

Application of Wave Field Synthesis in electronic music and sound installations

M.A.J. Baalman, M.Sc.

Electronic Studio, Communication Sciences, University of Technology, Berlin, Germany

email: marije@baalt.nl

web: www.nescivi.de

Abstract

Wave Field Synthesis offers new possibilities for composers of electronic music and to sound artists to add the dimension of space to a composition. Unlike most other spatialisation techniques, Wave Field Synthesis is suitable for concert situations, where the listening area needs to be large. Using the software program "WONDER", developed at the TU Berlin, compositions can be made or setups can be created for realtime control from other programs, using the Open Sound Control protocol. Some pieces that were created using the software are described to illustrate the use of the program..

Introduction

Wave Field Synthesis is a novel technique for sound spatialisation, that overcomes the main shortcoming of other spatialisation techniques, as there is a large listening area and no "sweet spot".

This paper describes the software interface WONDER that was made as an interface for composers and sound artists in order to use the Wave Field Synthesis technique. A short, comprehensive explanation of the technique is given, a description of the system used in the project at the TU Berlin and the interface software, followed by a description of the possibilities that were used by composers.

Wave Field Synthesis

The concept of Wave Field Synthesis (WFS) is based on a principle that was thought of in the 17th century by the Dutch physicist Huygens (1690) about the propagation of waves. He stated that when you have a wavefront, you can synthesize the next wavefront by imagining on the wavefront an infinite number of small sources, whose waves will together form the next wavefront (figure 1).

Based on this principle, Berkhout (1988) introduced the wave field synthesis principle in acoustics.

By using a discrete, linear array of loudspeakers (figure 2), one can synthesize correct wavefronts in the horizontal plane (Berkhout, De Vries and Vogel 1993). For a complete mathematical treatment is

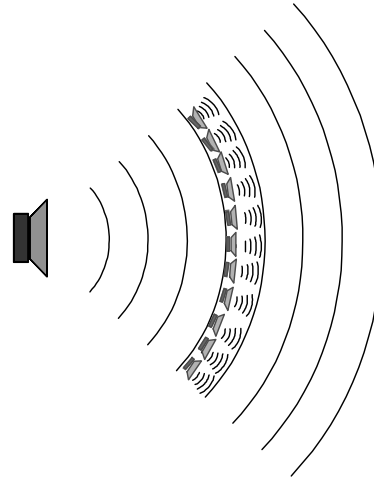


Figure 1. The Huygens' Principle

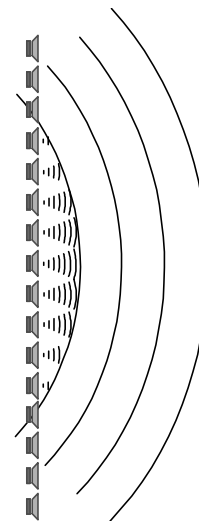


Figure 2. The Wave Field Synthesis principle referred to Berkhout (1988, 1993) and various other papers and theses from the TU Delft¹.

An interesting feature is that it is also possible to synthesize a sound source in front of the speakers (Jansen 1997), something which is not possible with other techniques.

¹ Sound Control Group, TU Delft,
<http://www.soundcontrol.tudelft.nl>

Jansen (1997) derived mathematical formulae for synthesising moving sound sources. He took into account the Doppler effect and showed that for its application one would need to have continuously time-varying delays. He also showed that for slow moving sources the Doppler effect is negligible and one can resort to updating locations and calculating filters for each location and changing those in time.

This approach was chosen in this project. Additionally, in order to avoid clicks in playback, an option was built in to crossfade between two locations to make the movement sound smoother.

Theoretical and practical limitations of Wave Field Synthesis

There are some limitations to the technique. The distance between the speakers needs to be as small as possible in order to avoid spatial aliasing. From (Verheijen 1998) we have the following formula for the frequency above which spatial aliasing occurs:

$$f_{Nyq} = \frac{c}{2\Delta x \sin\alpha}$$

where c is the speed of sound in air, Δx the distance between the speakers and α the angle of incidence on the speaker array. Thus the frequency goes down with increasing distance between the speakers, but it also depends on the angle of incidence, thus the location of the virtual source, whether or not aliasing occurs.

