The extended clarinet

Carl Jörgen Normark
Luleå University of Technology,
Innovation and Design
97187 Luleå, Sweden
jorgen.normark@ltu.se

Peter Parnes
Luleå University of Technology,
Computer science
97187 Luleå, Sweden
peter.parnes@ltu.se

Robert Ek
Norrbotten NEO
Luleå, Sweden
robert.ek@remusik.se

Harald Andersson
Luleå University of Technology,
Computer science
97187 Luleå, Sweden

ABSTRACT
This paper describes how a classical instrument, the clarinet, can be extended with modern technology to create a new and easy to use augmented instrument. The paper describes the design process, technical details and how a musician can use the instrument. The clarinet bell is extended with sensor technology in order to improve the ways the clarinet is traditionally played and improve the performing artist's musical and performative expressions. New ways of performing music with a clarinet also opens up for novel ways of composing musical pieces. The design is iterated in two versions with improved hardware and form factor where everything is packaged into the clarinet bell. The clarinet uses electronics that wirelessly sends sensor data to a computer that processes a live audio feed via the software MAX 7 and plays it back via loudspeakers on the stage. The extended clarinet provides several ways of transforming audio and also adds several ways of making performances more visually interesting. It is shown that this way of using sensor technology in a traditional musical instrument adds new dimensions to the performance and allows creative persons to express themselves in new ways as well as giving the audience an improved experience.

Author Keywords
Clarinet, Augmented, Musical expression, Sensor technology, Gestures, Motion

ACM Classification
Human-centered computing~Haptic devices, Applied computing~Sound and music computing, Hardware~Sensors and actuators

1. INTRODUCTION
Traditional acoustic musical instruments have been around for a long time. These often demand richness in physical control and some time of practice in order to play them. This is in stark contrast with many modern computer-controlled aspects of music making that are controlled by interfaces that demand sets of choices the user must think about instead of interaction using physical richness [5]. A traditional musical instrument gives the user more control by providing an overall view of the system where the performer can direct manipulate several parameters simultaneously by using various movements and receive feedback instantly. [6]. With the help of sensor technology and data processing capabilities, it is now possible to extend how traditional acoustic instruments are used and harmonize them with our current digital ways of making music [14]. Modern technology allows us to extend and enhance existing instruments, for example, a clarinet. There are also previous examples of clarinets being augmented with sensor technology [12]. Compared to digital instruments, augmentation of acoustic instruments can maintain the traditional way the instrument is played and maintain the performer's virtuosity at the same time as another layer of digital music creation is added [13]. Sensors can add non-visual and hidden interfaces for interaction controlled by gesturing, pointing, and tilting devices in the air without adding to the external complexity to the musical instrument [7]. Using sensors to augment instruments with gesture sensing capacities have been popular and it is shown that 62% of all NIME papers from 2001-2013 use the term 'gesture' [8] and thus the work presented in this paper builds on this way of interaction. Accompanist moves, are moves that are not directly effects of the music production [15] but they are shown to add to the communicative and expressive parts of the performance [2]. There are also attempts to transform accompanist moves that enhance the visual performance, but does not affect the sound production, into something that can be used to both provide sensor data for sound processing and provide a visual effect for the music performance [13]. Musical instruments can be complex in all of Janlert and Stolterman's complexity levels; internal- (complex mechanisms inside the instrument), external- (complex controls), interaction- (complex ways of using the instrument), and mediated complexity (complexity that depends on the context) [7]. Increased complexity stemming from technology can make us experience that we lose control of the situation [10]. By adding more possibilities for interaction with the clarinet, the complexity is also increased, however, increased complexity can also support the user and allow for a more advanced use and even allow for increased control and supported virtuosity with the instrument [7]. Too much deviation from the norm of the instrument by adding superfluous control complexity can add cognitive loads as well as deteriorate the performer's technical strengths [3]. Complexity, as well as the control of complex musical materials can also be managed by using familiar bodily sensations and actions [4]. For clarinetists, an example of a familiar movement would be a continuous upwards directed gesture while playing long sustained notes [1].

