The Development of Bǎi/摆: An Oscillating Sound Installation

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Abstract. Bǎi is an interactive sound installation that uses a pendulum speaker as an interface for audience participation. We track the movement of the hanging speaker with an HTC Vive tracker which allows to use its motion as input for the interactive dialogue. A 6-speaker setup is surrounding the pendulum and reacting to it. While interacting, the behaviour of the installation changes and goes through different states and levels of excitement. This results in a dynamically changing sound environment for the audience to explore. This paper elucidates the design goals we intended to achieve for the audience experience and the behaviour of the installation. We present a comprehensive description of the development process, including physical, software and sound design. Meanwhile, we discus different forms of interacting with the pendulum speaker and the surrounding speakers.

Keywords: Interactive sound installation · Interactive interface
Pendulum speaker

1 Introduction

Since the invention of the loudspeaker researchers, composers and artists have explored various ways of using speakers ranging from multi-channel speaker setups and hemispherical speaker designs to speaker sculptures and wearable speaker-based instruments. While speakers are often used in static positions, Gordon Monahan's *Speaker Swinging*, first performed in 1982, applies a moving speaker as a musical instrument for live performance. The three performers each swing a loudspeaker in circles with a sine or square wave as source signal [2]. The resulting sound is subject to the Doppler effect and the acoustic properties of the space. In his *Pendulum Music* [3], Steve Reich pioneered the pendulum principle. The performance involves phasing feedback tones resulting from suspended microphones swinging above the speakers. *Spatial Sounds* (100 dB *at* 100 km/h) by Marnix de Nijs and Edwin van der Heide (2000, 2001) is an interactive installation using a moving speaker. The installation interprets

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the visitor's position and movement and reacts to it both with its movements and the real-time generated sound. In return, the visitors react to the installation and go through different experiences and emotions [1]. What these works share is that they exploit the physical properties of a moving sound source (or microphone) in their design.

Fig. 1. 3D model of the space setup for Bǎi: an oscillation sound installation.

We have developed the interactive installation: Bǎi: an Oscillating Sound Installation. It applies a moving speaker in the form of a pendulum as an interface for the audience to interact with. The pendulum speaker is suspended from the ceiling and is surrounded by a 6-speaker setup standing on the floor (see Fig. 1). The speaker is touched and moved by the audience and reacts to it by means of sound. Furthermore, the surrounding speakers react to the pendulum approaching them resulting in a dynamic sound environment. Like in *Spatial Sounds* (100 dB *at* 100 km/h), the speaker senses the actions of the audience and reacts to them. Therefore there is no distinction between the input and output interface and the audience experiences a direct response from moving the pendulum speaker [1]. For the design of the audience interaction, we make use of the pendulum speaker's physical swinging behaviour. We have developed an algorithm to predict the natural swinging movement so that we can distinguish its self-movement from movement caused by the audience pushing, pulling and rotating the speaker. This allows us to react directly to the audience actions.

This paper describes and reflects on both the technical and artistic decisions that were made during the design and development of the interactive sound installation Bǎi. It covers the design goals and a short reflection upon what we have achieved so far.

2 The Installation

The name of the installation, Bǎi, is transliterated from the Chinese character "摆", meaning pendulum. The installation consists of a pendulum speaker, hanging on a cable from the ceiling at 2 m above floor height and 6 floor-standing speakers placed in a circle around the pendulum speaker. An HTC Vive base station is mounted on the wall inside the room, and emits infrared signals. An HTC Vive tracker is placed on top of the pendulum speaker, in order to continuously collect the absolute position and orientation data of the speaker in the room. The data is transmitted to a computer running a patch in Pure Data, a real-time graphical programming environment for audio and graphical processing [5]. We have programmed the sensor interpretation, rules for the interactive behaviour and the real-time sound synthesis for the surrounding speakers in Pure Data. Furthermore, Pure Data is controlling a software synthesiser in Ableton Live for the sound generation of the pendulum speaker itself.

2.1 The Pendulum Speaker

A pendulum has a clear inherent behaviour. The natural movement of the pendulum is an oscillating motion that slowly decays because of the friction with the air. This makes interacting with the pendulum speaker (and thereby the installation) not so much a process of having full control over the system, but rather a process of using and directing the behaviour of the pendulum. In order for it to produce swings that would not move too fast or tilt too high, the length, weight and mounting point of the cable that holds the pendulum are important design parameters. We established a minimum cable length of 3 m. The mounting point of the cable is placed 0.5 m above the pendulum's centre of weight, to keep the speaker relatively stable.

