Artistic approach to the WFS system

Ji Youn Kang

1. Introduction

During the last few decades, a number of different multichannel speaker systems and spatialization technologies have been introduced. Not only have different configurations of loudspeakers in concert situations evolved, but also headphone listening situations. Wherever we go, a nice pair of headphones with 3D technologies can allow us to listen to various spatial music. These ever-evolving technologies allow composers to approach the use of space, acoustics, and spatial concepts in their compositions in various ways. They also need to aim for the right listening situations, whether the music is heard at a concert or via headphones (Otondo, 2007). The distinction between multichannel systems for live sound diffusion following the Bayle's Acousmonium tradition and for sound spatialization following Chowning's studio panning tradition has blurred too. The overwhelming technologies ask for in-depth research, consideration, and experiences in dealing with spatialization in music because each different speaker configuration comes with unique attributes, which can vary depending on the panning technique chosen. It is certainly important for composers to find a way to integrate their compositional ideas into the technologies and the listening situations and 'the music has to be adapted to suit the particular performance situation' (Austin & Smalley, 2000).

A primary consideration for composers when approaching a multichannel system is to consider the individual channels as instruments within the context of the greater meta-instrument configuration (Fielder, 2016). Similar to composing for instruments such as violin and flute, composing with a multichannel system requires a close examination of what the system has to offer musically. This includes not only the spatialization possibilities, such as moving trajectories and the possible number of static sources at different distances, but also its timbral characteristics. However, it is crucial to consider that as the timbral quality does not depend solely on the hardware, but also on the choice of spatial audio technologies and the room acoustics.

Despite the availability of various technologies for spatializing sound, there are general problems in acousmatic listening, in which we immerse ourselves in the expe-

Musica/Tecnologia, 17 (2023), ISSN online 1974-0050, ISSN print 1974-0042, pp. 27-45
DOI: 10.36253/music_tec-15195 – http://www.fupress.com/mt

rience of the sound and listen differently (Beard, 2019). A well-known problem with conventional multichannel systems is the broken spatiality outside of the sweet spot. Typically, compositions are mastered in a studio, and it is rare for composers to spend most of their time at a concert venue or to have access to the same number of speakers. Composers carefully calibrate the spatial movements of sounds, their positions and harmonies, and their changes in time when composing their music pieces. However, at the concert, the audience is generally situated all over the place, among whom only a very small area has the desired spatial image.

Another concern is that the sonic space and the listening space are often divided in many acousmatic listening situations. Speakers are frequently placed in one part of the concert space, and the performers in another part, resulting in a detachment of sound sources (Otondo, 2007). This does not prevent us from appreciating the music, but it can be seen as a hierarchy in which the audience remains as observers. In most cases, the audience is seated and cannot move to another side of the listening location. Similarly, being surrounded by a number of loudspeakers gives a center-oriented experience that is not representative of the physical world. Hearing sound without seeing its causes happens every day (Kim, 2011), and those sounds do not circulate around us being centered. Unlike a sound installation where the audience is allowed to walk around the sounding space, the audience in an acousmatic listening situation is physically passive while being asked to actively listen. The reason why I see this as a concern is not about the limitations of physical variability of the audience, but about the inability to fully immerse oneself in the space where events are happening.

The first listening experience of the Wave Field Synthesis (WFS) system in 2006 made me think about these limitations because it changed the way I listen to acousmatic music. This was not because of the accuracy of moving sound sources, nor the number of loudspeakers overwhelmingly surrounding us, but of the immersion, the sense of sounds – not only through our ears but also on our skin by the air pressure moving throughout our body. We are literally situated together with the sounds. With the WFS system, it was truly possible to make sounds right in front of me, passing by my head.

Since then, I have worked intensely with the system for about eight years until 2013, and since 2018, I have been teaching spatialization with the WFS system to students at the Institute of Sonology, The Royal Conservatoire in The Hague. In this paper, I would like to first introduce the WFS system and then share a few important aspects that I have discovered and learned.

2. Wave Field Synthesis (WFS) System

Wave Field Synthesis is a spatial sound-field reproduction based on the Huigens principle (Berkhout, 1988). Unlike common spatial audio techniques such as Stereophonic panning, Vector Based Amplitude panning (VBAP) and Ambisonics where an impression of sound moving from one side to the other is achieved as a psychoacoustic phantom image and requires for the audience to sit at a sweet spot in order to perceive

Figure 1. Game of Life WFS System.

the trajectory, WFS enables sounds to be physically reconstructed within loudspeaker arrays as a wave field. It offers a larger sweet zone for the audience to observe the spatial images relative from where they are seated. WFS offers improved localization and movement perception compared to other spatial audio techniques, but it does not fully replicate the way we perceive sound in reality. A sound of an object arrives to our ears after going through a number of obstacles in the surrounding environment. The direction of the sound is heard together throughout our auditory system and we recognize and judge the localisation of the sound. The WFS offers an omni-directional sound, allowing the audience to locate sound sources from kilometers away or right in front of them. However, the system is located in a hall with its own acoustics, leading to some mismatches with how we perceive sound in our everyday lives. Nevertheless, the system offers various possible ways to spatialize sound sources.

The *Game of Life*[1] WFS system (Figure 1) in The Hague, The Netherlands is a mobile system with 192 loudspeakers and is operated using an open-source software *WFSCollider*[2] (Figure 2).

