realtime, highly accurate, low latency and lightweight message communication among computers, applications and other multimedia devices.\(^7\)

Indirect interaction – a phenomenon in which an individual experience an interactive situation by observing another person, where the observed person is interacting directly.

Proprioception – also known as kinaesthesia; a phenomenon that involves awareness of the spatial and mechanical status of the body, its position, movement, balance and tension.\(^8\)

Sonification – ‘the use of non-speech audio to convey information.’\(^9\)

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Introduction

‘The body is the ultimate instrument of all our external knowledge, whether intellectual or practical… Our own body is the only thing in the world which we normally never experience as an object, but experience always in terms of the world to which we are attending from our body.’\(^{10}\)

Over the last five years I have been investigating the phenomenon of movement sonification and different types of interaction ongoing within the experience. I have expanded my knowledge and skills in the fields of music, musical performance, dance, music theory, music technology, acoustics, physics, as well as cognitive and computer sciences.

During that complex process I began to wonder about the spectators’ perspective on the movement sonification practices, as my feeling was that in some cases (described later in the thesis) they may be confronted with overstimulation. On the other hand, an experience too simple or too predictable would neither be satisfying for me, nor engaging for the audience. Therefore, one of my fundamental tasks was to create the interactive situation consciously, considering both time and form in regard to participators’ attention.

This paper introduces the reader to an extraordinarily broad subject of movement sonification, namely how to create, participate in and understand the phenomenon, with special emphasis on the human perception and proprioception system. Particular attention is also paid to technological issues, presented and described using the example of IMU technology.

Presence of interactive elements in any movement sonification based work is undeniable. Usually the forms of art which are called ‘interactive’ are designed to require an active engagement of the audience. But during the process I started to question myself – what about the works, which are created to be just observed by spectators? How to think

\(^{10}\) M. Polanyi and A. Sen, *The tacit dimension*, University of Chicago press, 2009, p. 15-16.
about interaction, if it is not created by the audience, but the artists themselves? So the audience is participating interactive processes indirectly?

This thesis presents my point of view on direct and indirect interaction through examples of my previous compositions, as well as works created by other artists. The two last chapters are devoted to practical aspects – experiences and observations made from different perspectives – a composer’s, creator’s, performer’s and spectator’s. Based on my latest interactive work *Hypercycle* I discuss my way of creating an interactive situation, the process of using all possible elements to make the work engaging, yet not overwhelming or overstimulating.
1. Interdisciplinarity – the unity of knowledge

Moss, Osborn and Kaufman define interdisciplinarity as:

‘[…] the synthesis of two or more disciplines such that a new level of discourse and assimilation of knowledge is achieved. In practice, the process of interdisciplinary instruction often begins with a topic, theme, problem, or project that requires active student participation and knowledge of multiple disciplines in order to reach a resolution.’

The term interdisciplinary is defined as a phenomenon of ‘involving two or more academic, scientific or artistic disciplines’. The main value of each interdisciplinary work is to face the issues that are beyond the scope of any single discipline and to achieve the fullest integration of a wide spectrum of knowledge.

Wiliam Condee remarks in his article The interdisciplinary turn in the arts and humanities, that the disciplinary development in academic researches enables significant progress of the modern world. By limiting ourselves to some concepts or methods we can delve deeply into one subject and learn everything possible about it. However, some of the theories or ideas are drawn from various sources and need to be shaped by many different tools simultaneously. This is why interdisciplinary approaches are so crucial. It ‘constitutes a unique form of specialisation’ and provides ‘a selective integration within a spectrum of disciplines’.

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15 J. T. Klein, op. cit, p. 116

16 Ibid., p. 116
Many interdisciplinary art works I participated in and especially those, which were either technologically or conceptually incredibly complex, required my full attention and concentration. In some cases it was a great challenge. But sometimes they were overly complicated and just too difficult to understand or even to follow. Therefore, a variety of different approaches have concluded important questions in this context, that is: how to create interdisciplinary art and be fully understood? How to create interdisciplinary frameworks for an artistic research? And finally: how to create consistent, sophisticated, but also comprehensible interdisciplinary works of art? Those questions have been the true basis for my own artistic research.
2. The sound of motion. Following sonic movement perception

2.1. Perception – around sensory systems

Perception may be defined as an ability to recognise, select, process, organise and interpret information itself or its environment. This incredibly powerful phenomenon is an informational foundation for human cognition systems, and thus for all processes and outcomes of complex neural activity in our brain.

I shall illustrate this phenomenon, in order to explain the way I understand it, especially in the context of perception theory.

Imagine people watching a movie. When something funny is happening in the movie, people – through their visual and auditory systems – receive that as information, they subsequently interpret it and subjectively (depending on e.g. their sense of humor) react in a certain way – usually with smiling or laughing.

Let’s say that in those circumstances the brain of each person can be compared to a very powerful computer. In such a case, their senses can be seen as specific, sensory ‘informational inputs’ and their reaction – e.g. laugher or a smile – a response to the given information, a kind of ‘informational output’.

I perceive human reactions to various events of everyday life, in which they, using their sensory systems, react spontaneously, emotionally and instinctively, in a similar way. Humans might feel better at the sight or smell of food, they might be moved by their favourite song, they might stop in the middle of the street seeing an interesting advertisement hanging on the building.