We do not want the pendulum speaker to only act as an interface for triggering sounds in the surrounding speakers but intend to give it a form of interactive and expressive behaviour itself as well. In order to achieve this the surrounding speakers not only react to the movement of the pendulum speaker but the pendulum speaker also expresses its own movement in its sound and clearly reacts to people touching and moving the speaker.

2.2 The Space

For the first presentation of the installation we chose to use six surrounding speakers placed in a circle around the pendulum. Each of the surrounding speakers is functioning as a separate entity that individually reacts to the pendulum's movement. The audience can clearly recognise the interaction between the pendulum and the surrounding speakers since the sounds are spatialised around them and therefore easily localised. The installation is not meant to only interact with a single audience member. The swinging movement in space makes it possible for multiple audience members to interact with the installation at the same time. In that case the audience does not only interact with the speaker but

Fig. 2. The audience interacting with Băi at NIME 2018.

also interacts with each other through the installation. Furthermore, the audience can play different roles and alternate between engaging with the installation or observing it (See Fig. 2).

3 Interaction Design

Our approach to developing the interaction and behaviour of the installation is such that we interpret the term interaction as a dialogue between the audience and the installation. In such a dialogue the two parties communicate and react to each other while neither of the two parties is fully predictable, nor has full control over the situation. It is therefore important for us to create a surprising but nevertheless easy to understand form of interactive behaviour. The interactive behaviour is not static but develops in order to realise an interesting ongoing dialogue. We have set a number of goals to help us achieve this: (1) use analogies between the physical input and sonic output of the system, (2) give the audience the experience of interacting with a system that reacts to their input but also surprises them with its own unpredictable behaviour, (3) make the audience aware that their actions impact the way the system behaves, without being able to fully control it, and (4) make the audience perceive the system as 'beautiful', but also (potentially) 'upset' or 'dangerous' through the changes of its behaviour (see Sect. 4).

At the core of the design is the choice to use a pendulum speaker as interface to interact with the installation. Through pushing, pulling and rotating the speaker, the audience can set the pendulum into different oscillating motions. The installation does not have a fixed form of interaction but alternates between different rules (and therefore different modes of behaviour) depending on the state the installation is in. At first, it may seem that the environment reacts to the motions predictably. However, the pendulum's self-movement influences the system's behaviour, even when the audience does not directly interact with it, which brings unforeseen results. This, combined with the fact that hard physical labour is needed to restrain the pendulum, leads to a tense dialogue between the participant and object, struggling for control. The movements resulting from this dialogue cause the sounds in the environment to change between different states of stability and chaos.

3.1 Physical Interaction

As we mentioned before the pendulum itself has a strong and clear form of, what we call, natural behaviour. The audience is interacting with this behaviour by accelerating, holding and rotating the speaker. It can swing in a line or a circular way. After touching the speaker, it will continue to oscillate corresponding to the new energy applied to it. We decided to try to distinguish the natural motion of the pendulum from the audience interacting with it. In order to do this, we have developed an algorithm that learns the period, phase and amplitude of the swinging behaviour, we then analyse and compare the current phase and position of the pendulum with the predicted natural movement. This way (human) interruptions of the natural movement can be immediately detected and its energy can be quantified by calculating the amount of deviation. The detected human energy put in to the installation is used to influence the sonic and interactive behaviour of both the pendulum speaker and the surrounding speakers. After interacting with the speaker, the algorithm learns the new swing movement and interprets it as the new natural movement. We believe that this direct form of interaction, realised in this way, gives the audience a feeling that the pendulum is alive and able to respond to the audience's actions. We intent this to result in a playful and physically intensive interactive endeavour.

3.2 Software Development

One of our goals for the experience of the installation was to give the audience the feeling that they are interacting with a system that has a form of autonomous behaviour. The installation was designed to noticeably react to the audience, but also have a certain amount of unpredictability in how it reacts. Furthermore, in order to motivate the audience to interact with the installation for longer periods of time, we chose to let the behaviour evolve as a result of the amount of energy that the audience puts into the installation. To achieve this, a system of rules was developed that was inspired by mathematical models, used to model the dynamics of biological populations. In the process of developing the software, these original models were modified and adapted freely in order to make the interaction with the installation intuitive and fun. The software uses this set of a models to translate the input data from the sensors to parameter values and mappings that control the sound that the installation outputs (see Fig. 3).