The WFSCollider is capable of spatializing sounds individually using UChain, and each UChain is located in a UScore with a timeline view. It resembles DAW software,

[1] *The Game of Life* foundation https://gameoflife.nl/en

[2] *WFSCollider* https://sourceforge.net/projects/wfscollider/

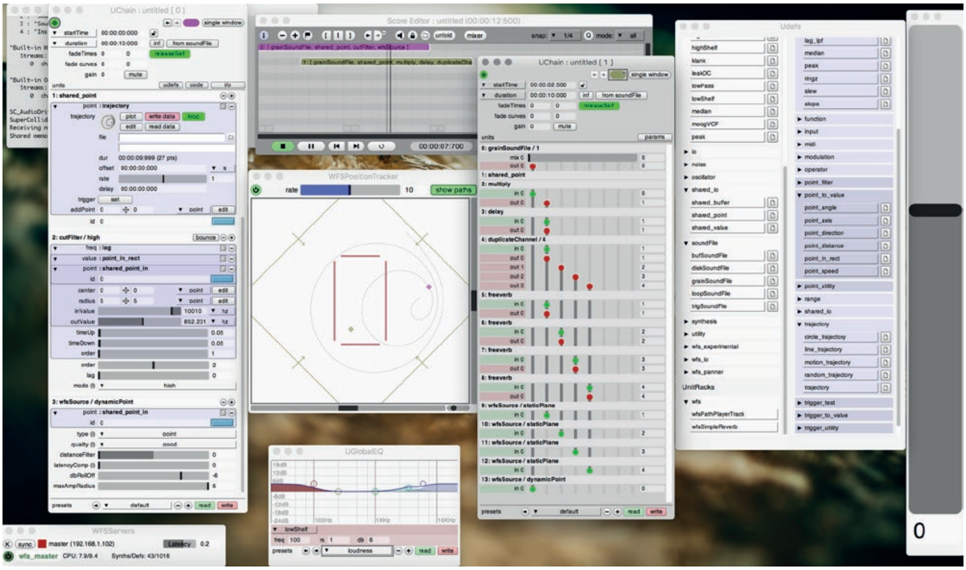

Figure 2. *WFSCollider* (https://sourceforge.net/projects/wfscollider/).

where one can arrange sounds in a timeline and edit them. However, the UChain is unique as it offers time information (e.g., starting and ending time, duration, etc.), a type of sound source (e.g., oscillator, synthesis, or sound file), and a type of spatialization, such as point source (Figure 3), plane wave (Figure 4), and static/moving sources of point source and plane waves, as well as an index source, which skips the WFS calculation and allows a sound to be located at a single loudspeaker. The trajectory interface shows the configuration of the speaker arrays as a square, which is also reconfigurable depending on the system setup and the number of loudspeakers. The user can intuitively move the location of the sound or draw a trajectory using a mouse. It also comes with a number of additional functions, such as creating a pattern or using a function written in SuperCollider, the programming language the WFSCollider is built on. The integration of additional functionalities is limitless. However, an advantage of using the WFSCollider is not limited to its extendibility but rather its accessibility without requiring programming skills. Anyone who has sound materials and spatial ideas can easily learn the software and compose spatial music. The resulting sounds are specific to the design of the software, and accordingly, there cannot be a generalization to what every WFS system technically offers.

The WFS system comes with limitations too; due to the closely located small loudspeakers, spatial-aliasing happens above certain frequencies. (Baalman, 2010) Also when the sounds are moving inside the speaker arrays, the constructions of the wave fields are reversed (Figure 5). This is clearly an interesting artifact. When I was using the system for the first time, I was advised not to make too many sounds inside the speaker arrays because the localization of the sound inside is not as accurate as sounds being outside of the speaker arrays. However, it is not unclear as to perceive them being out of the trajectory when we are listening; one can clearly feel the sound

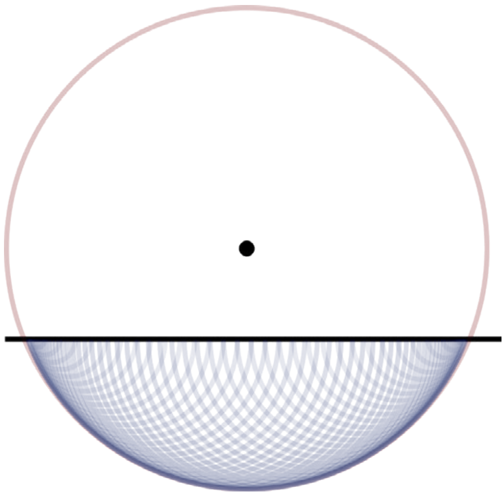

Figure 3. A point source outside of the speaker array.

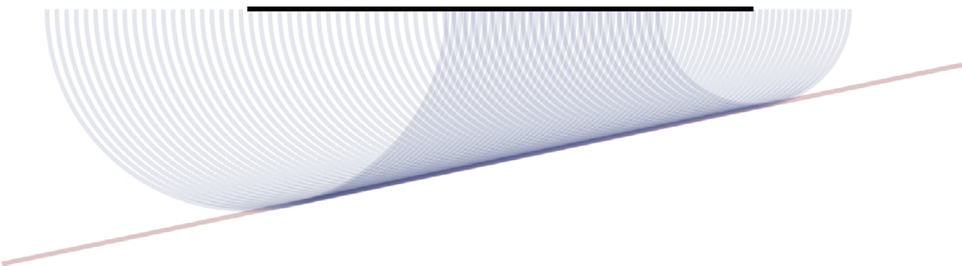

Figure 4. A plane wave source.

moving around, and it even adds physical sensations of the sound pressure as mentioned earlier. More about this character will be discussed in the next subchapter. Another disadvantage is that the system is not easily accessible, and is expensive to build. The opportunities to compose a piece for the system is therefore limited, and to work with the system on location can also be limited. However, the number of the system is growing. Also, if one finds a chance to compose for the system, it is also not necessary to compose always 'with' the system. On the other hand, I encourage my students to spend more time working without the system but with the WFSCollider stereo simulation. When one works with the system, their creativity could be bound to which they just have listened and it is difficult to go beyond what is heard, while working with imagination can open up more possibilities and be extremely powerful. It is also questionable whether or not the piece will be replayed in another situation, as electroacoustic music can be performed again on another occasion. Indeed, it always requires a WFS system to listen to the piece exactly how it is composed, but the WFSCollider offers a possibility to render into a version with various types of multichannel systems. When it renders, the new version does not use the WFS calculation but VBAP. The spatial images are therefore not experienced exactly the same, but one

