Kugelschwung - a Pendulum-based Musical Instrument

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ABSTRACT

This paper introduces the concept of Kugelschwung, a digital musical instrument centrally based around the use of pendulums and lasers to create unique and highly interactive electronic ambient soundscapes. Here, we explore the underlying design and physical construction of the instrument, as well as its implementation and feasibility as an instrument in the real world. To conclude, we outline potential expansions to the instrument, describing how its range of applications can be extended to accommodate a variety of musical styles.

Keywords

laser, pendulums, instrument design, electronic, sampler, soundscape, expressive performance

1. INTRODUCTION

Many current musical performances that utilise technology leave the audience confused, due to the “black box” nature of their working creating a barrier between the audience and the performer. To counteract this, we set to work creating an instrument that could engage the audience both visually and audibly. We decided to explore the use of pendulums, as their steady, rhythmic motion is familiar to most people, making them highly expressive and approachable for musicians and musical newcomers alike. Our project culminated in a live public performance in front of more than 100 faculty staff and students from the Computer Science department at the University of Bristol.

1.1 Influences

Our initial inspiration for this instrument came from the BeatBearing [2], which is a “tangible rhythm sequencer”. This showed us an implementation of a fully interactive rhythm-based instrument. After imagining pendulums in a similar way due to their harmonic properties, further investigation led us to examine the natural rhythmic properties of the Pendulum Waves apparatus [3]).

This highlighted the differences between Pendulum Waves and BeatBearing to us, in that BeatBearing provided a rigid yet rudimentary rhythm platform, whereas Pendulum Waves allowed for a unique soundscape but was not suitable for rhythmic timekeeping. Since we were aiming to make a *musical* instrument, we decided to take the Pendulum Waves apparatus as a primary inspiration for Kugelschwung.

Using Pendulum Waves as a basis for research, we extended our findings and learned more about the application of pendulum-based instruments in the real world. Two notable examples we found were the Gravity Harp used during Björk’s *Biophilia* tour [6], and Pendulum Music by Steve Reich [8]. Both artists are known for their experimental approach to music, and so examining these instruments highlighted the potential of applying an instrument like the Kugelschwung to electronic music from a minimalist perspective.

The Kugelschwung could be considered to be part of the family of digital musical instruments based around moving mechanical systems [9], which would include instruments such as the Gyrotyre[10], the Strimidilator[1] and the Rulers[5]. Such instruments make use of mechanical movements as part of the instrumental interaction, using sensors to detect parameters of these movements. While interaction is initiated by the performer, the energy of this interaction causes a mechanical movement which continues to create sound for a period of time after the initial interaction.

2. PHYSICAL DESIGN

This section details the physical design of the Kugelschwung, including the physics that underlie its operation, the materials used in the construction of the initial version of the Kugelschwung, and the electronic circuitry that senses the physical movement of each pendulum.

2.1 Underlying physics

The Kugelschwung device at its lowest level is a simple set of pendulums, mounted in parallel. Each pendulum’s movement is interpreted via the addition of light sensors mounted directly below the central point of the pendulum’s fixation to the structure. Kugelschwung approximates a simple har-

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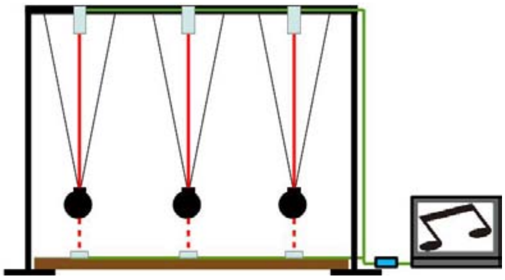

Figure 1: A diagram of a simplified Kugelschwung, with 3 pendulums, connected via a Phidget interface kit to a computer

monic oscillator by using light, inextensible strings, large ballast weights and measures to keep the effects of friction to a minimum. Kugelschwung's highest and lowest frequencies respectively were 4Hz (240BPM) and 1Hz (60BPM), with a base rate of 2Hz (120BPM).