Because a clarinet is an instrument with a complex external complexity, the aim of the extended clarinet presented in this paper is to augment the instrument with new possibilities and at the same time preserve the instrument's external complexity and only increase its internal complexity [7]. This is accomplished by avoiding making the instrument look too technological with visible electronics or controls. As this might affect the interaction complexity [7], another aim is to

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find ways how to interact with the music as natural as possible without forcing the performer to compromise any virtuosic qualities of the acoustic instrument. There is a risk that controlling an additional layer of interaction can deteriorate the performers virtuosic skills [9,12]. The last aim of this project is to find a way to use gestures and sensor technology to provide an augmented visual expression as well because visualization of the digital parts of the performance can help the audience understand and relate to the expressions of the performer [11].

2. METHOD

The work presented in this paper has been a multidisciplinary project that has utilized several different competences. The project team has consisted of people knowledgeable in computer science, industrial design, interaction design, sensor technology, data communication, and musical performance. The work process started with identifying which part of the clarinet that could be extended and modified without changing the physical and audio appearance of the instrument and the *bell* of the clarinet was chosen. A 3D scanning of the original clarinet bell was done in order to be able to replicate the bell without changing parameters affecting the sound noteworthy. See Figure 1. The model of the bell was digitally modified in order to allow for mounting of sensors and electronics and was 3D-printed. Electronics were mounted inside the bell and a cover was modeled and printed in order to cover up the sensors and give the clarinet a look that would not focus too much on the sensor technology and yet make it look attractive. Finally, programming took place to allow for communication between the clarinet bell and a computer with the software MAX 7.

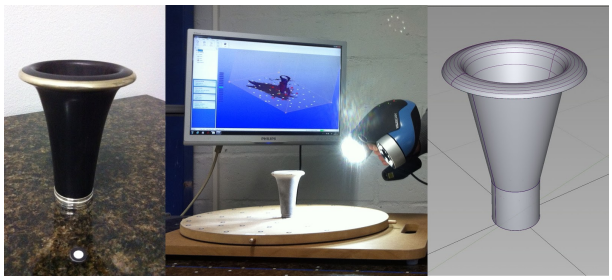

Figure 1. A thorough process to maintain acoustic qualities

The first iteration of the extended clarinet made a proof of concept that would be improved in the second iteration. The artist played and evaluated the extended clarinet at several occasions and came with suggestions for improvements. The second iteration of the design and development of the extended clarinet fixed problems with reliability, performance, and interaction with the clarinet and also focused on adding new hardware and a different set of buttons for simpler interaction and finally a new cover to fit all of the new electronics was developed. Again, the artist played and evaluated the clarinet at several occasions. In the following two chapters the two iterations are presented more in detail.

3. ITERATION 1

The goal of the first iteration was to create a proof-of-concept together with a professional musician and get feedback on the usage via a real physical prototype of the instrument.

3.1 Technical aspects

The first prototype used a Spark Core as the main controller, a battery with capacity of 450 mAh with a SparkFun Power Cell as power handler, a NeoPixel strip with a pixel density of 144 LEDs per meter, an accelerometer (SparkFun MMA8452Q), a magnetometer (SparkFun MAG3110), and a touch button controller (Adafruit AT42QT1070). Figures 2 and 3 shows iteration one of the extended clarinet and the internal technical architecture.