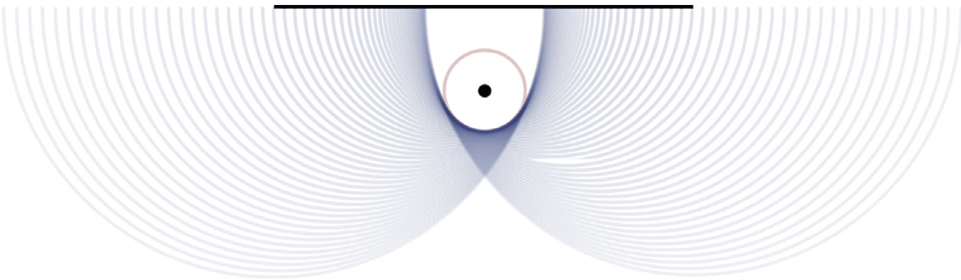

Figure 5. A point source in front of the speaker array with "inverse time" wavefield calculation.

can re-master the piece using another multichannel system, as the preview setting is available in order to listen with the other systems.

Despite all the limitations, it is worth trying out the system. Among many reasons it gives an opportunity to deeply think about the connection between your musical ideas with space. Every single sound that goes into the timeline on your score must have its physical location or a spatial behavior, which comes with distance, speed, and variations of those. They require decisions based on one's artistic approach to how their music should be heard. I would like to address a few critical points that the WFS system offers and artistic aspects of those attributes with examples from my own pieces and experiments.

2.1 Physical experience of sounds and sense of distance

As mentioned earlier the WFS system gives a unique experience of listening to acousmatic music; it gives a physical sensation that the sound is present or approaching so close to the audience, penetrating our bodies, and sometimes right on our heads. This is due to the fact that the WFS system reproduces sounds based on physics and the air pressure of the sound can be felt when the sounds are moving inside the speaker arrays and passing by closely or through the audience. The audience can feel as if they are situated with the sounds coming and going, different from being surrounded by it. Often it feels so embodied and intimate that the audience gives a physical reaction such as turning their heads when sounds are quickly approaching them. Such a unique experience of listening is what the WFS system distinctively offers, and it opens up a number of creative ideas because the performing and listening space are no longer separate, but we are in the same musical space. This attribute raises questions to composers how to utilize it in an artistically meaningful way.

The feeling of nearness or being unified with sounds offers a possibility to work on the variation of dynamics without raising their level but by moving them far or close to the inner location of the speaker arrays. Natasha Barrett talks about this when she describes compositional considerations in a 3D virtual sound field; the composer can work with more intimate sound proximities and also enlarge the spatial difference between distant and near sound materials (Barrett, 2002). The relationship with a close and far sound can be emphasized by differentiating their distance, and accordingly the amount of the intimacy as its perception is not bound to one being softer than the other; rather one being more physically closer than the other.

2.2 Clear(er) distinction between juxtaposed sounds

When trying to juxtapose various sounds at the same time, either to create a sound mass, or to depict individual sound with its own musical path, the WFS system gives more clarity in listening to each sound source than conventional multichannel setup in which they may mask each other due to lack of channel required to contain and distribute many sound sources simultaneously. A different spatial depth is provided by spreading many sound sources extensively, using both moving and static sources. Not only the density of the sound-space can therefore be heavier, but also can be organized into an extensive sonic field. Such a possibility allows us to come up with diverse approaches toward distinctive acousmatic landscapes.

I have worked on implementing various types of sound mass with the WFS system. My very first WFS piece *Hu-tn Gut*[3] shows this approach clearly. *I am very interested in understanding how the imagery and spatial articulation proper to the Korean ritual tradition dialogues with technology in spatial organization. For example: what are the difficulties, if and how do they influence each other? I mean not from a factual point of view, which is already established, but more from a perceptual, aesthetic and space concept perspective. I hope it is clear what I mean. I would like to start a post doc research about this... Hu-tn Gut* is the first process of *Nae-Rim Gut,* which is one of the most commonly performed Korean traditional rituals. Before the main ritual starts, all kinds of -lame- Gods are first invited – so that the main ritual does not have any disturbance from them – by playing metallic instruments and holding the branches of trees, then serve food, play music, and dance to please them. Gods and demons come into the space, have food, and enjoy music for a while, and shamans take them away by playing the last part of music (Kang 2008). *'Hu-tn'* means 'nonsensical.' The ritual has a clear structure; *invitation – party – farewell*. The locations vary: it begins in the front yard, moves into the living room for the party, and finishes at a far enough place where one cannot hear the sound of music any longer.

The sound mass movement is used in three different manners in order to reflect on the process of invitation of Gods, their party, and their departure. Processed percussion sounds call them in, and slowly each God, represented by differently textures synthetic sounds, enters the space and starts *dancing*. Figure 6 shows an example of the amount of juxtaposition in the piece, as well as a rough metaphorical image of how each layer is a combination of different streams of rhythmic electronic sounds.

The spatialization of each layer in the first part (invitation) moves in the same direction at the same speed (Figure 8 left) The movement of the mass accordingly is uni-

[3] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

Figure 6. Structure of the third part in 'Hu-tn Gut' and a snapshot of inner structure of a sound stream of figure.