Nevertheless, even if people’s reaction for such event may be seen as a very similar, the way they perceive it seems to be a very subjective experience, which may be also dependent on e.g. the event’s complexity or its circumstances. However, from my own point

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of view it is difficult to define those elements precisely, for instance to draw the line between a simple and a complex perceptual experience.\(^{20}\)

Scientists have been investigating the nature of our perception and perceptual recognition, how particular elements of all sensational experiences influence each other and are mutually dependent.\(^{21}\) Complex interrelations between ourselves and the world that surrounds us attract researchers from the full spectrum of the cognitive sciences, psychology and neuroscience.\(^{22}\)

However, it is not only through scientific approach that we try to understand or interpret the phenomenon of perception. Art, as well as science does not exist in isolation. I perceive them both as elements of an integral part of the human nature. Moreover, both of these disciplines have been long contributing to the practices of understanding reality.\(^{23}\)

It is therefore not surprising at all, that artists have shown a wide interest in the fields of neuropsychology and cognitive studies.\(^{24}\) Through artistic expression, conceptual language, experiments and observations they are trying to find the most effective way of creating the connections between themselves and the audience.

The aforementioned elements are a crucial part of my own artistic inquiry. It is important for me to understand how my work is perceived both by myself and others. Based on performative practices, analysis of my previous experiences with artistic movement sonification and knowledge within the broad field of cognitive sciences gained by me so far, I am trying to ‘predict’ the most probable interpretation of each element of the piece and all elements as a whole.

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\(^{22}\) M. C. Tacca and A. Cahen, eds., *op. cit.*, p. 5.


2.2. Proprioception, kinaesthesia

A phenomenon of ‘muscle sense’ was proposed by Charles Bell, who distinguished motor from sensory nerves\textsuperscript{25}. In his opinion human motion abilities may be experienced as either conscious (through muscle sense) or subconscious (reflexive control of movement)\textsuperscript{26}. Almost a century later Charles Sherrington created a classification of the all senses, in which proprioceptors, neurons located within muscles, tendons and joints are responsible for informing about mutual mechanical stimuli generated within the musculoskeletal system\textsuperscript{27}.

Proprioception or kinaesthesia (both terms may be used as synonyms\textsuperscript{28}) means one’s own ‘pro-prius’ bodily perception\textsuperscript{29}. That involves awareness of the spatial and mechanical status of the body, its position, movement, balance and tension\textsuperscript{30}.

This awareness of one's own body may be used as an important element of the work of art based on movement sonification. I understand proprioception as an ability to recognise my own body in space. That I am able to move all its parts simultaneously and consciously, with different intensity and in all directions. Moreover, I am under the impression that it is experienced by most of people it in a similar way.

In that case the body becomes a specific, intuitive instrument, which – through any motion tracking devices – is able to control a sound. So I, as the work’s creator, being aware of this unique value, should able to presume how the sonification of one’s own motion may be perceived by that person.


\textsuperscript{27} B.C. Stillman, \textit{op. cit.}, p. 668.

\textsuperscript{28} \textit{Ibid.}, p. 668.


\textsuperscript{30} B.C. Stillman, \textit{op. cit.}, p. 667.
Using physical and auditory domains the creator is therefore able to design a virtual, intuitive, three-dimensional space in which users may have a sense of their limitations or boundaries, all of these represented by points, surfaces or subspaces. Furthermore participants, due to the proprioceptive abilities, are able to recreate even long or complex motor sequences, which help them to explore and learn about the space itself, as well as how to move and interact within it. Additionally, knowing that users can consciously perceive and control the speed of their own movements, the creator is able to give those data specific properties or functions e.g. triggering or stopping the sound.

2.3. Movement sonification

Sonification is the use of non speech audio to every information. More specifically, sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation. By its very nature sonification is interdisciplinary, integrating concepts from human perception, acoustics, design, the arts, and engineering.31

Movement sonification is a process of using musical or sound material to represent data derived from human body motion. Data may be obtained by using various kinds of devices – motion sensors and motion-capture devices, gesture controllers, game controllers, cameras or even mobile phones32,33. Those are able to collect information about the body, for instance the head, arms or legs position, body’s movement, acceleration of the movement, the electrical activity of the muscles, etc.

The practice of converting motor data to audio signals is becoming ever more popular in different research fields nowadays. The relation may grow out of one of the most fundamental features of the sound – its kinetic character. Human beings are able to identify the location and origin of a sound source, as well as the direction of its movement or its trajectory.

Movement sonification practices provide a wide spectrum of information, which is most commonly used to support processes of motor control and motor learning in sports, medical experiments or rehabilitation. It has also been developed towards artistic practices, especially in dance performances, gaming and sound design.

2.4. Auditory-motor and visual-auditory-motor skills. Perceiving sensations

Many forms of art can be called monosensory, which means they only involve one single sense. Most of those are predominantly visual or auditory. There are also more complex audiovisual forms, which engage both senses – sight and hearing.

Interactive artworks containing elements of movement sonification, appear to be a real multisensory challenge, since, besides visual or auditory elements they involve the user’s own physicality, their body perception’s stimulation, or more precisely – proprioception.


Ibid.
That is why interactive forms of art in most cases require visual-motor and auditory-motor coordination from active participants. However, it is proven that external auditory and visual stimuli can help people improve the overall performance of their sensorimotor synchronisation and to enhance perception accuracy for complex movements. \(^{41-42}\) Especially when all signals are well synchronised, people detect and react on the stimuli simultaneously. On the other hand, if the signals are not synchronised with each other, people will interpret them independently, so they will follow only one, primary stimulus \(^{43}\) (one signal) with the highest reliability. \(^{44}\)

Through that example above I would like to emphasise how important it is to understand the relation between all senses engaged in the interactive situation. Depending on which sensory stimuli are going to be used, the creator should bear the dependencies between all sensory elements in mind, to make the interaction as intuitive and as comprehensible as possible for all users.