Excitement and State. In our system, each of the surrounding speakers forms a separate entity that produces its own characteristic sound. The character of the sound is determined by calculating two main features for each speaker: 'excitement' and 'state'. These features were implemented in order to achieve an evolving form of interactive behaviour. The state determines both the character of

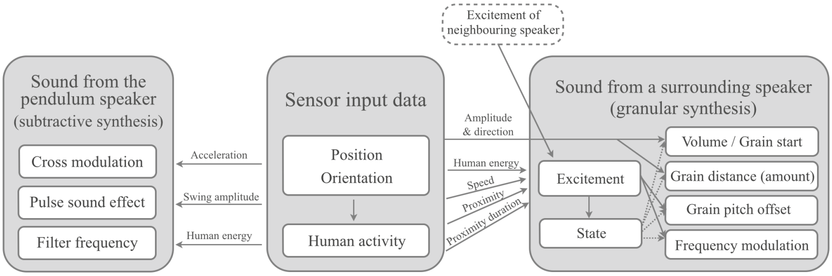

Fig. 3. Diagram with mappings of the input data to the sound output parameters.

the sounds that are produced, and how the speaker reacts to the movement of the pendulum. The level of excitement ranges from 0 to 100. It is a variable to describe how 'excited' a speaker is within its current state. It is continuously updated by an algorithm that uses (1) audience interaction–how much energy has been put on the pendulum speaker, (2) the pendulum's proximity to the speaker, (3) the duration the pendulum is within a certain proximity of the speaker, (4) the pendulum's speed, and (5) the level of excitement of its neighbouring speakers. The excitement level is calculated for each speaker separately. When a speaker's level of excitement reaches 100, it shifts to the next state. When its level of excitement decreases to 0, it falls back to the previous state. There are 10 states in total, starting from 0. Each state has its own mapping strategies. They are designed is such a way that the audience perceives a clear change in sound and interactive behaviour and gets challenged by the new interactive behaviour.

We have added some additional rules to the state changes. A speaker can only switch to a new state when the state difference between the speaker and its neighbouring speakers is less than 3. Otherwise, it will not change state and influence the neighbouring speaker's level of excitement instead and wait for it to get to a higher state. Due to these rules, the system as a whole evolves as a result of the individual speakers' behaviour.

The pendulum speaker also has its state. It is determined by, what we call, the system state. The system state is the average of the states of all surrounding speakers. An important exception to these general rules is that when the system state equals to 8, all of the speakers' states will shift to 9. This state lasts 30 s as a clear stage and builds up to a point where there is no return, because the feedback mechanisms in the system drive it into a state of uncontrollable chaos where all speakers stop being influenced by the audience. We will discuss this special state in detail in Sect. 4.

Growth and Decay of Excitement. The level of excitement increases while the pendulum is close to a surrounding speaker and it slowly decays while the pendulum is further away from it. Furthermore, the growth rate of the excitement varies with the amount of audience interaction. More interaction results in a higher growth rate. When the pendulum is following its natural movement the growth rate will get lower and the speakers start 'cooling down'. Each surrounding speaker has its own growth rate related to the audience interaction. We believe that the implementation of growth rate adds to the intuitive nature of the interaction with the system. We have decided to make the decay rate increase once a surrounding speaker reaches state 4, which means its level of excitement will decline faster and its state will easier fall back to its previous state. Thereby it becomes harder for a surrounding speaker to reach a state higher than 4, especially when there is no continuous human activity detected by the pendulum. To avoid that the states would alternate too fast, a minimum time that a state lasts has been defined.

4 Sound Design

Two different sound synthesis techniques are used to make a clear sonic distinction between the pendulum and the surrounding speakers. While the pendulum generates machine-like (low to mid frequency) sounds, higher frequency sounds are generated from the surrounding speakers. The algorithms that are used to interpret and translate the input data into sound, make the installation react both directly and indirectly to the interaction with the audience. This gives the audience a sense of control, but at the same time makes the sounds that result from the interaction unpredictable. Meanwhile, the sound results of the installation can develop from calm and peaceful to chaotic and aggressive. This was done to make the audience perceive the installation as beautiful and calming when handled carefully, but also dangerous and distressing when handled aggressively.