2.2 Materials and construction

The initial version of Kugelschwung was designed to produce up to eight independent signals. It uses eight lasers and corresponding light sensors to supply the controller program with the physical signal inputs needed for it to generate the notes. The project was built around the Phidget I/O board [7] and as such used the standard sensors supplied with this interface kit. The project would however easily be portable to an Arduino or a Beagle Board. The structure primarily consists of a metal frame with laser mounting points and a row of sensors below, as shown in Figure 1.

Each pendulum is attached to two points on the frame equidistant from the mounting of its corresponding laser using lightweight, inextensible strings. By fixing the pendulums to two points on the plane the pendulums are restricted to one axis of movement. An inextensible string was chosen due to the irregular rhythms that resulted from using more flexible alternatives (such as elastic bands) during testing. The pendulums were suspended at different heights to produce different time periods of oscillation.

Precision light sensors were used to minimise the impact of ambient light in the room, although the conditions still required a relatively low amount of ambient light. Although these light sensors were Phidget branded, any standard light dependent resistor coupled with a suitable voltage divider could be used as a substitute.

2.3 Electronics

The Kugelschwung is powered by a 4.5V battery (three 1.5V cells) supplied to all 8 lasers in parallel. Attached to each laser is an NPN-Transistor which allows for computer controlled switching of individual lasers through a Phidget digital out interface. Figure 2 shows the electronic circuitry required for two lasers.

Cable management was implemented using a 32 core copper shielded cable attached above the pendulums, following along the frame. This was important for the instrument as cables could not be allowed to interfere with the motion of the pendulums.

3. SOFTWARE, MAPPING AND PERFORMANCE

This section details the software that allows the user to control the Kugelschwung's operation. We also discuss the mapping used for our initial rehearsals and the inaugural performance itself.

3.1 Software Interface

The gateway to controlling the sensors and receiving their readings comes in the form of a Phidget interface board, which connects to a computer via USB. Since the controller program we wrote was in Java, we utilised the Java API that is associated with the Phidget board, which enabled readings from the sensors to be used by the program.

The controller program first scans for all the MIDI devices currently interfacing with the computer at the time of its execution, and selects the device to be used for sound output. A command line interface is then provided to the operator, allowing them to interact with various components of the structure. The following commands are available from this command line interface:

- **all** - toggles all lasers on/off, depending on their current state
- **0...7** - where each number between 0 and 7 toggles the state of individual lasers
- **hi** - toggles the higher half of the lasers on/off (lasers 4-7)
- **lo** - toggles the lower half of the lasers on/off (lasers 0-3)
- **inst 1...128** - changes the instrument sound that the pendulum signals trigger, initially choosing from the MIDI set
- **note 0...** - changes the root note that the pendulums base a scale around (first pendulum assuming this note, others assuming the other notes in the scale in ascending order). For reference, *60* is a major scale based around middle C
- **vol 0...127** - changes the master volume of the instrument (by universally changing the volume property of the MIDI signals being sent)
- **journey** - a pre-programmed automation that systematically cycles through each instrument of the MIDI set with 2 second intervals - this was included for testing purposes, but also showcases the instrument's range
- **stop** - turns off all lasers and shuts down the program

The controller operates as the pre-processing element of the sound creation procedure, preparing the MIDI signals that are either played directly, or fed to other software synthesisers as triggers for more realistic VST instruments. We used *FL Studio* [4] but any digital audio workstation (DAW) program should be suitable for the required purpose.

3.2 Mapping

During development we experimented with a number of different approaches as to how the instrument should be used. Initially we discussed a split layout, where half of the pendulums were used for one instrument, for example a drum-kit, and the other half were used for another instrument, such as a synthesised bass. This approach required two operators, with one additional person acting as a computer operator. However, we found that with eight pendulums on offer, the range and capabilities of either instrument would be too limited with only a subset of the pendulums available.

