Applications for Proximity Sensors in Music and Sound Performance

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Abstract. A low cost accessible sound and music control system is described (the *Benemin*). The interface employs an array of infrared distance measuring sensors that can be mapped to either MIDI pitches or MIDI control messages. When mapped to pitch, a user can interact with the system directly as a musical instrument. When mapped to controller messages, the system can be used as a multiparametric sound-controller. The *Benemin* has been designed to be inclusive such that it is aimed at users with or without specific needs. A model for testing is presented along with an indication of preliminary results.

1 Background

There are a number of commercial hardware-tools that have been designed to facilitate interaction within music based environments for performers with specific needs. Two commonly available and, subsequently, often used platforms are Soundbeam[3] and MIDI Creator[4]. Both platforms allow users with a variety of physical and cognitive disabilities to interact and control sound in a way that might not normally be achievable. Although there are significant differences between the two, both employ the use of discrete (on/off) or proportional sensors that allow a user to trigger pre-programmed musical events. In this respect, Soundbeam is probably the most complete hardware package as it incorporates sensors, that relay information to a base-unit that can also produce sound. In contrast, MIDI Creator does not produce sound directly, instead, the information received from the sensors is converted into standard MIDI[5] messages.

One feature that is common to both devices is the use of an ultrasonic transmitter/receiver to measure the distance of an object (e.g. a body part) from the sensor[6]. This information is mapped onto the appropriate MIDI note messages for a given musical scale or mode. As the object is moved back and forth, so the

[3] http://www.soundbeam.co.uk/

[4] http://www.drakemusicproject.org/makepage.asp?page=4cMC

[5] The full MIDI specification is available as a standalone resources but is covered in considerable depth in various general texts e.g. The MIDI Manual [4].

[6] In Soundbeam this is the main mode of operation whereas with MIDI Creator this is one of a number of input mechanisms.

musical notes move up and down within the scale. This allows a performer to produce a melodic line with only limited dexterity. Although this is a particularly intuitive and responsive method for retrieving and mapping actions onto sound, there are a number of apparent constraints to consider; most of these stemming from the one-dimensional nature of the sensor-based input.

The first consideration is that there is no immediate relationship between the user's interaction and the volume of the sounds produced; the sound level will always be at a default setting. Musical output will therefore tend to be dynamically limited. Although additional sensors could be employed such that one sensor controls the pitch and another sensor controls volume (in much the way that a Theremin[7] operates) there would be additional demand placed upon the user in terms of coordination. The second consideration is that to move from one note to another accurately will tend to lead to the triggering of all notes between. It is possible to move out of the beam and back in at another point, but knowing exactly where the 'window' for each pitch is located requires considerable precision and also the knowledge that the musical scale in use will remain constant.

An additional consideration is that the mapping of action to sound will tend to result in a monophonic output. Again, as with volume, this might be addressed using additional sensors but for the same reasons outlined earlier, this may not be easy or intuitive for the user to control. Finally, there tends to be no facility for enhancing the musical output through various recognised expressive techniques e.g. vibrato or tonal colour. It is also worth considering that the use of additional ultrasonic distance-sensors to enhance the number of musical parameters that can be controlled could be prohibitively costly.

2 The Benemin: An Experimental Platform

To explore possibilities for alternative methods of mapping proportional sensors onto music and sound control, an experimental platform (the *Benemin*) has been developed. In the long-term, the aim is to produce a cost effective and versatile sensor based sound control device that can be used as part of an ongoing commitment to post-graduate community-arts provision.

2.1 Overview

The *Benemin* is essentially a linear-array of eight infrared distance measuring sensors mounted near-horizontally, on a base and in front of the user (see Fig. 1). When a user places a hand (arm, foot, finger etc.) into the area above one of the sensors, MIDI messages are sent to an external sound-module to produce sound. In the default mode, these messages are simply *note-on* or *note-off* messages where the volume of the note sounded corresponds to the distance from

[7] The Theremin is an early electronic musical instrument. Invented by Leon Theremin in 1919, the instrument is played by moving the hands in close proximity to two antennae.

the sensor to the object it is detecting. Potentially, all sensors can be activated at the same time. With this in mind, the *Benemin* can be thought of as an eight-note polyphonic musical instrument. However, it can also operate in an alternate mode, sending a continuous stream of messages that are to be interpreted and acted upon by external software processes. In this respect, it can also be considered as a multiparametric control device.