4.1 Sound from the Pendulum Speaker

We use U-he Diva, a virtual analogue synthesiser in Ableton Live, to generate the sound for the pendulum speaker [4]. The control parameters are calculated in Pure Data and sent to Ableton Live via MIDI. The machine-like sound is produced by two oscillators passing through a voltage-controlled filter (VCF). Using cross-modulation, a sawtooth oscillator and a sine wave oscillator modulate each other's frequencies. The VCF is a low-pass filter, that filters the sounds of both oscillators.

For the sound design of the pendulum speaker we use a mechanical machine as a metaphor. The control parameters for the sound synthesis are derived from the pendulum's own physical behaviour. The amount of human activity is mapped to the amount of the frequency modulation and the filter frequency. The audience can 'power on' this machine by putting energy into the pendulum. The pendulum's position is used to play a single midi note that gets triggered every time the pendulum travels a specific distance in space. Furthermore, the swing amplitude controls the velocity of each midi note. When the pendulum swings, it generates pulse sound effects. The linear acceleration of the pendulum is mapped to cross-modulation between the oscillators, to make it sound like a machine engine is operating and accelerating. Meanwhile, the rotation rate of the speaker is mapped to the pitch of the synthesised sound. The faster the pendulum rotates, the higher the sound. In this way, the amount of human activity is used to create direct feedback when the audience interacts with the pendulum speaker. The more energy the audience is trying to put into the pendulum, the more active and powerful the machine will be, and the more dynamic the sound will be. The parameters decline again when no one touches it. The state of the pendulum speaker is used to make it sound more aggressive. When the pendulum speaker reaches state 9, it stops triggering midi notes but generates a continuous and stable sound. The cross-modulation and low-pass filter are removed, and the pitch goes much lower. The machine turns out to be 'over-excited', and cannot be controlled or influenced by the audience any more.

4.2 Sounds from the Surrounding Speakers

In contrast to the synthetically generated sounds from the pendulum speaker, the surrounding speakers produce a more natural sound. The sounds are generated using a granular synthesiser built in Pure Data. Each of the speakers have their own individual synthesiser that uses the same sound sample but with a pre-edited different pitch. The original sample is a recorded hit of a bell. When the pendulum hangs exactly at its equilibrium point in the centre of the space, the surrounding speakers will not generate any sound at state 0. But when the pendulum moves towards one of the surrounding speakers the sample is played in full length. It sounds like the audience is using the pendulum speaker to hit the surrounding speakers, and 'awake' them.

In a later state, the granular synthesiser is used as a polyphonic sample playback engine. The distance between the pendulum and each surrounding speaker is mapped to the grain distance which sets the rate at which the grains are triggered and results in overlapping grains with a variable density. Currently, up to 100 overlapping grains can be generated resulting in dynamic and rich sonic textures. We believe that this behaviour makes it intuitive for the audience to perceive what kind of effect the pendulum speaker has on each of the surrounding speakers. Next to that, the distance value is also mapped to the start point of each grain player. There is a clear and loud hit at the beginning of the sample. We found that using the start point was an optimal parameter as opposed to the use of volume control since it applies the natural decay of the sound. The closer the pendulum moves towards a surrounding speaker, the louder sound it produces. This behaviour can be easily understood by the audience and is intended to help them to understand the behaviour of the implemented excitement.

We have implemented different mapping strategies for the different states, in order to create distinct sonic characteristics for each state. Initially we implemented 5 states. As the state of a speaker increased, the sound transforms from stable harmonic tones into abstract and unrecognizable synthetic noise. However, the changes between the states were large and sudden. We then decided to implement more states to transform the original sample in a more gradual way. This makes it easier for the audience to perceive changes of the system while navigating through the various states. In order to create more complex dynamics in the playback of the grains, we have added frequency modulation for states above 3 and randomised the start point and pitch within a specific range of each grain. Subsequently, the grains create a more complex, and use a wider sonic range. The original sampled sound gets dispersed because the hits are intensified and blurred as the speaker reaches higher states. The sound becomes more and more chaotic as the speaker gets excited. In state 9, all of the surrounding speakers play the full length of the original sample with frequency modulation and repeat at a random interval. The sounds become more machine-like compared to state 0, and assimilate into the pendulum's synthesised sound. After reaching the highest state the system 'cools down' and needs a little rest before it starts responding again starting in state 0.