Spatial aliasing has a result that a wave field is not correctly synthesized anymore and artefacts occur. This results in a bad localisable sound source. This limitation is a physical limitation, which can not really be overcome. However it depends on the sound material whether or not this aliasing is a problem from a listener's point of view. In general, if the sound contains a broad spectrum with enough frequencies below the aliasing frequency, the source is still well localisable.

On the other end of the frequency spectrum there is the problem that very low frequencies are hard to play back on small speakers. For this can however, just as in other spatialisation systems, a subwoofer be added, as low frequencies are hard to localise by the human ear.

Another limitation is that a lot of loudspeakers are needed to implement the effect. Because of this, there is research done into loudspeaker panels, so that it is easier to build up a system.

Finally, a lot of computation power is needed, as for each loudspeaker involved a different signal needs to be calculated. With increasing computation power of CPU's, this is not really a big problem. At the moment it is possible to drive a WFS-system with commercially available PC's.

System setup at the TU Berlin

The prototype system in Berlin was created with the specific aim to make a system for the use in electronic music (Weske 2001). The system consists of a LINUX PC driving 24 loudspeakers with an RME Hammerfall Soundcard.

For the calculation (in real time) of the loudspeaker signals the program BruteFIR by Torger² is used. This program is capable of making many convolutions with long filters in realtime. The filter coefficients can be calculated with the interface software described in this paper.

With the current prototype system it is possible to play a maximum of 9 sound sources with different locations in realtime, even when the sources are moving. This is the maximum amount of sources; the exact amount of sources that can be used in a piece depend on the maximum filter length used. A detailed overview of the capacity was given in a paper presented at the ICMC in 2003 (Baalman 2003).

Interface software

In order to work with the system, interface software was needed to calculate the necessary filter coefficients. The aim was to create an interface that allows composers to define the movements of their sounds, independent of the system on which it eventually will be played. That is, the composer should be bothered as less as possible with the actual calculations for each loudspeaker, but instead be able to focus on defining paths through space for his sounds.

The current version of the program WONDER (Wave field synthesis Of New Dimensions of Electronic music in Realtime) allows the composer to do so. It allows the composer to work in two ways with the program: either he creates a composition of all movements of all the sound sources with WONDER, using the composition tool, or he defines a grid of points that he wants to use in his piece and controls the movement from another program using the OpenSoundControl protocol (Wright e.a, 2003). The main part of the program is the play engine which can play the composition created or move the sources in realtime; a screenshot is given in figure 3.

The array configuration can be set in the program. It is possible to define the position of various array segments through a dialog.

WONDER includes a simple room model for calculation of reflections. The user can define the position of four walls of a rectangular room, an absorption factor and the order of calculation. The calculations are done with the mirror image source model (see also Berkhout 1988).

² Torger, A., *BruteFIR*,
<http://www.ludd.luth.se/~torger/brutefir.html>

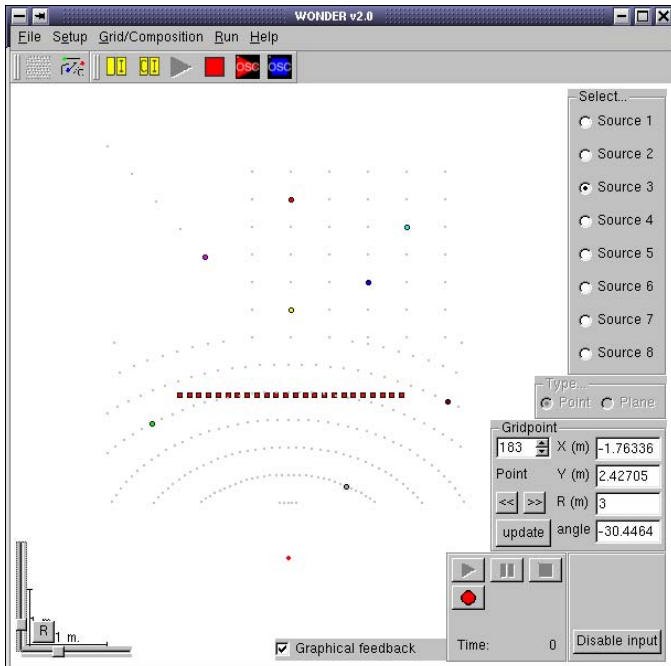


Figure 4. The user interface of the play engine of WONDER

Experiences with composers

During the development of the program, various compositions were made by different composers, to test the program and to come up with new options for the program. These compositions were presented at different occasions, amongst which festivals like Club Transmediale in Berlin (February 2003) and Electrofringe in Newcastle, Australia (October 2003). I will elaborate about two compositions and one sound installation.