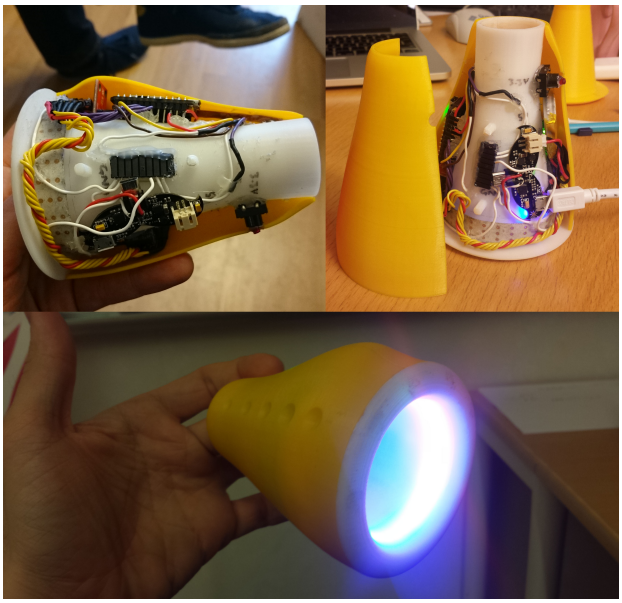

Figure 2. First iteration of the clarinet bell

The touch button controller used separate connections for each button, which were connected to the controller's digital inputs. The accelerometer and magnetometer were connected to the controller via I^2C, however, the magnetometer was in the end not used due to software issues. The sensor data from the accelerometer as well as the button states were transferred over Wi-Fi to a computer via IP/UDP for processing. Due to low amount of CPU power available in the controller on the instrument, no calculations using the data were performed on the controller itself. Instead the computation of accelerometer data in order to estimate the roll and pitch angles of the instrument was done in MAX on the computer. This allowed the system to provide a high level notion of motion and gestures as a way of interacting with the instrument and making it easier to program how to affect the sound and music in real-time. See figure 3 for an overview of the hardware architecture.

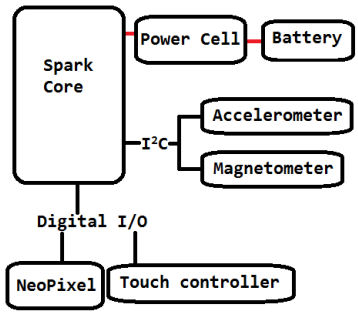

Figure 3. First iteration wiring diagram

3.2 Interaction aspects

One of the major changes compared to a traditional clarinet is the possibility to use motion and gestures in order to transform the music played. The clarinet bell contains several touch buttons in order to switch between different modes for the gestures. One mode allows the performer to tilt the clarinet upwards while playing, in order to loop the playback of the

current notes played while the clarinet is tilted upwards. The other mode incorporated in the first prototype involves a pitch bend function depending on the clarinet angle, meaning that if the musician turn the clarinet while playing the music will automatically be affected. The buttons together with a wireless interface also controls the LED strip built into the clarinet bell, which is one way to provide an augmented visual expression of a performance. The light can be turned on and off and the hue of the color can be changed in order to provide an interesting visual effect to the performance.

3.3 Musician's evaluation

The instrument prototype was evaluated by the professional musician involved in the project on a number of aspects. Generally the first prototype was a good proof of concept. It showed that it was an efficient way to track artistic movement to modulate the audio signal with incoming data from the sensors. A few successful showcases were done with the extended clarinet, which offered some really good feedback. The professional musician involved in this project reflect on the prototype with the following comments: *"As a musician you always use movement as a means of expression and I was struck with the notion that this bell could be used in so many ways to enhance musical ideas. Through my occupation as a professional clarinetist in a chamber ensemble focusing on contemporary music I meet a lot of composers and have already initiated a couple of collaborations to find out what a composer might do with it."* (author's translation).

3.3.1 Technical aspects

The clarinet was first evaluated on the ability to hide all of the internal complexity of the sensors and electronics and not deviate too far from the visual appearance of a clarinet. The evaluation showed that the clarinet mainly kept its original appearance while hinting that this is an extended clarinet with augmented functions because no highly salient controls or electronics were visible. The bell casing, however, show that the clarinet offers something more than an ordinary clarinet.

The ease of use of the clarinet was also evaluated. It was shown that the set up procedure was believed to be too difficult to handle. It often took too long to set up the Wi-Fi connection due to limitations in the hardware. For example, the embedded controller did not have any display and thus had no way of providing feedback on IP-number etc. which is a general problem of embedded systems operating in a non-fixed network environment.

The reliability was evaluated and the prototype provided somewhat unreliable data quality that fluctuated too much and sometimes lost chunks of data. The sensor data itself was not reliable and stable enough for a concert. To be a really useful instrument the positional data has to reliable and accurate so that the audience can perceive the performer's intentions and perceive a pattern with consistency in the performer's actions and the visual and auditory output. The battery life was also too short to be usable in concert purposes because the time of the performance would be very limited.

3.3.2 Musical and artistic expressions

The way of interacting with the clarinet was evaluated on how natural it felt to use and how much additional complexity was added. The way of using gestures to control sustain and pitch bend function felt natural for the performer. Even though the complexity of the instrument was increased and demand some practice before it can be used with full potential, it did not add unnecessary cognitive load or other obstructions for playing the extended instrument. However, the approach of using touch buttons on the clarinet bell to switch between modes and functions was proven to be unreliable, even though they were visually attractive (i.e. hidden behind grooves in the shell). It was too difficult to locate the correct button and the touch buttons did not provide any additional feedback that the wanted function was selected. With sufficient feedback, this additional action of using one hand to press buttons on the bell while playing was believed to be simple enough so the quality of the performance and the ability to play the original clarinet would, with a little practice, not deteriorate noteworthy. All things considered the extended instrument would become too complicated for a musician to use, however, the expressive aspect were promising.