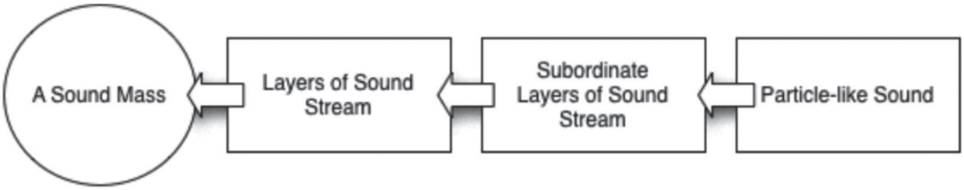

Figure 7. The progress of a sound mass in Hu-tn Gut.

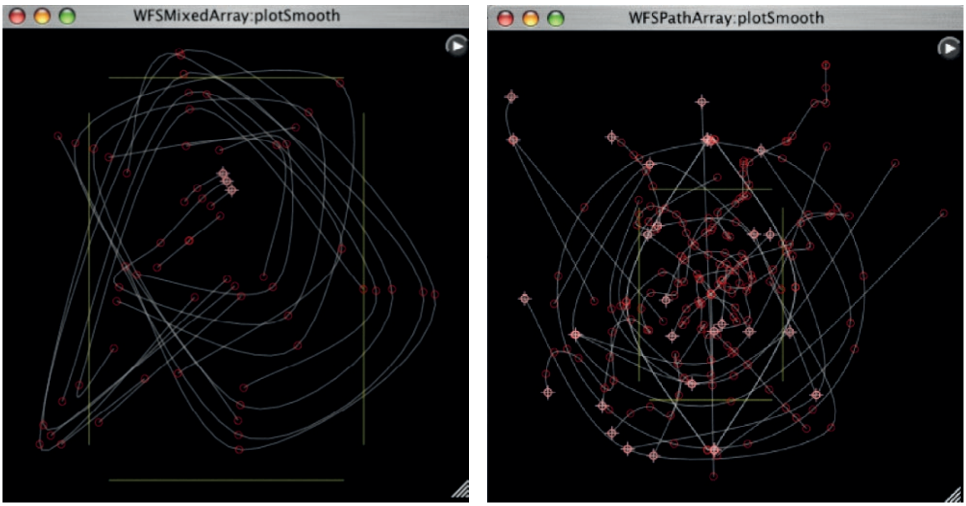

Figure 8. Two different mass movements for the second and the third parts of *Hu-Tn Gut.*

fied as well as its speed. However, those layers are still clearly heard individually rather than one single mass, but a group of distinctive layers. In the third part (farewell) each layer is moving away toward the front after its individual wandering (Figure 8 right). One can hear quite clearly their own unorganised 'dancing' motion, and after some time they all move away to one direction. This clear distinction in the spatialization of sound masses in each section helps to give each part a clear structural character.

2.3 Hearing Doppler effect in moving sound sources

One of the most frequent complaints from composers who work with the WFS system is that they constantly hear the frequency shift that the doppler effect causes. The moving sources of the WFS system cause two different kinds of doppler shift; the first is a simulation of the natural doppler shift by distance between a sound source and a reference point – a listener –, and the second is one per speaker caused by distance between a sound source and individual speakers. These effects are unavoidable as they are part of physics happening when sounds are moving through the air – and when we think for a moment, we don't experience that many sound objects moving so quickly around in our daily lives other than cars, motorcycles, mosquitos, and sometimes airplanes for which we lived with those sounds for a long time. The WFSCollider includes the doppler effect by default accordingly, and one cannot remove it from the source. Sound is heard via a speaker system, and the system comes with its colors due to the way it is built and works, and therefore this phenomenon is inescapable. When sounds move slowly, the effect is logically not very observable, but when they move fast enough, the frequency shift is clearly heard, shifting the frequency of the source materials. It is therefore understandable to hear the complaints because composers carefully sculpt their sounds or bring carefully recorded sound materials. Nevertheless, when the doppler effects become a bother, it gives an opportunity to think of the reasons why we try to move specific sounds at a specific speed and what we expect to hear as a whole. When the speedy movement is used, it must be chosen for its musical role and expression.

This character makes us think of the system as an instrument too; composers research on all the possibilities an instrument can contribute and approach it with the most suitable musical choices. The same principle applies to composing with the system; when one embraces the sounding characters and what the system offers us to do musically, the choice of the sounds and their gestures are carefully made for it. Then such an effect can become a strong character that can be utilized in order to reveal a specific musical gesture that is unique to the system. It certainly influences the choices of sound materials, the choice of musical gestures, and thus the spatial imagery to be created.

2.4 Spatial granulation by extremely speedy moving sources

When sounds are moving faster and faster, they start sounding not as moving continuously anymore, but jumping. The doppler effect causes such a *spatial modulation* that the original sound quality and gesture are entirely broken, and are becoming granulated. For example, a slowly moving sawtooth wave with 500-700 Hz frequency – a mosquito-like sound – will turn into the sound of falling stones on concrete ground. The sense of 'moving sound' disappears as well. Depending on the characteristics of the source material, the granulated sound will also vary in time. By modulating further, the speed of the moving source together with other parameters of the sound such as frequency, spectral modulations, etc, a number of different results can come out. This characteristic of the system can be seen as a good example that the spectral components of sound and its transformation are strongly dependent on and bound to the spatial parameters, where the speed becomes a fundamental parameter for such a radical and unpredictable morph of sound.