5 Experience and Discussion

During a three-day exhibition at the NIME 2018 conference, some observations of the audience interacting with the installation were made. We also had informal conversations about the work with some of the visitors. Although we did not use a strictly defined method for reviewing, our observations gave us some preliminary indications of how the audience reacts to, and interacts with the work. We noticed that, at first, many visitors were mostly observing the installation instead of interacting with it. Some mentioned that 'they were not sure if they were allowed to touch the work'. After interacting with the installation, most of the participants that we observed independently discovered the different forms of movement that the pendulum speaker reacts to, without the need for specific instructions. This seems to indicate that the basic form of interaction is intuitive. Most of the visitors also seemed to quickly notice that moving the pendulum towards a surrounding speaker resulted in this speaker reacting by playing a sound. Some visitors specifically mentioned that the interaction reminded them of handling a bell or wind chimes. Thus, it seems that the direct and noticeable sound results can help the audience understand the interaction and navigate through different types of sound composition. However, it seemed to not always be clear to the audience that the installation's sounds were able to develop from calmly to aggressively sounding and that the effects of the audience's interaction with the sounds would then also change. For some visitors, this was due to them handling the pendulum speaker so gently that the installation would always sound calm and not aggressive. Other visitors did put enough energy in the installation to make it sound aggressive, but seemed to not be fully aware of how their actions altered the sounds. Although we also noticed that with the current setup, visitors needed some explanation before being able to experience the full dynamics and concept of the installation. A clearer distinction between different 'states' of the installation might help visitors to more easily discover the different sounds of the installation independently. Lastly, our observations indicated that visitors had quite varying sensations while experiencing the installation. Some visitors avoided close proximity to the pendulum, but to others purposefully stood right under the pendulum to 'get a rush of it swinging right over their head'. Some visitors experienced the installation while laying on the floor and reported that it was a calming experience to them. This indicates that the audience was able to perceive both sensations of beauty and danger, which we aimed to convey with the installation. We believe that a good interactive installation should explain itself to the audience. In other words: it should steer the audience in such a way that it reveals its behaviour to the audience. Our initial observations indicate that there is still some room for improvement.

6 Conclusion

Bǎi is an interactive installation that uses a pendulum speaker as an expressive control interface by sensing its position, speed and rotation. Besides performing its own natural movement, the speaker gives both physical and audible feedback to the sensed input. The audience's actions have a direct impact on the sound the speaker produces. Since there is no distinction between the input and output interface we believe that creates is an intuitive way for the audience to interact with the system. The installation tries to challenge the audience when they are playing with, and adapting their behaviour to the interface. We do this in order to give the audience the feeling they are controlling and interacting with a system that noticeably reacts to them, but also has its own behaviour and thereby a certain amount of unpredictability. On its turn, the pendulum speaker interacts with the surrounding speakers. This happens in a bidirectional way. While the pendulum speaker's movement triggers sounds in the surrounding speakers it also influences the excitement and state of the them. The pendulum's state gets affected by their state in return. We have constructed a dynamic relationship where the states of the surrounding speakers shift up and down, depending on the intensity and duration of the audience's input.

There are several options for the audience to be engaged in the installation. One might stand alone and observe the installation, or walk around and move the pendulum speaker. It is possible for others to join simultaneously and either observe or join the interaction.

While our installation is based on a complex system, we believe that the responsive interaction method is easily understandable. The initial observations during the previous exhibition have given us some indications, but for a good review of the interaction of the audience with the installation a thorough study needs to be done. Where the goal of this paper is to describe the development, choices and behaviour of the installation our next step will be a structured evaluation of the interactive behaviour of the installation. The goal of this evaluation is not only to create insight in the current system but will also be used to further develop it.

References

1. van der Heide, E.: Spatial sounds (100 dB at 100 km/h) in the context of human robot personal relationships. In: Lamers, M.H., Verbeek, F.J. (eds.) HRPR 2010. LNICST, vol. 59, pp. 27–33. Springer, Heidelberg (2011). https://doi.org/10.1007/978-3-642-19385-9_4
2. Monahan, G.: Speaker swinging. http://www.gordonmonahan.com/pages/speaker_swinging.html. Accessed 17 May 2018
3. Reich, S.: Pendulum music. http://www.ubu.com/aspen/aspen8/leadPendulum.html. Accessed 17 May 2018
4. Diva Homepage. https://u-he.com/products/diva. Accessed 17 May 2018
5. Pure Data. https://puredata.info. Accessed 17 May 2018