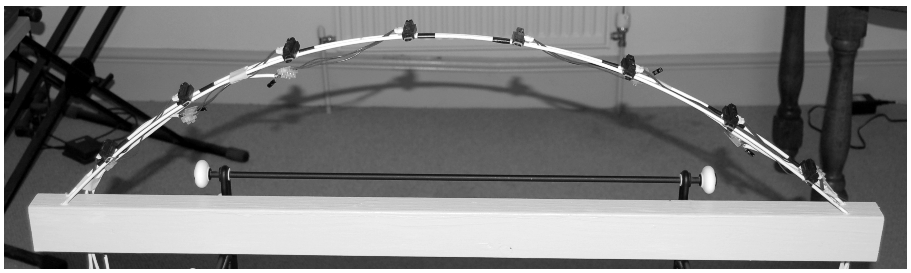

Fig. 1. The Benemin.

2.2 Design Considerations

The central aim behind the project has been to adopt an inclusive approach to the design of an accessible musical instrument; one that can operate flexibly to suit a variety of individual needs. At an inspirational level, a user should be able to produce sound with the minimum of physical and cognitive demand. At this level, the device could be used quite simply to elicit an audible response to a particular action. At a higher level, it would be desirable for the user to be able to control sound within a more defined musical context e.g. sounding notes from pre-defined sets of pitches. At a higher level still, it would be desirable for a user to be able to control sound expressively through the additional control of dynamics and/or timbre.

According to Malloch *et al.* [2], Digital Music Instruments (DMIs) can be categorised within three distinct modes of performance behaviours: skill-based, rule-based and model-based. Of these, the mode of musical interaction-behaviour most similar to that of playing a conventional musical instrument lies within the skill-based domain. The implication is that the user will be interacting in real-time in response to a continuous audio-stream. The other two models of musical interaction-behaviour operate at increasingly abstract levels of interaction with the user's interactions being less and less involved in terms of immediacy of output. With this in mind the central design consideration was for the system to employ a skill-based approach to interaction; a user's interaction should be directly mapped onto the sound that is output.

Additional design considerations have been for the system to be polyphonic (allowing more than one note/sound to be produced simultaneously), to allow dynamic control (i.e. play notes at different volumes) and to allow a note to be played easliy and discretely (i.e. without having to pass through other notes). It was also seen as desirable to enable the *Benemin* to operate as a multiparametric sound controller such that it could be used to control music in a more abstract sense.

2.3 Technology and Software

To detect motion, the sytem uses a total of eight Sharp GP2Dxx infrared sensors (see Fig. 2), incorporating eight of these within the overall design. The Sharp GP2Dxx series of distance measuring sensors are popular within amateur robotics and are either digital (continuously firing when a threshold is crossed) or analogue (providing a constantly changing voltage reflecting the distance of a given object). As analogue devices they can register distances between 10cm and 80cm. A discussion on the relative merits of IR sensors is provided both by O'Sullivan and Igoe [3] and Miranda and Wanderley [1]. In simple terms, the Sharp sensors are particularly low cost and very easy to integrate into microcontroller applications although they do not have the same length of range as some ultrasonic sensors. Requiring only power connections, and no further electronics, the output from each GP2Dxx sensor can be fed directly into either a digital or analogue input pin depending on the type of sensor. The platform that has been developed is based on a PIC18f452 microcontroller. This is a very common low cost 8-bit microcontroller that has thirty-two programmable input/output pins, eight of which can be set to monitor analogue input.

The low cost and ease of integration means that arrays of sensors can be configured easily to assess different approaches to capturing actions and mapping them onto sound parameters; for the current design there are eight analogue output sensors in use. Although, it is conceivable that more sensors could be incorporated there are additional factors that suggest that this number may not be significantly greater. Firstly, the sensors need to be separated slightly to minimise spurious readings caused by interference. Secondly, the sensors need to be spaced in such a way that a user can avoid accidentally triggering more than one sensor at a time. Having more than eight to ten sensors mounted with such spacing could simply lead to problems in terms of being able to easily reach the furthest sensors.