2.5 Simulation of various acoustics and coexisting different spatial properties and acoustics

The WFSCollider comes with a number of effects (Figure 9) that make it possible to process the sound source in real-time. Convolution reverb is a useful one among those that can be used in order to vary the acoustic properties of the sound source, and it is possible to modulate its parameters over time and to use your own impulse responses. Plane wave (Figure 4) sources can be a great tool to simulate an acoustic

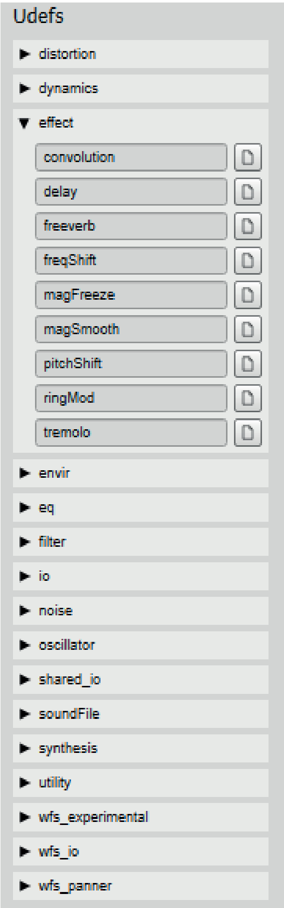

Figure 9. Various effect in *Udefs*. 'Udefs' is a list of unit definitions, and a unit is used to define a type of sound and spatialization in *WFSCollider*.

quality. For example, one sound without much of its own spatial cue can have its own position or movement, and can also be duplicated with a plane wave without having a fixed localization where a convolution reverb is applied.

I have applied this to many of my compositions, resulting from the separation between the reflected space and the sounding space. It is true that whichever reverberation is applied to a sound, it collides with the acoustics of the listening space. When there are more than one objects with their own spatial cues, then they would create a conflict, but it is also possible for many spatial illusions to collide into one total spatial illusion (Barret, 2002). The goals of applying different spatial cues are to reveal altered spectral quality by unique and different spatial cues, (re)contextualization of an environment, and/or unidentified reference to the current listening environment.

Another example that I implement often is that I place the same sound source into three different locations: 1) locating a sound being completely dry and far from the centre; 2) applying a reverberation but moving from one point to the other, while wet/dry rate changes over time by its distance, and 3) locating it at the opposite position with a few millisecond (1-20ms) delay. The sound material for this is normally one with a dynamic gesture rather than a long static one – although this does not sound uninteresting – so that the sound quality does not vary too much by the accumulating reflections. The result is interesting; the ever-changing number of artificial reflections gives strange room quality and the delayed layer gives a sense of being in a 'closed' location; imagine that you are walking on a street surrounded by buildings, the opposite side there is a load construction with a drilling machine, and then you hear the reflection of that machine in your side.

Dennis Smally talks about 'placing a room of a certain dimension inside another room' in the interview with Larry Austin (Austin & Smalley, 2000). I have implemented this in the last piece of *Nae-Rim Gut*, *Madang*.[4]

Madang comes from '*Madang-Gut*' a compound word of *yard* and *ritual* that is a traditional festive event. It can happen as an independent event or the last process of rituals where all the participants celebrate the rituals at the front yard or the square in town. It consists of various cultural events including music performance, theatre plays, and dance.

As the last piece of the project, the important aspect of this composition was to reflect the entire ritual, the characteristics of such a complicated process, to release the tension of the heaviness the ritual carries, and to give a festive atmosphere. The found approach was to juxtapose the first four compositions on top of each other. Each composition – two live electronics pieces and two WFS compositions – is rendered into a quadraphonic piece, and then juxtaposed both in music and in space. The parameters that shape the pieces as a single entity was to consider each piece as one square sonic field and by placing and moving them in different distances the dynamics of the piece was decided. Figure 10 shows the first sketch of the graphic score; the black square is the inner space of the WFS speaker arrays, and blue, red, green and yellow ones refer

[4] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

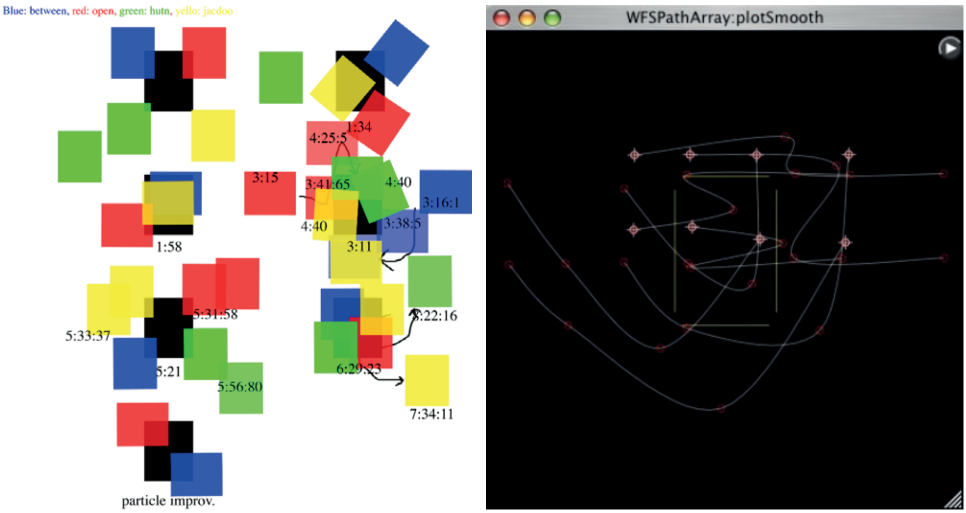

Figure 10. Spatial score of *Madang* and an example of the movements of 4 pieces.

to four pieces. There are time codes written in order to trace where and how far and long the squares have to move.

The decision has been made purely to reveal different complexities at a moment. Such complexities are not only revealed by the juxtaposition of differently sounding pieces, but also the spatial properties of each piece caused by 4 different performing spaces combined in one space. Natasha Barret talks about a state of conflict arising when the spatial information inherent to each sound-object is conflicting with their 3D spatial dispositions. Then the original spatial properties disappear due to the juxtapositions of different sonic fields (Barret, 2002), but there emerge new properties. Complexity could be one way to describe it; the four rooms become one in time and space with its own context and orientation. What is happening in between, before four rooms gather at a place, is probably rather more complicated in its musical figure and sonic phenomenon.