\(^{44}\) M. T. Elliot et al., op. cit., (accessed 30 December 2021).
3. Movement sonification technology. Inertial Measurement Unit sensors

A variety of approaches have been developed to offer a compact and affordable solution for body-motion data acquisition and processing. That is why large and ever growing number of different devices may be used in researches on the auditory-motor and visual-auditory-motor interactions.

For the purposes of the master’s thesis, I will focus on the wearable, self-contained Inertial Measurement Unit sensors (IMUs), which constitute a huge group of measuring tools and have been widely adopted in movement sonification practices.

The term ‘inertial measurement’ corresponds to a combination of a three-axis accelerometer and a three-axis gyroscope. Those two obligatory sensors embedded in each IMU can measure a variety of factors, which I will describe in more detail later in the text.

IMU sensors tends to be a common choice while working with motion-tracking for various reasons, although the most important one in my opinion is that they are sourceless, meaning they are mainly related to the motion of the body on which sensors are fixed, as well as – if using magnetometer – the value of magnetic intensity, absolute and available almost everywhere. As result the wearer can move freely, with minimal space restrictions. Moreover, IMU devices are also very affordable, have compact dimensions and usually need low processing power.

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48 N. Ahmad et al., op. cit., p. 557.
3.1. IMUs data

Most IMU devices allow users to accurately measure: angular position (also called orientation), described as a relation by which any position with respect to any other position is established, angular velocity (often referred to as rotational velocity), which represents the rate of change of the sensor’s orientation, acceleration – defined as the rate at which sensor changes its velocity over time and the specific force, which consists of both the sensor’s acceleration and the Earth’s gravity. Most of IMUs provide a continuous flow of realtime sensor data.

It is important to remember, that IMU devices are NOT able to precisely measure either the absolute positional tracking, or the distance between sensors.

As mentioned previously, IMUs consist of two, or sometimes three types of sensors – accelerometers, gyroscopes and increasingly, magnetometers.

3.1.1. Accelerometer

An accelerometer is a tool that measures changes in gravitational acceleration (relative to the Earth’s surface), created by e.g. tilt, vibration, movement of a person or an object, on which it is mounted. For motion capture purposes triaxial sensors are used. Those are made of three single axis sensors built into one housing, so they can measure the

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51 M. Kok et al., *op. cit.*, p. 3.


53 M. Kok et al., *op. cit.*, p. 3.


movement’s acceleration in three directions simultaneously over time, i.e. acceleration along $x$ axis, acceleration along $y$ axis and acceleration along $z$ axis.

It is essential to understand that accelerometers cannot distinguish rotation from acceleration, so they might be used to determine orientation angels in some cases.

For movement sonification purposes it is recommended to use accelerometers in combination with magnetometers, to obtain the most accurate measurement results (that relation will be discussed in the further part of the thesis).

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**Figure 1: The graphical representation of three dimensional linear acceleration detection by the accelerometer**

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58 M. Kok et al., *op. cit.*, p. 7.
3.1.2. Gyroscope

Gyroscope (also called gyro) is a tool consisting of a spinning wheel mounted on two gimbals\textsuperscript{59}, used for measuring angular velocity. Similarly to an accelerometer, the gyroscope is a triaxial sensor, meaning that it reads the rate of rotation round three axis, with respect to an internal space\textsuperscript{60}, and thus the rotational speed of a person or an object, on which sensor is fixed, in three dimensions simultaneously. Those changes in orientation are described as \textit{roll}, \textit{pitch} and \textit{yaw}, around \textit{x} axis, \textit{y} axis and \textit{z} axis respectively\textsuperscript{61}. of Angular velocity is measured either in degrees per second (°/s) or revolutions per second (RPS).

\textit{Figure 2: The graphical representation of roll, pitch and yaw (three dimensional angular velocity) detection by the gyroscope}

\textsuperscript{59} O. J. Woodman, \textit{An introduction to internal navigation}, no. 696, University of Cambridge, August 2007, p. 8.


\textsuperscript{61} M. Pedley, \textit{op. cit.}, p. 4.
3.1.3. Magnetometer

A magnetometer is a triaxial tool allowing users to measure the local magnetic induction\textsuperscript{62} – magnetic field strength and direction of both Earth’s magnetic field and the one created by the presence of magnetic materials in the surrounding\textsuperscript{63}. The strength of magnetic field is measured in tesla (T). IMU sensors which consist of magnetometers are recommended for dynamic orientation calculations because of less drift errors that occur\textsuperscript{64}.

3.2. Minimising errors – IMUs configuration

Gyroscopes are mechanical tools, which consist of moving parts which cause friction, and thus increase the instantaneous measurement miscalculations\textsuperscript{65}. Accelerometers create time-related errors such as bias offset drift\textsuperscript{66} or velocity random walk\textsuperscript{67}. Magnetometers, on the other hand, are not accurate enough to replace either gyroscopes or accelerometers because of recurring errors related with e.g. Earth’s magnetic field deviations\textsuperscript{68}.