Although the Sharp sensors meet many of the requirements for the overall design, there have been two noticeable issues with their use. The first is that there is a small 'dead-zone' of about 4cm above the sensor. Although an object can activate the sensor within this space, the readings are 'wrapped around', matching readings obtained at a higher distance within the sensor's range. Readings from this very low area are therefore not usable as they simply cannot be distinguished from readings that can originate elswhere. Additionally, the sensor reading tends to be quite 'noisy', with occasional wide fluctuations. These can be reduced quite satisfactorily using a simple smoothing algorithm that keeps a running average based on previous readings.

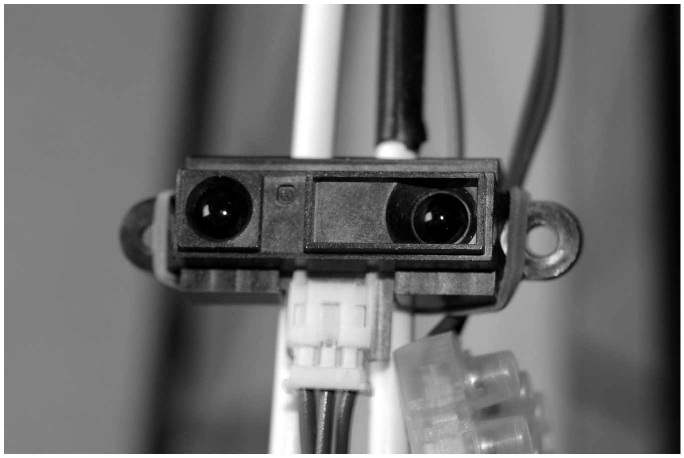

Fig. 2. Sharp sensor.

The system operates in one of two modes: as an *instrument* or as a *controller*. In the default mode of *instrument* each sensor corresponds to a note within a particular scale or mode (with a series of different scales and modes being available to the user). As a *controller*, each sensor is mapped to produce a continuous stream of MIDI controller messages.

2.4 Pitch Mapping

Whereas previous conventions have favoured the mapping of distance onto pitch, the current configuration under assessment in this project maps distance onto volume. In *instrument-mode* Each sensor corresponds to a given pitch or sound and as the user moves an object (e.g. hand, foot) into the active range of a sensor, a pitch or sound is turned *on* with a volume level that corresponds to the distance (height) from the object to the sensor. Moving out of the active range turns the note *off*. In effect, the array produces readings that represent two dimensions. However, there is a further advantage to this configuration in that it is both feasible and intuitive for the user to activate more than one sensor at a time thus making the instrument-array polyphonic. Potentially, all sensors can be activated simultaneously with independent volume levels. Realistically, it is unlikely that users will have more than two sensors active at a given time. Even so, in musical terms, two notes played together will create harmonic intervals which provide a richer means of expression.

Although there are different levels of volume available for each note mapped to a particular sensor, this initial volume level cannot be altered without deactivating the sensor and reactivating it at a different height. This effectively completes a note by sending a MIDI note-off message and begins a new note with a new volume level. This restriction is the same as that experienced when playing a piano and is an unfortunate constraint of the MIDI specification rather than a limitation of the sensors or system design. However, there is a method for achieving this additional level of expression that becomes available if the *Benemin* is operated in its other *controller-mode*.

2.5 Controller Mapping

In *controller-mode*, when a sensor is activated or deactivated a MIDI *note-on/off* message is still transmitted but whilst the sensor is still *active* there is also a continuous stream of MIDI controller messages available, these constantly update as the user moves within the scope of the sensor. Using appropriate additional software (e.g. Reaktor or MAX MSP) the MIDI *note-on/off* messages can be used to trigger the playback of one or more samples and the additional message-stream can be mapped within the software to control other parameters e.g. modulation or timbre. If this stream is mapped onto volume then individual notes can be triggered and faded-in or out in a way that is not allowed for in the MIDI specification. This additional level of expression is similar to the way in which, for example, wind players can alter the volume or tone of a note in a coninuous fashion.

3 Testing

Although the system has been tested informally, a more rigorous system of testing is currently underway. The *Benemin* is being trialled within a number of special-needs school in the West Yorkshire area of the UK. A Specialist Teacher for pupils with multiple sensory impairment is working with a variety of users with differing individual needs with the system operating in its default mode (*instrument*). Initially, the system is being trialled as an inspirational musical-toy and also as a basic improvisatory-tool. Users will be encouraged to simply interact with the *Benemin* and respond to the sounds that are produced, coordinating and controlling these further depending on their both their interest and abilities (physical and cognitive). Users are being monitored interacting with the system by the specialist teacher, with video records being kept where possible. It is anticipated that much of the data gathered from this phase of testing will be qualitative as the users are not being set specific goals or tasks.