Marc Link, a composer residing in Berlin, wrote a piece called Ping-Pong Ballet. The sounds for this piece were all made from ping-pong ball sounds, which were processed by various algorithms, alienating the sound from its original.

Using these sounds as a basis, the inspiration for the movements was relatively easy as the ping-pong ball game provides a good basis for the distribution in space of the sounds. In this way he created various loops of movement for the various sounds as depicted in figure 4. Paths 1 & 2 are the paths of the ball bouncing on the table, 3 & 4 of the ball being hit with the bat, 5 & 6 of multiple balls bouncing on the table, 7 & 8 of balls dropping to the floor. Choosing mostly prime numbers for the loop times, the positions were constantly changing in relative distance to each other. The movement was relatively fast (loop times were between 5 and 19 seconds). In the beginning, the piece gives the impression of a ping-pong ball game, but as it progresses the sounds become more and more dense, creating a clear and vivid spatial sound image.

In the composition "Beurskrach" created by Marije Baalman, four sources were defined, but regarded as being points on one virtual object, i.e. these points made a common movement; the sound material for these four points were also based on the same source material, but slightly different filterings of this, to simulate a real object where from different parts of the object different filterings of the sound are radiated. During the composition, the object comes closer from afar and even comes in front of the loudspeakers, there it implodes and scatters out again, making a rotating movement behind the speakers, before falling apart in the end. See figure 5 for a graphical overview of this movement.

The sound installation "Scratch", that was presented during the Linux Audio Conference, makes use of the OSC-control over the movements. The sound installation is created with SuperCollider, which makes the sound and which sends commands for the movement to WONDER. The concept of the sound installation is to create a

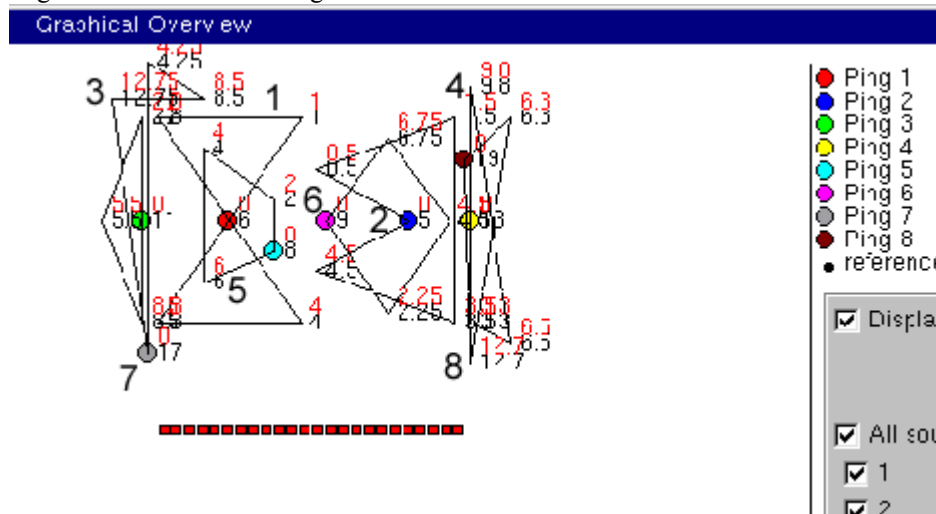


Figure 3. Overview of the movements of the composition "Ping Pong Ballet" (screenshot from a previous version of WONDER)