Each composition (each room) in *Madang* has different characters; the first two pieces involve instruments such as cello, recorder and Jing (a Korean gong), and the last two with electronic sounds. The first two pieces were recorded in two different concert spaces. In this piece, the original roles of sounds in the original pieces are re-organized simply by their momental superimpositions caused by moving them in the same space. The original quadraphonics spatial characters in the pieces do not share anymore their original spatialities. Both the unfolding sonorities and spatialities are creating a new musical context.

2.6 Diffusion and spatialization

When talking about sound spatialization in Electroacoustic music, we can come up with two different traditions: one is to apply spatial algorithms into the number of channels while creating sounds or composing the piece. When performing such pieces one can adjust the levels of each channel in order to reveal the composed, pre-designed sound sources in balance, but the spatial images are not altered. Another approach is a sound diffusion of a mono or a stereo music composition to multiple loudspeakers using a diffusion desk. While the composition is fixed, it is distributed to multiple, and often different types of loudspeakers – loudspeaker orchestra – in real-time in order to articulate, expand, and isolate certain gestures in music and to reveal timbrel characters by sending them to a specific set of loudspeakers. Moving sound around in space is not the main concern, but rather the articulation of the music through performing different passages through differently sounding arrays of speakers (Zvonar, 1999).

Although one of the significant differences is in the deterministic character of the two traditions, they require completely different practices. Sound diffusions do not use spatialization algorithms. Moving sound sources are possible but limited to the motion of the fingers on the mixing desk. Therefore, composing for a sound diffusion needs a particular strategy. Spatializations rendered in multichannel have more possibilities to generate and pre-program various geometric shapes and trajectories. Above all, it makes it possible for each sound source to have its own gesture when they are distributed in time. As mentioned in the chapter 2.2, the WFS system maximizes such a complexity of polyphonic spatiality and its clarity; a more vividly structured sound mass can be realized. The number of layers simply depends on the capacity of the servers and the complexity of each movement, yet it normally exceeds 25 moving – possibly lengthy – sound sources. Then an ambiguity of the localization of the sound can also be considered if one tries to merge those layers into a cloudy total mass. Plane waves can be used solely or together with point sources in order to achieve that as they make it possible to simulate PA loudspeaker simulation. Comparing the point sources with clear locations and gestures, the plane waves only work with a direction and a distance. It can also move, and when it does, its movement feels more massive than the one of point sources. This does not offer the same impact as sound diffusion in practice, but the sound results of diffusion can be simulated, or co-exist with various spatializations.

2.7 The 3rd dimension

The WFS system suggests 2-dimensional hearing experience of sound. Ideally the best experience of spatiality can be achieved when the listener is seated in the same height as the speaker arrays. The WFS system at Institute of Sonology (Figure 11) is set up in such a way – probably one of the most transparent environments as the studio has a proper acoustics aided by the acoustic panels and the height of the system matching our ear level –, and the Game of Life system is set up slightly higher than that. This is because the WFS in Sonology is for studio mastering while the Game of Life WFS is for concerts. When it is set up higher than our ear level, it prevents the other people from blocking the moving sounds. Regardless, the system is generally located in a concert hall with its acoustic condition. The reflections of the hall are therefore unavoidable. This means that it is difficult to observe the transparency of the sound journey.

This can be seen as a problem as the desired sonic images cannot be fully achieved. However, such an issue does not belong only to working with the WFS system and it does not seem to come across as a disadvantage. The concert space can help the composition to shine, to resonate with itself, and to even reveal undiscovered areas of sonic exploration (Kang, 2021). Students in Sonology work in this studio over the year, and at the end of the school year the Game of Life system is installed in a bigger concert space. Their impression of the experience in two different environments tell that the help of the room acoustics make their pieces truly resonating – although the WFS system in the studio has a higher resolution with many more loudspeakers than the Game of Life system. The sonic environment sizes they feel in both locations vary as well, yet the core of the spatiality of the entire music remains the same.

These 'sizes' do not only mean the horizontal plane, but it certainly extends to the vertical dimension. Together with the work of the room acoustics, our psycho-acoustics help to feel the height of sound as if they are flying above our heads. Such an impression is hard to be formulated due to the complexities in each different acoustics, but it can be learned and integrated to a certain extent by experiences and experiments.

2.8 Live possibilities

The WFSCollider offers possibilities to perform live electronic music with the WFS system. The number of input channels for the system is depending on the num-

Figure 11. Wave Field Synthesis Studio at Institute of Sonology (http://sonology.org/).

ber of input channels in the main audio interface. The Game of Life system has 8 analogue inputs and 8 ADAT inputs, but they cannot be used together. Accordingly, the total input is limited to 8, which can be seen as a limitation. Composing for the WFS system requires its justification; one could ask themselves if their musical and spatial ideas can better be achieved using other types of speaker configurations. Hopefully I elaborate on the reasons why I am addressing such a question. There is no fixed answer to what the right strategies would be in such a wide range of spatial music approaches. Nonetheless it is important to think about the limited number of the input sources and what each input will consist of, and how to spatialize them. An important point to be considered is that each input does not necessarily occupy one location nor move alone. Each channel can also be processed, re-created, or modulated by using various effects available in WFSCollider. This aspect can open up creative solutions to the limited input channels.