In evaluating the clarinet's potential of adding new ways of artistic expression it was found that it indeed opened up new ways of expression. The ability to sustain notes and make use of pitch bend by using body movements also an added strong cognitive function for the audience when physical actions is interpreted in different audio modulations.

The visual expression of the clarinet prototype was evaluated but the LED-strip built into the clarinet bell was experienced more as a gimmick and a way of showing that this instrument contains something new than a way of extending the visual expression of a performance.

In general, the first iteration proved that the ideas were possible to realize but more work was needed. These problems had to be addressed in another iteration of the extended clarinet bell prototype.

4. ITERATION 2

The goal of the second iteration was to create a more reliable and usable instrument that could be used by any musician by addressing the identified problems mentioned above.

4.1 Technical aspects

For the second iteration the Spark Core was exchanged for its sequel, the Particle Photon. The battery was replaced with a larger one with a capacity of 2000mAh and a LiPo fuel gauge was connected to provide information about current battery status. The accelerometer and magnetometer were removed and replaced with a single IMU (Inertial Measurement Unit, SparkFun LSM9DS1) that included an accelerometer, a gyroscope, and a magnetometer, all with three axes. A small display (SparkFun MicroView) was connected to the Photon via I^2C to allow for easier setup and configuration. The touch buttons and controller used in the first iteration were replaced with standard momentary push buttons connected to the Photon's digital inputs.

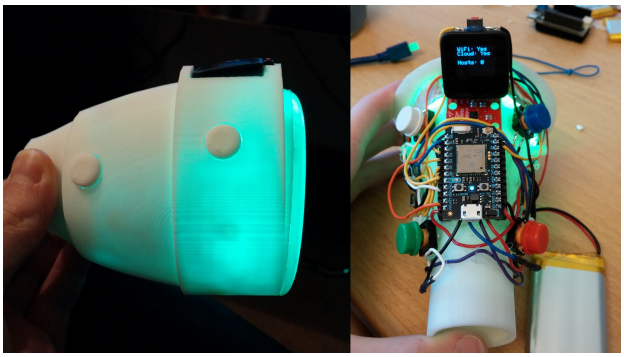

Figure 4. Second iteration of the clarinet bell

In addition to sending the button states and the sensor data, the sensor values from the accelerometer and magnetometer were used on the Photon to estimate the instrument's current orientation in terms of roll, pitch, and yaw angles, which in turn were sent to the computer. Filtering of the sensor data was implemented on the Photon in order to provide smoother data and remove unwanted fluctuations. This is a major change compared to iteration one where no computations were done in the clarinet itself. Three types of filters were added, a simple moving average filter, a low-pass filter, and a one dimensional Kalman filter, to provide several options, allowing the more advanced end user to choose the filter which best suites the user needs. The filter parameters could be set continuously during playing by the musician. This allows the musician to create different experiences and allows for integration of the sensor data into the performance. Figures 4 and 5 shows the second iteration of the extended clarinet and the updated internal technical architecture.

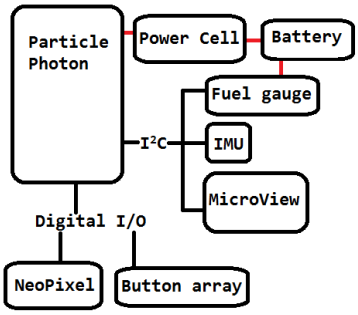

Figure 5. Second iteration wiring diagram

4.2 Interaction aspects

The second iteration of the clarinet used mainly the same gesture based interaction. The touch buttons were replaced with traditional push buttons due to lack of feedback in the touch buttons while performing with the clarinet. The patches built in MAX were designed with Vizzie clippings as a model. There are sets of modules for different purposes. An input module takes care of handling input data from the sensors and microphone. A second module is purely for settings and calibration. From the input module data streams can be connected to different modules that transform audio and/or light by using the sensor data. At this point in the project modules have been built for pitch bend, sustained looping of notes, wah-wah, bell-light, hue-light and 3D modeling. Because of the modular system additional modules can be developed at any time and use the desired sensory data. See Figure 6 for an overview of the modules in MAX.