Each device as an individual entity causes many different measurement errors. That is why devices, which contain the combination of magnetometers, gyroscopes and accelerometers seems for me to be the most common choice in artistic practices. Thanks to the metod of mutual improvement of the information provided by all elements simultaneously it is possible to minimise the errors.

\textsuperscript{63} M. Kok et al., \textit{op. cit.}, p. 24.
\textsuperscript{64} N. Ahmad et al., \textit{op. cit.}, p. 257.
\textsuperscript{65} O. J. Woodman, \textit{op. cit.}, p. 8.
3.3. IMU technology within the perceptual context – the technological-sensory structure of the movement sonification

Having discussed the perceptual processes related to movement sonification, as well as basic IMU technology, I would like to consider the connections between those two areas, to find the most accurate structure of information pathways. I believe that it might help readers to better understand all interdisciplinary relations between different scientific and artistic elements related with movement sonification in my works of art.

For that discussion I will use and expand a diagram created by Thomas Mitchell, Sebastian Madgewick and Imogen Heap, who have been researching mechanisms of musical, performative interactions related with hand gestures technology.

3.3.1. Basic sensory structure of the movement sonification

In *Musical Interaction with Hand Posture and Orientation: A Toolbox of Gestural Control Mechanisms* Mitchell, Madgwick and Heap present a detailed description of practical possibilities of hand tracking gloves, designed for performative purposes. To describe the informational pathway between the gesture and sound they create a diagram called *gestural musical instrument structure*, which, in my understanding, corresponds to the gestural sonification created by the user of that specific instrument.

![Figure 3: Gestural musical instrument structure](image)

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It is worth pointing out, that authors define the input information as a *gestural input*. In that case it might not only correspond to the gestural information associated with hand movements, but rather the movement of the whole body. The term *musical gesture* is commonly used to describe ‘an action pattern that produces music, is encoded in music or is made in response to music’\(^{70}\). The phrase appears in a considerable amount of modern music research.

For the purpose of my studies I would like to expand the diagram above, as in my opinion it may be used to represent even broader group of devices – not only those which can read hand gestures, but the whole range of motion tracking technology. To clarify that, I am going to replace ‘gestural musical instrument structure’ by ‘motion sonification structure’ from now on.

Moreover, in those interactive works, which contain wearable motion sensors the audio output has a great impact on the user. That person, besides listening is also controlling a large part of data in real time, so it is reasonable to say that their action is influenced by the audio itself. In that case, the way the user is perceiving the sound influences the whole informational chain. This process is known as *biofeedback*.

I have no doubt that Mitchell, Madgwick and Heap are aware of the phenomenon described above. However, I would like to highlight the importance of biofeedback in regard to the motion sonification processes in my own artistic practices. For that reason I am going to add another link in the structure representing the impact of audio on the user. The audio signal is processed by the user’s auditory system – described here as ‘human auditory system’, which by definition processes, how we hear and understand sound within the environment\(^{71}\):

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Figure 4: Motion sonification structure

Now the diagram not only presents the informational chain in the motion sonification process, but also highlights the importance of user’s perception – how someone’s interpretation of sound may impact the way the person moves and therewith the whole shape of the interactive work.
4. How to use movement sonification in artistic works efficiently and practically

All the issues discussed so far form a significant body of theory related with movement sonification, backed by scientific research. The fourth and fifth chapters are devoted mainly to my own thoughts and reflections based on practice. It includes the summary of experiences, problems I have been struggling with and decisions I had to make at different stages of my work and which contributed to some extent to correct conclusions, improvements and better results.

The majority of contemporary works based on movement sonification practices are vast – they contain elements of interdisciplinarity, interactivity and multimediality, require knowledge in many different areas, e.g. music, performative arts, physics or computer science. That is why it is so important to decide on certain elements at early stages of the project, which may simplify the whole process of creation. One such element is the type interaction.

Definition of ‘interaction’ has not been clarified yet and especially in the wide area of art, many different interpretations of the term may be found. I understand the phenomenon as: an engaging participation, in which particular input information provided by the user causes a specific response and that response may neither be completely random, nor fully predictable.72

Many contemporary forms of art, which are called ‘interactive’ are designed to require an active engagement of the audience. But what about the works, which contain interactive elements, yet they are created only to be observed by spectators? The phenomenon experienced by them is one of the types of interaction, especially interesting to me in the context of human-computer interaction (HCI), which I call ‘indirect interaction’ and which I will discuss more thoroughly later in this chapter.

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Interaction methods based on motion tracking, gesture or whole body recognition, used for artistic purposes, can take many different forms\(^73\). Depending on what scope the interaction has, i.e. how many individuals may be engaged in the interactive situation, who has an active impact on the shape of the piece and if anyone is experiencing indirect interaction, specific relations are formed between participants. I would like to present two kinds of interactive works, defined by those relations. I called them ‘hypo-interactive’ and ‘hyper-interactive’.

A good understanding of all relations between creators, performers and spectators within the interactive work can not only significantly help in finding appropriate technological solutions. It may be also very useful in shaping the overall form of the composition (e.g. if and how many interactive elements it will contain) or help to determine if the work will have a linear structure (one-dimensional, e.g. composition fixed in time) or infinite structure (multidimensional, e.g. sound installation).

### 4.1. Indirect interaction

Even if the spectators are only passively observing what is happening on the stage, we cannot state that they are not experiencing the interactive situation at all. The interaction is not caused by them, but it is still consciously perceived, they understand that someone’s motion somehow affects the sound. Nevertheless, one cannot say either that this type of interaction takes its fullest form, as it is perceived through someone else’s body. For the purpose of this study I would like to call that phenomenon ‘indirect interaction’.