A challenge in live electronics for the WFS is to come up with performance strategies based on what WFSCollider and the system can do specifically. Normally performances of live electronic music involve performative aspects such as changing parameters in real-time using controllers and performing with instruments played by the composer or other instrumentalists. Also, the pieces can be fully composed, or be improvised. Then there come parameters that have to be controlled in real-time: spatializations. Mentioned earlier, spatialization does not come only with a location and movement, but with distance, speed, and acoustic properties. In case of improvised music where the performers cannot anticipate fully how the music will flow in time, then it is questionable how the spatialization will be achieved without knowing the sonic properties and the relationships with other sounds. Localization in the WFS system is made in a cartesian coordinate plane with (x,y) – or possibly in a polar coordinate system (distance and angle)-. In order to move a sound source in space, it requires two parameters controlled at the same time as a pair, which is difficult to control with a linear controller like a fader or knob. Also, there could be variations of speed that do not depend too much on the way our finger moves. In case of already composed music pieces, especially with a live performer with an instrument, it is also questionable where the performer should be located – inside the speaker arrays, or outside? if outside, then which side and how far? – what the instrument is and how loud it is, and whether or not the instrumentalist has to listen clearly to the electronic sounds. Not having a clear stage, or rather to say, no division between the audience and the sonic space could become a question to solve in order for the music to meet a desired sound result.

Another significant issue is that the live input is supposedly and preferably received without any latency especially when one is processing it in real-time, or to perform in duo with demanding accurate time cues. The general latency level is not high for rendering a score, but when there is a live input source, the latency, even being minimized, is audible. A solution to reduce the problem of latency happening with live input is to link the source always to an index source, preferably close to the desired WFS sources. This means that the input signal is reaching at least one speaker first by skipping the WFS calculation before it goes into its desired location or moves.

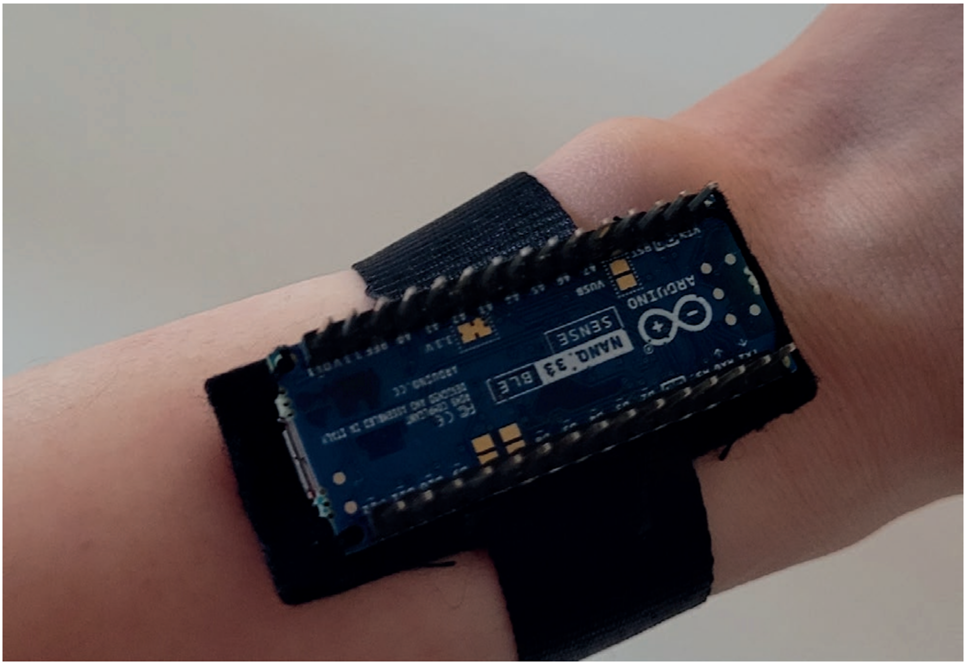

Figure 12. Arduino nano 33 BLE on a wrist.

As mentioned earlier, the latency is long enough to be noticed, but short enough to be masked in this way. The index source used in this context is probably not desired artistically, but it works as a bridge to its desired position or movement. In this way multiple performers are able to synchronize with each other without any latency.

With all those restrictions and challenges, there are still a number of possibilities to perform it in real-time, some of which can be out of the 'conventional' ways to approach a live electronic music composition.

One example of live control with a sensor where the cartesian coordinate system is mapped already. This can be done with an accelerometer, gyroscope, or magnetometer sensor, or a combination with them where they can also be controlling the other parameters in sound processing. In 2020-2021, I have experimented with *Arduino nano 33BLE* (Figure 12), a small sized microcontroller. The sensor is connected to the *WFSCollider* via Bluetooth, and communicating via Open Sound Control (OSC) signal. There are three different mappings made: 1) drawing a spatial trajectory in real-time; 2) changing the speed of multiple, pre-designed spatial trajectories; and 3) a conditional decision-making point for on-going sound processing. (Kang, 2021)

In this experiment, it was important to limit the drawing function with the sensor to a specific moment in order not to make unified motions being created in multiple trajectories. Rather it is better to be used for a distinctive moment of the music where there is a space for the sound to be traveling within an improvisation situation. In my

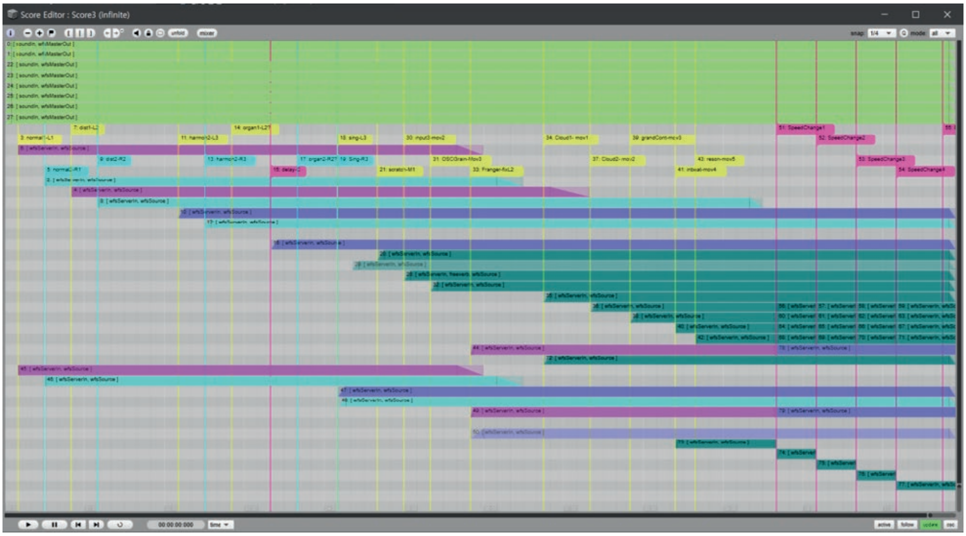

Figure 13. The UScore of The Voice (2021).

experiment for the piece *The Voice*[5] in 2021, this function was used at one event, the light green-blue event in the middle layer of the score in Figure 13.