4.3 Visual expressions

An important addition is that the second iteration of the clarinet allowed for altering data with gestures to better integrate with visual elements on the stage. The visualization of the collected data was divided into three parts, visualization using the LEDs in the instrument, using Philips HUE lights to alter the lighting in the room, and to control 3D graphics.

All visualizations are based on the estimated orientation of the instrument, mainly mapping the values to different colors to visualize movement. Common for all, is that the current orientation around the Z axis in degrees is directly mapped to the corresponding color on a color wheel to use as a base for the visualization. All visualizations are controlled via different software parts in MAX 7 on the computer.

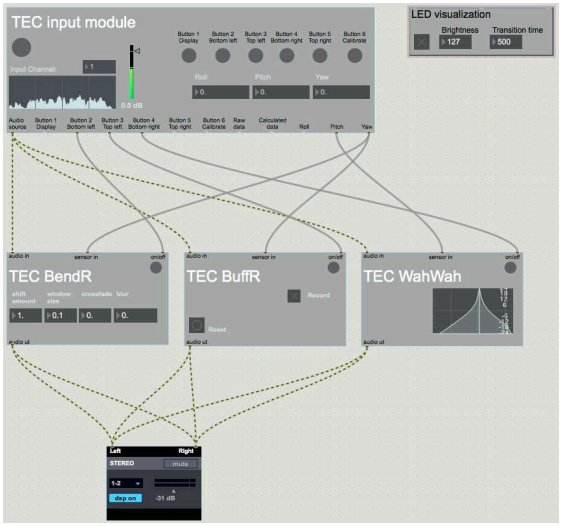

Figure 6. MAX modules

The visualization using the LEDs in the instrument use the pitch value to offset the base color, thus giving a visualization of movement around two axes. To achieve smooth transitions and avoid flickering a transition time of 0.5 seconds were used for the LEDs and new values were sent at the same interval.

The HUE visualization consisted of three HUE light bulbs. Only the base color was used, but it was sent to all lights with different delays, where the first light got the new value directly, the second got it after 0.9 seconds and the third after 1.8 seconds. This was done to let the lights act as a flowing timeline. By only using the base color for the HUE lights the audience is given a reference for hue pitch offset used for the LEDs.

The 3D visualization provided a simple augmented reality based 3D visualization. It consisted of a simple 3D scene with floor and back wall with wooden textures. On the back wall the video feed from a camera was projected in order to add the reality element. The floor in front of the video plane had eight stretched spheres, which would change its materials emission parameters depending on the current orientation around the Z-axis, giving the illustration of the light directly in front of the musician lighting up. The base color was added as scene lighting to match the real life scene. The pitch and yaw angles were used in the 3D visualization to control the position of the camera, allowing the musician to control the 3D view. The yaw was used as with the lights to always have the camera in front of the musician, while the pitch value was used to control the camera's elevation. Figure 7 shows the 3D-visualization in action[1].

4.4 Musicians evaluation

The professional musician involved in the project evaluated the second iteration of the prototype on the same aspects as the first iteration. Figure 6 shows the musician playing the clarinet. This is also shown in video example 2[2].

4.4.1 Technical aspects

The prototype's ability to hide internal complexity was once again evaluated because the cover of the clarinet bell was redesigned to fit the new hardware. Even with a display added and more salient push buttons the prototype managed to hide its internal complexity and at the same time give a hint that this clarinet bell is augmented with new possibilities.

[1] https://www.youtube.com/watch?v=anE8Xp-KeZU
[2] https://www.youtube.com/watch?v=4hHQ6px3iM4

The new display improved the setup procedure greatly with information on IP address and connectivity information. The Wi-Fi connection of the second prototype and the transfer of sensor data was much more reliable than the first prototype. Any drop out or packet loss was not noticeable.

4.4.2 Musical and artistic expressions

The clarinet was evaluated on the interaction aspects. The motion and gesture aspect of the extended clarinet was now proven to work satisfactory. Even though there is no other feedback regarding gesture position except the audible feedback provided by the loudspeakers, it was proven that the performer could use the system with ease. As long as the performer can rely on the sensors' capacity to provide the same position every time the instrument is played the performer can approach the way of playing similar to how a dancer performs. The dancer does not get any additional feedback about body posture but can to rely on his or hers muscle memory and motor skills. The same also relates to string instruments where the musicians need to practice his or hers muscle memory and aural skills in order to find the desired notes. The improved reliability of the second iteration of the clarinet was key to its performance.