As identified earlier, the *Benemin* is designed to work at different levels of complexity in terms of performance-interaction. With this in mind, a second phase of testing will be carried out that is more task-specific. Here, users will be required to achieve particular goals or tasks. These will be divided into musical and abstract tasks. With the musical tasks the outcome will need to make musical sense e.g. to replicate a short musical phrase or perhaps to improvise a section of music. With the abstract tasks, the audible results will be superfluous to the task, for example the user might be asked to activate a particular sensor or sensors in a specific way or order. It is anticipated that data gathered during this second phase of testing will be quantifiable, however, it is also recognised that the majority of users involved in testing will have specific individual needs. With this in mind, it will be difficult to generalise across the entire spectrum of users; any generalisation will be limited to smaller sub-groups who share similar needs.

It is hoped that the inclusive nature of the design process will allow the *Benemin* to become a performance tool that is useful to music performers in general rather than being seen as a tool that is aimed purely at users with disabilities. It is important therefore, to also assess the usability of the interface with users who do not have specific needs. To achieve this, there is an additional, and separate, level of testing that is aimed at professionals who are likely to use such technology within, for example, a community music setting. This will require users to perform relatively complex musical tasks in ways that an improviser might when leading a community workshop for learners of mixed cognitive or physical ability.

3.1 Preliminary Results

At an informal level, the *Benemin* has been assessed in improvised performance settings with users without specific needs and is proving to be promising in terms of both user interaction and musical output. It is noticeable that the distance between the furthest sensors might be too great for users with limited mobility. Allowing considerable separation between sensors is based on both technological and physical constraints. However, the actual distances used are relatively arbitrary and there should be scope within the system to reduce this spacing to compact the overall array. It should also be recognised that the choice of a linear horizontal array within this intial design is also relatively arbitrary and was chosen purely to imitate existing musical conventions (e.g. the keyboard). Alternative approaches to sensor layout will be considered as results from phase one and two testing become available.

At a more formal level, prelimiary observations from phase one testing are also showing the *Benemin* to be both usable and rewarding. However, this phase of the testing has only just begun and it would be naive to read anything into these initial impressions until a fuller set of observations become available from both phase one and two.

4 Future Work

The type, number and pattern of sensors used in the intial design of the *Benemin* have been based on a combination of musical intuition and existing musical conventions. The convention for the musical keyboard is to have low notes on the left of the player moving to higher notes on the right. Many musical scales and modes are based on eight notes, hence eight sensors affords the same musical interaction as a diatonic intrument such as a traditional flute or whistle. However, it is recognised that testing may show that a greater number of sensors or a different approach to sensor layout may benefit the user either in ease of use or in musicality. It is also appreciated that there are likley to be compromises to be made between the two. Such issues will be considered during the follow-up design stage based on the results of testing.

Personal experience with the *Benemin*'s interface has identified that there is scope for users to have further control over the sound produced by wearing additional sensors on the body-part(s) being used to activate the sensors. For example, an accelerometer could be used such that in addition to controlling the pitch and volume of a note, timbre might be altered by tilting the hand (arm, foot) being used. Although this should afford greater levels of musical expression it may also require additional levels of dexterity, perhaps making the instrument less usable. However, sensors for monitoring angle in this way have become far more affordable and their worth will be assessed during future designs.

5 Conclusion

The initial design of the *Benemin* has shown that it is possible to achieve a low cost musical controller that is expressive and polyphonic. The instrument follows established musical conventions and allows the player to interact with up to eight notes or sounds simultaneously. Designing the system to operate in two different modes (as an *instrument* or as a *controller*) allows the *Benemin* to operate as either a standalone instrument (producing sound from an external sound module) or as a multiparametric sound-controller (controlling sound with external software environments). The system has been kept at a low-cost by employing technology that has become increasingly popular for use in amateur robotics. Although the system currently uses Sharp infrared distance measuring sensors, alternate sensors (e.g. accelerometers) will be considered if they can be shown to be of use without making the system prohibitively expensive. Results from initial testing are showing the system to be easy to use whilst also being musically useful. A more sustained approach to testing with users with various specific needs is currently underway.

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