Indirect interaction is a phenomenon in which an individual experience an interactive situation by observing another person, where the observed person is interacting directly. The interaction in those kinds of works is usually either controlled by engaged performers\(^74\).

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or by the creators themselves\textsuperscript{75,76,77}.

A participator of indirect interaction experiences the artwork (within which the interaction is created) differently than an active participator. However, it is also a different experience than participating the work of art, which does not contain interactive elements at all.

‘Indirectly’ interactive elements may intensify the whole experience of any work of art. Thus I consider indirect interaction as an extremely interesting phenomenon and an important factor of communication created between a performer and spectator.

4.2. Hypo-interactive and hyper-interactive works

If the work engages one’s indirectly, yet it contains interactive elements, it is ‘hypo-interactive’. In the hypo-interactive work interaction is executed by a specific person or group of people, but it is not designed to be created by anyone from the work’s environment. Usually it takes the form of a performative situation, like dance or drama. Presence of the spectators in that situation is still necessary.

\begin{figure}[h!]
\centering
\includegraphics[width=\textwidth]{hypo_interactive_diagram.png}
\caption{Two examples of the hypo-interactive works. Each of them includes indirect interactions}
\end{figure}


\textsuperscript{76} Ralf Schmid, Pyanook [website], https://www.pyanook.com/ (accessed 10 January 2022).

If all recipients of the work may be directly engaged in the interaction, i.e. by using controlling devices they are influencing one or more parameters of the artwork, they are experiencing a direct interaction. Regardless of whether the work is designed to involve one or more individuals simultaneously, it may be joined by anyone from its environment. In that situation the work is ‘hyper-interactive’. It contains only elements of a direct interaction. Usually it takes a form of an installation, interactive film or interactive architecture.

Figure 6: Two examples of the hyper-interactive works. Each of them includes only direct interactions
4.3. Multidimensional sensory perspective – poetic principles of movement sonification

Mette Ingvartsen is a Danish dancer and choreographer who, through combination of dance or movement with other domains, such as visual art, technology or language explores the relations between human and non-human agency. In one of her book called *The Artificial Nature Series* an interesting approach of reflection is presented. She describes specific rules and mechanisms related with e.g. time, environment and perception in performative forms, expressing affections and philosophical meaning. She calls those ‘poetic principles of performance’.

The idea of artificial nature or non-human moment as a part of theatre performance is not related with movement sonification at all. However, the thing I find very useful here is her way of explaining those concepts. I do believe that defining the principles in a more ‘poetic’ manner, especially in the artistic research, which very often relate to emotional expression, intuition or perception, is much more relevant than purely scientific language.

Following Ingvartsen’s concept of poetic principles, I am now going to present my own practices with sound-based performative forms, seen through different perspectives – as a creator, performer and spectator.

4.3.1. Embodied interaction

When performers move their body to the sound, the movement is interpreted as a dependent on their interpretation of it. However, when movement sonification elements are present, it works the opposite way. The sound becomes a dependent element, dependent on the body movement, reacts on each slightest change of the body's position.

The concept of interaction embodied in music traces its roots throughout the work of many other artists including Atau Tanaka and Marco Donnarumma, who discuss the instrumentality of body schemata with regard to digital technologies incorporation in *The Artificial Nature Series*.  

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Body as Musical Instrument\textsuperscript{79}. Regarding that, I will describe my first and most important poetic principle, which applies to both direct and indirect interaction:

The sound, whether created or controlled by the movement, is naturally perceived as a specific ‘motion extension’. The spectator no longer recognise the sound as an individual entity. It is inextricably linked to and perceived through the gesture. Consequently, the body is treated as a musical instrument, which the user needs to understand and learn in order to control the sound freely and intuitively.

\textbf{4.3.2. Multidimensional movement. Fragmentary space recognition}

When sensors are programmed in such a way that they can affect the position of sound, and especially when the sound is designed to be performed on a multichannel system, the user perceives the movement of two elements as one – the movement of their body and the movement of the sound itself, which follows their motion. The phenomenon applies to both types of interaction – direct and indirect.

This poetic principle makes the space tangible. One can imagine that every change of their limb position takes you to another sonic space or to the liminal space between different spaces. The sound from the other hand becomes a specific language, which helps to translate and understand those areas.

\textbf{4.3.3. Performer as a creator}

If the composition requires the involvement of performers, i.e. contains elements of indirect interactivity, collaborative work is extremely important, and this applies both to choreography and music. It is crucial for a creator to understand the way of expression of each performer individually, in order for freedom of their movement to be maintained. Each of performer has their own range of movement in their joints, as well as different length and

\textsuperscript{79}A. Tanaka and M. Donnarumma, \textit{op. cit.}, p. 79.
weight of their limbs. Thus the most optimal and most effective movement patterns will differ between them. Moreover, the use of sensors may cause certain movement limitations and consequently block the performer, so that they are not able to achieve the fullest motion spectrum, nor the best sound results.

The most effective way of working with performers and my third poetic principle is to always create the sonic experience together, through practice, trying out each gestural sequence separately, defining which sound may or may not work in this particular moment, or vice versa – through specific sound trying to find the most accurate gestural sequences.