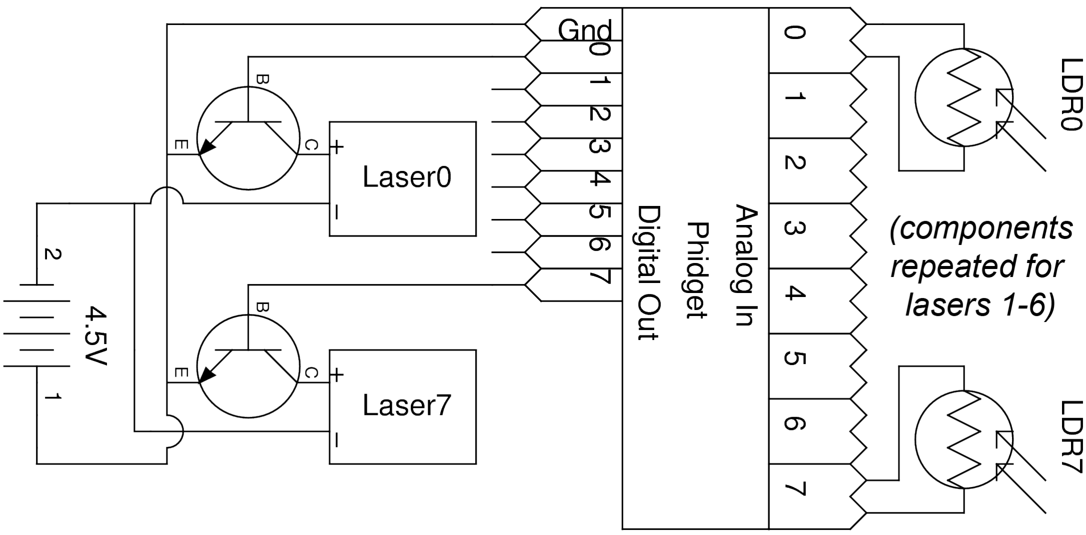

Figure 2: A circuit diagram of the electronics behind Kugelschwung (only wiring for the first and last lasers are shown for the sake of compactness - all lasers and sensors are wired in the same way)

Given this, we opted for a general instrument interface, that could assume the sound of any instrument it was set to emulate (providing there existed a software synthesiser for it). This allowed the natural phasing characteristics of the pendulums to be far more apparent and influential on the overall sound. Furthermore, due to the abstract phasing of pendulums of different lengths, Kugelschwung was more naturally geared towards making music of a more electronic and ambient nature.

We opted for a standard tempo base of 120BPM, and the other pendulums acting as exact divisions of that (e.g. some at 60BPM, others at 240BPM). However, the tempo chosen is entirely up to the musician(s) using the instrument at that time.

3.3 Performance

The arrangement of the first official public performance consisted of three people operating the pendulums (regulating their rhythms and controlling when they were in motion), one operating the computer interface (to toggle the lasers and change the instrument sounds on the fly), and another on an electric guitar to provide an additional melody to the overall sound (though this addition is entirely optional). While three people was the optimal number of users for that specific performance, there is nothing to stop the instrument being remade to a larger scale to facilitate more players simultaneously - we made it to this relatively small scale due to budget and portability constraints.

Playing the instrument revolves more around live spontaneity and the environment rather than the recital of a pre-defined composition, due to its unpredictable nature. The addition of the guitar helps to add a foundation of familiarity for the audience, creating an "overspill of liveness" that allows them to focus more on the musical contrast the Kugelschwung provides.

Due to the physical tangibility of the instrument, there are many different ways to interact with it. You can let the pendulums swing on their own accord to generate a steady pulse, or you can manually start and stop them to produce a syncopated rhythm. Alternatively, you can ignore the pendulums altogether, and interact with the lasers with your hands - though this is not the intended method. Essentially, the performer is allowed to interact with the instrument in whatever way they see fit to express themselves - there are no specific restrictions.