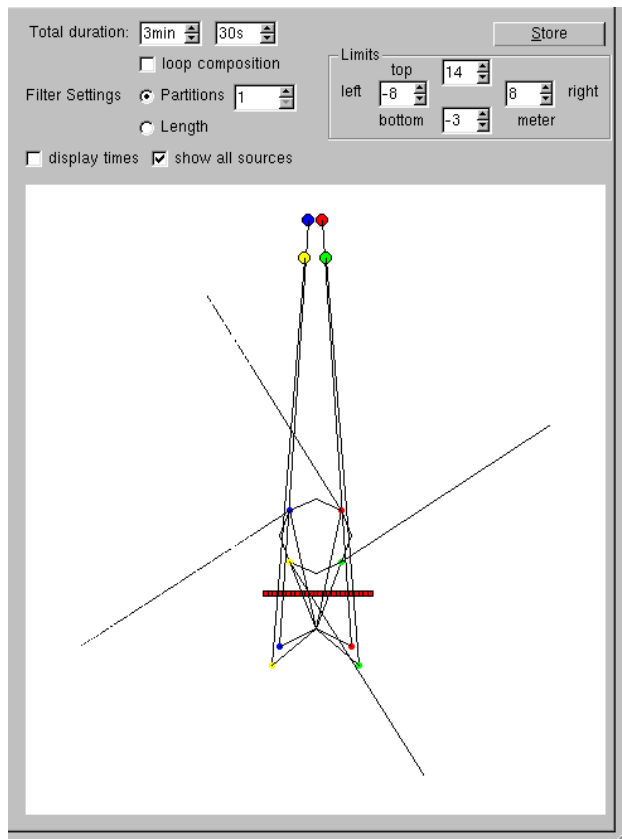


Figure 5. Overview of the movements of the sound sources of the composition "Beurskrach"

kind of sonic creature, that moves around in the space. Depending on internal impulses and on external impulses from the visitor (measured with sensors), the creature develops itself, and makes different kinds of sounds, depending on its current state. The name "Scratch" was chosen because of two things: as the attempt to create such model for a virtual creature was the first one, it was still a kind of scratch for working on this concept. The other reason was the type of sound, which were kind of like scratching on some surface.

Conclusions and future work

The program WONDER provides a usable interface for working with Wave Field Synthesis, as shown by the various examples of compositions that have been made using the program.

Future work will be, apart from bug fixing, on integrating BruteFIR further into the program, in order to allow for more flexible use in realtime. Also an attempt will be made to incorporate parts of SuperCollider into the program, as this audio engine has a few advantages over BruteFIR that could be used. Also, there will be work done on more precise synchronisation possibilities for use with other programs.



Figure 6. The sound installation "Scratch" during the Linux Audio Conference. In the ball are accelerometers to measure the movement of the ball, which influences the sound installation (photo by Frank Neumann).

Other work will be done on creating the possibility to define more complex sound sources (with a size and form) and implementing more complex room models.

Credits

WONDER is created by Marije Baalman. The OSC part is developed by Daniel Plewe.

References

- Baalman, M.A.J., 2003, Application of Wave Field Synthesis in the composition of electronic music, *International Computer Music Conference 2003*, Singapore, October 1-4, 2003
- Berkhout, A.J. 1988, A Holographic Approach to Acoustic Control, *Journal of the Audio Engineering Society*, 36(12):977-995
- Berkhout, A.J., Vries, D. de & Vogel, P. 1993, Acoustic Control by Wave Field Synthesis, *Journal of the Acoustical Society of America*, 93(5):2764-2778
- Jansen, G. 1997, *Focused wavefields and moving virtual sources by wavefield synthesis*, M.Sc. Thesis, TU Delft, The Netherlands
- Huygens, C. 1690, *Traite de la lumiere; ou sont expliquees les causes de ce qui luy arrive dans la reflexion et dans la refraction et particulierement dans l'etrange refraction du cristal d'Islande; avec un discours de la cause de la pesanteur*, Van der Aa, P., Leiden, The Netherlands
- Verheijen, E.N.G. 1998, *Sound Reproduction by Wave Field Synthesis*, Ph.D. Thesis, TU Delft, The Netherlands
- Weske, J. 2001, *Aufbau eines 24-Kanal Basissystems zur Wellenfeldsynthese mit der Zielsetzung der Positionierung virtueller Schallquellen im Abhörraum*, M.Sc. Thesis, TU Chemnitz/TU Berlin, Germany
- Wright, M., Freed, A. & Momeni, A. 2003, "OpenSoundControl: State of the Art 2003", *2003 International Conference on New Interfaces for Musical Expression*, McGill University, Montreal, Canada 22-24 May 2003, Proceedings, pp. 153-160