Before that process starts, it is crucial for the composer to know human computer interaction (HCI) techniques and sonification methods, to be able to propose different solutions, in order to create the best relation between sound and movement. From the other hand, it is extremely important for the performer to understand how this technology works and to have enough time to learn how not to be restrained by it. The worst possible result is to give up on artistic expression in order to implement technological solutions. Therefore in the final stage of the process sound parameters should always be adjusted to performer’s individual way of moving.

4.3.4. Performer: The feedback loop reaction

The feedback loop reaction is an incredibly interesting phenomenon I realised about while working on performative compositions, where choreography was fully improvised. When the participator of the artistic situation creates the sound with the use of motion sensors, they instinctively follow the sound they have just created, trying to move their body in accordance to the sound. The rule applies especially to professional performers, who usually work with non-interactive forms of art.

That chain of actions creates a specific ‘feedback loop’, where the movement is ‘fed’ by the sound, ‘fed’ by the movement, etc. It creates a very powerful feeling of intimate

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connection between the participator and the music, as they are becoming one being. This impression may significantly intensify the whole experience and enhance the performer’s expression.

4.3.5. Space: value flow

Another defining principle of the space recognition is significantly useful during the process of data calculations. It is important to think about space as ranges or value flows, rather than a collection of points.

An individual cannot put their hand in the exactly same position several times in a row. Having regard also to the technical specification of motion sensors, explained in the third chapter of the thesis, it is obviously impossible to obtain perfectly accurate data results. Accordingly, an error margin should be applied to each data calculation. That is why my main focus is on ranges of numbers, not numbers themselves.

4.3.6. Strike a balance

In the process of creating any interactive form of art, the level of interaction complexity must be considered. The relation between movement and sound can take many different forms. Therefore my sixth poetic principle is: find a balance between all interactive elements, use both obvious and complex musical gestures, as the level of interaction difficulty should change in time.

An interesting description of movement strategies is proposed by Sofia Dahl et al., who classify musical gestures in accordance to their function\textsuperscript{81}. Moreover, they point out important roles of gestures in stage performances and that those gestures are related to performer’s personality.

\textsuperscript{81} S. Dahl et al., op. cit.
A practical example of this poetic principle might be find in one of my compositions called *Micro Error Code*. At the beginning the relation between sound and movement is very simple – a quick downward move of my hand triggers the sound. I repeat the gesture three times, so that all spectators have time to understand how it works. Thereafter, I start to control the overall sound by changing its location, volume and timbral character. Again, spectators get a very clear information about the indirect interaction and how the sound is controlled by my hand.

After a while an additional layer emerges, played independently from my motion, so both controlled and not controlled layers are playing together. The aim is to make the overall form more diverse, but also allows me to ‘play’ with spectators perception, so at some point they are not entirely sure if the sound is controlled by me or not. In the case of this composition I am able to keep their attention, so they are constantly focused, trying to understand all relations between the sound and the movement.

### 4.3.7. Emotional intensification

Every interactive situation I have created so far engages three sensory elements. Movement, sound and image as a one experience carry a very intense, powerful sensory message, which may – even subconsciously – intensify experienced emotions.

McCarty and Wright remark in the article *Technology as Experience* there are four elementary components of technological experience: 1) compositional component, 2) emotional component, 3) spatio-temporal component and 4) sensual component. They point out, that the sensorial quality orients us to the concrete, palpable character of experience. On the other hand, through the emotional quality we tend to summarise and remember the experience.

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82 John McCarthy and Peter Wright, 'Technology as experience.', *interactions*, vol. 11, no. 4, 2004, p. 42.
That is why it is the most powerful principle above all of the previously explained, especially in regard to the direct interaction. If interaction is well designed, all sensory stimuli work in a comprehensible way. The message sent to the user’s perceptual system is a very strong and complex information, so the whole experience becomes immensely engaging, both perceptually and emotionally.
5. Hypercycle – Interactive sound installation

5.1. Background

The work *Hypercycle* is my exam piece for the master degree in electroacoustic music composition. It is also a great summary of my practical experiences with movement sonification from the last six years.

I have started practicing movement-based activities at the beginning of 2017, through the collaboration with dancers Anna Kamińska and Patryk Durski, along with the composer Przemysław Degórski. At that time we were much more focused on modern dance forms, with a refined choreography rather than just being highly performative or using improvised motion. The sound, on the other hand, was a very performative, experimental factor, generated in real time through Myo gesture control armbands and Max MSP software, coming directly from the movement. And even if it did not always sound great, movement sonification was our major goal. So during that process we often shifted our attention away from aesthetic perfection towards highly sophisticated technology, which was not yet fully understood by us at that time.

However, as soon as the technology had been better understood, we realised that this form of sound was no longer satisfying. Therefore, we started to move away from a real-time generated sound towards our own previously prepared recordings.

The relation between motion and sound was also more developed. Through the movement dancers were quite easily able to turn on and off the sound, change its volume or its intensity. One of the compositions, in which we did use all previously mentioned elements is *What’s that noise I hear when I shut my eyes really tightly?*, created in 2017 during artistic residency at the Krakow Choreography Center and premiered during the BaletOFF Festival 2017.

Being overwhelmed by the power of motion sonification expression, as much as my progress of understanding the technology in 2018 I decided the prepare a multimedia

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spectacle as a part of my BA project. SYNESTE7JA.1 (eng. SYNESTHESIA) is an audiovisual performance for two dancers, small orchestra and electronics, created in cooperation with Anna Kamińska, Patryk Durski, visual artist Paulina Wyrt, Agata Dankowska responsible for the project of architectural scenery, Przemysław Degórski (this time as a conductor) and Symphony Orchestra of the Music Academy in Poznań.