Therefore, performing on the instrument is an expressive and emotionally-driven experience that incorporates a lot of the performer's physical actions - since they will find themselves acting more on impulse than conventional musical knowledge.

3.4 Feasibility

The obvious advantage of Kugelschwung is the physical tangibility of the interface. This open-ended physical approach allows many to use the instrument at once, and for the performers to interact with each other's movements and actions to make a more unique sound personal to those playing it. This makes the instrument's focus more of a group based object for collaborative use as opposed to something that a single musician would necessarily use.

In its current state, changing the sound settings of the instrument requires a relatively comfortable level of technical skill, in order to be able to use the simple command-line interface. However, should the scale of the instrument be enhanced, there is nothing to stop this being replaced with a more user-friendly computer interface, or by bypassing the computer altogether and going with an on-board series of switches and dials.

The current features of Kugelschwung certainly have the potential to be appealing to the electronic ambient music community, and, to a lesser extent, musicians writing music in other genres. The irregularity of the overall pendulum motion however makes this instrument unsuitable for playing a conventional song without a large amount of prior rehearsal, and so isn't a viable option for conventional use.

4. FUTURE DEVELOPMENTS

While overall we feel that the development of the Kugelschwung has been quite successful, our experiences rehearsing and performing with it have raised a number of areas of possible improvement.

Figure 3: Kugelschwung in action, with guitar

4.1 Physical structure

As mentioned previously, the decision to build the instrument with eight pendulums was as much a personal choice as a mandatory one. We built the structure frame using parts that were readily available to us. This resulted in a physical structure that was usable for our testing, rehearsal and performance sessions, but that would not (for instance) be robust enough for regular performance and/or touring.

In order to make this instrument more accessible for a wider audience, the structure would have to be a lot more resilient and resistant to tampering and wear-and-tear, by concealing and insulating the electronic components and wiring, and by making the frame joints sturdier. Similarly, custom-made pendulum weights would be required to allow for a detailed fine-tuning of the mechanical response of the instrument.

4.2 Interface

Currently, Kugelschwung requires a computer to act as an interface to interpret the physical signals and create audible notes. Ideally, we would aim for a fully on-board interface, with all the receiving and processing of signals performed on the instrument itself via dedicated hardware. This would make the instrument more portable, more accessible for new users, and would eliminate the need for a computer with a specific hardware configuration. Furthermore, we would switch to more advanced communication methods, such as OSC, instead of MIDI (which we use currently).

If the processing was to be brought on-board the instrument, then the controls would have to be as well. This would render the old command-line based controller program obsolete, since it would have to be replaced by a series of physical switches and sliders, with potentially a simple LCD display for visual feedback (instrument selected, volume, etc). While this is harder to implement, it puts the emphasis on the instrument to handle every stage of the sound production, as an instrument should.

4.3 Musical direction

Currently, this instrument is designed to be used as a singular unit, convertible to the purpose of any instrument sound (permitting that one instrument sound is used across all pendulums). Another proposed configuration discussed during design however was to construct it using a more modular design, in that a musical group could be formed using multiple smaller Kugelschwung units that each represent a different instrument. This opens up the feasible usage of Kugelschwung to an open-ended combination of highly versatile instruments.

5. CONCLUSION

This paper has illustrated how pendulums can be used as an instrument to create musical performances. Although we consider the Kugelschwung to have been a successful tangible interface, further research and development could improve it into an instrument capable of having a practical application in a wider range of musical genres, for a wider audience.

One notable feature of the Kugelschwung is that despite it only taking a newcomer a few minutes to make basic music with the instrument, for a more experienced musician it could take a large amount of time to devise a new composition. This follows the guideline given by Wessel and Wright [11] that a new instrument should offer a "low entry fee" with "no ceiling on virtuosity" and shows the true flexibility of the instrument and the potential for pendulum-based instruments to be used for both entertainment and serious composition.

6. ACKNOWLEDGEMENTS

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