Another possibility is that either the control for the spatialization or for the processing can already be composed, and work as a 'score' for the other to fit in. It is not uninteresting to have a fixed time and gesture already composed, and the other musical elements follow them. Mapping between musical parameters and spatial parameters can also be implemented in this platform. By doing so, one does not think of the music and space separately but together.

WFSCollider also opens up a unique possibility to generate a score file using *SuperCollider*. One can skip the graphical user interface (GUI) and directly code the score and execute it in real-time. This surely requires knowledge in *SuperCollider* programming. An Icelandic composer Bjarni Gunnarsson presented in 2022 his live electronic music 'Wildfires' where he generated 22 scores that are activated in real-time but in no particular order (Gunnarsson, 2022). In each score, he created events with 'infinite' duration, so that each score is composed without a fixed duration. The sequence of the orders depends on his execution, not necessarily one after the other. This can be compared to having 22 different instruments in front of the performer, who decides how to play them in time.

3. Conclusions

The WFS system opens up the possibilities to think deeply about the use of space in music in such a way that spatialization is strongly connected to the evolution of

[5] Audio/Video materials related to this article are available at the following DOI: https://doi.org/10.5281/zenodo.10252898

sound and music. Various approaches and aspects are introduced, and I hope them to be an inspiring opinion rather than a guideline; there is no absolute answer to how we must use an instrument, but we can always be open to how others compose with it.

When discussing sound spatialization, it is crucial to think firstly about the sound source materials such as synthetic sounds, synthesisers, field recordings, and studio recordings, which call for in-depth listening in order to discover their *spatiality*. Therefore different approaches are required. This is probably the most important practice when approaching the WFS system as well. I hope to have another opportunity to write specifically about this in the future.

A spatial audio system such as the WFS system is an instrument with a unique voice and it broadens our thoughts toward the implementations of musical space; it is not only a tool for sounds to move and locate somewhere, but also to shape, alter, and transform the sounds together with their spatial gesture. The WFS system does not give you the most realistic sonic image like in reality, – as a number of critiques are based on – and even if so, it might not be an interesting musical instrument to compose with. The differences make it unique, and give a room for composers to utilise them. It also does not solve every issue on spatialization in electroacoustic music. Nevertheless, it forces us to use every single parameter in sound spatialization, not in a single manner but with choices of variations, and integration and utilisation of real and virtual acoustics. This is an invaluable practice that one can carry on in daily musical practice.

Bibliography

Austin, L., & Smalley, D. (2000). Sound Diffusion in Composition and Performance: An Interview with Denis Smalley. *Computer Music Journal*, *24*(2), pp. 10-21. http://www.jstor.org/stable/3681923

Baalman, M.A.J. (2010). Spatial Composition Techniques and Sound Spatialisation Technologies. *Organised Sound*, Dec 2010.

Barret, N. (2002). Spatio-musical composition strategies. *Organised Sound*, Dec 2002.

Otondo, F. (2007). Creating Sonic Spaces: An Interview with Natasha Barrett. *Computer Music Journal*, June 2007.

Beard, D. (2019). Acousmatic Listening and a Critical Awareness of Place. *International Journal of Listening Volume*, *33*(Issue 3: Listening in Unusual Ways in Unusual spaces: Ethics, Listening and Place), pp. 129-132.

Berkhout, A.J. (1988). A Holographic Approach to Acoustic Control. *Journal of the Audio Engineering Society, 36*(12), pp. 977-995.

Otondo, F. (2007). Creating Sonic Spaces: An Interview with Natasha Barrett. *Computer Music Journal*, *31*(2), pp. 10-19.

Fielder, J. (2016). A History of the Development of Multichannel Speaker Arrays for the Presentation and Diffusion Acousmatic Music. Austin, TX.

Kang, J.Y. (2008). The Holomovement of Music. Institute of Sonology. The Royal Conservatoire in The Hague.

Kang, J.Y. (2021). Sound spatialization in live electronic music. 'Music, Education and Society' lectorate 2021. The Royal Conservatoire in The Hague. https://www.researchcatalogue.net/profile/show-exposition?exposition=1441817

Kim, S.-J. (2011). A critique on Pierre Schaeffer's phenomenological approaches: Based on the acousmatic and reduced listening. In J. Ziherl (Ed.), Proceedings of the International Conference Pierre Schaeffer: mediArt (pp. 123–133). Rijeka, Croatia: Muzej moderne i suvremene umjetnosti/Museum of Modern and Contemporary Art.

Zvonar, R, (2008), A History Of Spatial Music, CEC Canadian Electroacoustic Community, http://cec.concordia.ca/econtact/Multichannel/spatial_music.html

Gunnarsson, B, (2022), Programme note on 'Wildfires' at the WFS Festival 2022.

The Game of Life foundation https://gameoflife.nl/en

WFSCollider https://sourceforge.net/projects/wfscollider/

SuperCollider https://supercollider.github.io/

Institute of Sonology http://sonology.org/