Figure 7: SYNESTE7JA.1 (eng. SYNESTHESIA) multimedia performance. Premiere in The Castle Cultural Centre in Poznań, 26 April 2018.

‘SYNESTHEZIA.1 is an interactive performance, a real-time composition based on movement sonification practices. Performers treat their body as a specific instrument, exploring relationships between motion, sound and vision, how these three significant fields of expression interact with each other, how their relation affects on the spectators perception.

To create the feeling that performers – together with the sound – become one being, Myo gesture control armbands are used. Devices allow users to capture all changes of arms’ speed, rotation and tension of the muscles. The information is transmitted in
real time to Max MSP software that converts data into sound values. All of the parameters are mapped and used during the process of creating the octophonic, performative composition on stage. Another sound layer is created by the ensemble, which signal, picked by microphones and encoded in Ambisonic format, is constantly moving in the octophonic sound system.

Another key element of the performance are visualisations, presented on four walls which surround the stage. They are reflecting both movement and sound changes. The image and sound are mapped in a way to ‘close’ performers in the audiovisual cage.”

While working on SYENESTHE7JA.1, I began a deep exploration of interactivity, its meaning and theoretical background, as well as discovering inspiring artists like Imogen Heap, Atau Tanaka, Letitia Sonami and the collective fuse*, who have been developing gesture and motion technologies in music. Moreover, during that process I realised about interesting aspects related with interaction in some of the previously mentioned works. I understood, that there are some works, which contain interactive elements, yet spectators were not directly involved in the interaction. However, those elements seemed to be an incredibly important perceptual factor. That was a time when the very first, vague idea of indirect interactivity was born.

During that time I have also started my own performative practices, also using various multi-channel systems, including 3D dome systems. Examples include Quaternion Multiplication (2017), where motion was captured by R-ioT sensors or Micro Error Code (2019), in which I was using NGIMUs. In the latter work the relation between motion and sound reach the most advanced and richest form I have created so far as a solo performer. Highly multi-layered sound include both real-time generated signal, as well as previously recorded material. System allows me to turn the sound on and off, change its volume, pitch, intensity, density or texture of it.

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I would like to emphasise that I have seen those compositions as etudes, as they helped me to better understand how to use the body movement in practise, both on and outside the stage, as well as how to create its best sound transcription. However, seeing the lack of performative abilities of freely moving the body in front of many eyes, I have realised that my performance is more a presentation of technological skills rather than work of art, which is as substantive as conceptually and aesthetically attractive. That is why after some time I completely stopped practicing movement sonification on stage.

After finishing *Micro Error Code* composition, I decided to finally try to create a fully interactive work, in which each recipient would be able to significantly impact the shape of the work. I also wanted to involve more than one person to create a situation where participants are able to create interactive situations with each other.
5.2. Sonic material preparations. Tuning systems. Looping forms

From the very beginning I wanted to use recordings of acoustic instruments, which in my opinion beautifully represent movement itself. As a cellist, acoustic sound always reminds me a specific physicality, the physical pressing of a finger or a bow against a string. On the other hand, I perceive limb movement through a phenomenon of the air resistance, being in opposition to the air while passing it through, which even though cannot be seen, we can both feel and hear it. Moreover, being inspired by amazing artists, especially woodwind players such as Ben Bertrand, Colin Stetson or Bednik Giske, I decided to make recordings of the instruments, which are closely associated with the ideas described above. I have recorded string and wind instruments, more specifically: violin, viola, cello and alto saxophone.

During the recording process, the instruments were recorded separately. The recordings were divided into two stages - the first one took place in January 2020 at The Castle Culture Centre in Poznań. During two days I was working closely with violinist Kosma Mülller, violist Kamil Babka and cellist Anna Szmotała. Recordings of the alto saxophone took place in October 2021 at the Royal College of Music in Stockholm. The material was recorded by saxophonist Marcus Warnheim.

We focused on creating a kind of base containing sounds repeated at many different volume levels, played with different articulation and timbre. I decided to use a specific scale: c-ci-e-ei-(f)-g-(gi)-a-ai-h. In the scores I have also highlighted very slow microtones glissandos performed between the individual notes within the scale.

Cello-raw-example_E-05.wav
Sax-raw-example_d5-gliss-01.wav

The next step was to clean the material and divide it into smaller pieces, which I was planning to use as a base for the melodic-harmonic structure.

85 doi.org/10.5281/zenodo.6303660
86 doi.org/10.5281/zenodo.6303662
A sound installation is a non-linear form – time changes depend on the input information generated by the user, it should not simply end at some point, but either continue indefinitely or, as in the case of Hypercycle, have a looping structure.

The previously prepared sound material is divided into three layers - the first one contains recordings of the saxophone (controlled by the first user), second one recordings of strings (controlled by the second user) and the last one is the background layer, the subtle sound on which user has no influence and which was necessary to keep the overall form more advanced, but also consistent and comprehensible for the user.

Those layers are also divided into smaller parts, each consists of sixteen different chords. Each chord is in fact a looping wavefile. According to the master clock localised in the Max MSP patch, groups of sounds or chords are triggered (synchronised to the background layer), so the user is able to play different tones in time, depending on where his hand is placed. This specific form, containing almost 60 files allows users to create and control melodies freely in space and time, without noticeable changes or sound glitches.