The complexity of this prototype iteration was also evaluated. The system adds complexity to the instrument, for example in the case of the pitch bend module the performer have to be precise with the instrument's position to be able to control the desired pitches. For a performer to be able to use the full system potential he/she will have to spend a great deal of time practicing. However, this is quite similar to how any instrument requires a large amount of time to master because the extended functionality of this clarinet would be new to most clarinetists.

Figure 6. The extended clarinet in action

The second iteration provides better ability to enhance the performer's musical ideas and can better augment musical expression with pitch bend and sustained notes and also with added functions such as wah-wah effect. The second iteration also delivers these expressions with much more accuracy. Better data with much less dropouts and simpler calibration procedure makes it possible to repeat musical gestures with the same expected outcome over and over again. The performer will have much more control over the instrument and can rely on that the audience will perceive the performer's intentions better than the for first iteration. The ease of use both in setting up the system and running it results in more time actually spent on making music.

The visual expression of the prototype was evaluated and it was shown that the addition of using external HUE-lamps and the connection to 3D visualizations can provide more possibilities to create a more holistic and ambient visual expression for the audience that can be connected to expressions of mood or similar. However, more research is needed in order to fully explore how the visual expressions can be used and how an audience experiences them.

5. FUTURE DEVELOPMENT AND POSSIBILITIES

The goal with this project was to develop a robust system that could deliver good data to be used as a part of an artistic expression. At the time of writing, the goal has been reached but there's room for improvement. Possible improvements includes reduced weight without losing battery time and also implementation of Soft Access Point functionality within the Photon to allow for easier setup, i.e. that the clarinet could act as a Wi-Fi base station in itself and the controlling computer would then connect to the clarinet directly.

The new instrument can be used in two ways, as an instrument where the musician plays music composed for a traditional clarinet and modifies the music during the performance. The other way is by composing new musical pieces that take the new functionality into account. Such a musical piece is currently being composed in order to test, visualize, and make use of the possibilities of this clarinet.

The sensor data provided could be further used to enhance both the audio and visual experience. Finally, other musicians, besides the one directly involved in the project should be involved in the testing and evaluation of the extended clarinet.

Figure 7. 3D rendering controlled by sensor data

6. CONCLUSIONS

By extending a traditional instrument like a clarinet an enhanced experience is created. The extended clarinet provides an augmented version of a traditional clarinet that uses gesture based interaction to increase the performer's, and music composer's possibilities to play and create novel forms of

music. Evaluation by a real musician has proven that the extended clarinet is easy to handle, non-obtrusive and reliable and can be handled by a professional musician by herself without involving a technician. The ease of use and reliability is very important for the new type of instrument to be adopted and used by a general user group.

The first prototype of the extended clarinet was a proof-of-concept where a number of development points were identified: *reliability, easy of use, usage time* (too small battery)*, setup time* and *setup method, sensor data handling* and problems with the *physical interaction*. The second prototype improved on all these development points and proved to be much more reliable. Faster setup time, higher reliability and much better handling of the data from the sensors. This means more freedom for musical expression and also increased confidence that the system will work throughout performances. There are also more sensors built into the second prototype and at the moment of writing only a fraction of the possibilities of this new extended clarinet is being utilized.

The use of novel techniques for creating and augmenting musical instruments in this fashion, using inexpensive open hardware components, allows for individuals to express themselves musically in a new way, adding a level of bodily involvement and gestures to the creation of music and empowering dynamic creativity.

Through motion and visualization a new way of conveying emotions linked to the music is introduced, where the artist can for instance direct the instrument downwards and move slowly in order to create a more dismal visualization when playing gloomy music, or change the lighting to animate with bright colorful lights when directing upwards and moving around to convey happiness and activity. The key is that the musician, herself can control this in real-time during her performance.

The added level of bodily involvement allows for redefining of musical creation and processes involving music, for example where dance moves would normally be choreographed to match the music, the process could be altered, where the music could be created partially through the dance moves.

Overall, the system works in a satisfactory manner, providing new methods of interaction with the instrument in order to influence the music through motion and provide visual feedback of the collected data to the audience, and thus extending the overall experience.

7. ACKNOWLEDGMENTS

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