Figure 9: Fragment of Hypercycle Max MSP sub-patch containing the sample section.
5.3. Technological solutions

For the purpose of installation I use four NGIMU sensors – The Next Generation IMU created by UK based company x-io Technologies Limited. Devices communicate using OSC protocol, which allows the real-time data compatibility with a host computer via Wi-Fi, using a dedicated wireless router. The information about the movement is read, translated, converted and used for sound control in Max MSP.

The work was spatially presented over 29 channels. To control the multichannel sound played on the Klangkupolen in KMH's Lilla Salen system, Ambisonics Externals\textsuperscript{87} for Max MSP were used.

5.4. Interaction, control, conceptual meanings

The name \textit{Hypercycle} comes from the combination of two words – ‘hyper-interaction’ and ‘cycle’. It is my first composition which does not contain indirect interaction elements, so it is hyper-interactive. The interaction requires from the participants to constantly perform rotational movements. Most of them unconsciously start to spin around their own axis, following their own gestures.

On the one hand, I wanted to give each participant the fullest possible control over the sound, on the other hand, I did not want to get people overwhelmed with the amount of data. According to the definition of interaction, in the context of human computer interaction (HCI) and in order to aim for the most ideal interactive situation, the recipient should be in a situation where ‘particular input information provided by the user causes a specific response and that response may neither be completely random, nor fully predictable’. Therefore, I decided to allow the user to have control over the following parameters: 1) pitch, 2) chord type, 3) volume of the unprocessed sound of instruments, 4) volume of the processed sound.

\textsuperscript{87} Tools for surround sound processing, released by ZHdK’s Institute for Computer Music and Sound Technology.
of instruments (passing through spectral-processing and reverb VST plugins) and 5) position of the sound in space.

As mentioned previously, the installation is designed for two participants, meaning a maximum of two people can actively join the installation at the same time. One of them controls saxophone layers, which contain both raw and processed recordings of the alto saxophone. The other participant controls layers of string instruments, again processed and unprocessed.

Each user has two sensors - one in the left and one in the right hand. Each of them controls the parameters using rotational movements around the X, Y and Z axes. Detailed instruction presented below, both as a graphic and as videos.

Figure 10: Hypercycle – instruction describing possibilities of impacting the sound using arm gestures
5.5. Exhibition

The presentation of the installation took place on Thursday, December 9th 2021 in Lilla Salen at Royal College of Music in Stockholm. About 30-40 people took part in the installation within two hours. Considering the heightened Covid-19 restrictions on gatherings during that time I find it a most satisfactory result.

Before taking a part in the interactive experience, I each participant was informed what both sensors do and how to use them. Additionally, instructions were presented on the board, placed on the stand within their sight.

Figure 11: Hypercycle – exhibition

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88 doi.org/10.5281/zenodo.6554842
89 doi.org/10.5281/zenodo.6554845
From my observations and after conversations with some users, I would like to suggest the following process of experiencing the installation: Most users spent the first few minutes processing the instructions. Following the instructions present on the board, standing in one place, they were doing particular movements, firmly focused on one hand, then the other one. After a while, their movement was gradually becoming more and more free and natural, within the wider scope, engaging both hands simultaneously. Finally, they were intuitively moving within the sonic space, most of them involving the whole body. Eventually some of them were also starting to pay attention to the other person’s behaviour, in some cases they were trying to interact with each other.

Hypercycle–exhibition.mov

5.6. Impressions

After participating in Hypercycle, many shared their feelings and thoughts regarding the whole experience. Everyone agreed that the installation was very engaging, although it was difficult for some participants to process all information at the beginning. However, after some time each of them was able to more or less intuitively, yet very consciously control their movements in order to achieve specific sonic results. Some people found it interesting to be able to interact with another person or to discover each other ‘sound spaces’, communicate without words, but through mutual observation.

Some users shared their ideas on how the system could be used in the future. One of them had an idea of arranging the sound environment in various architectural spaces in order to achieve an additional site-specific value.

Another person had an interesting suggestion of using the technology with children, who, despite their lower ability of large information processing, could be able to use sensors much more boldly and intuitively. That could very possibly be a creative way of developing

90 doi.org/10.5281/zenodo.6303655
not only their sound and movement abilities, but also familiarise them with contemporary music through play and participation.

Figure 12: Hypercycle – exhibition

6. Conclusions

In this thesis I have presented my most important experiences related with the process of creating movement sonification experiences. Based on many compositions of mine, especially the interactive installation called *Hypercycle* that I described in detail, I presented my artistic approach, particularly related to perceptual, conceptual and technological aspects.

One of the most significant inputs of the work is, in my opinion, the deliberation on the phenomenon of indirect interactivity, as well as hypo- and hyper-interaction. A good understanding of all relations between creators, performers and spectators within the interactive work is significant to me especially in the context of finding appropriate technological solutions, as well as in creating the form and structure of the composition.
My future plans are associated with exploring the importance of three dimensional space in regard to motion sensor technology. I would like to take a closer look at multichannel sound, especially 3D dome systems, in order to have a better understanding and control over the sound and movement relation.

I am also considering conducting the study of using movement sonification with children. As mentioned in the fifth chapter, I do believe it could be a creative way of developing not only their sound and movement abilities, but also familiarise them with contemporary music through play and participation.
Reference List


Sound Music Movement Interaction – ISMM, Sound Music Movement Interaction [website], http://ismm.ircam.fr/

