A New Framework for Interactive Control of Mechatronic Instruments

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***Abstract*—Over recent years there has been significant developments in the burgeoning field of mechatronic musical instruments. These developments have seen mechatronic instruments greatly increase in complexity, and concomitantly, their expressive capabilities. However, the development of designing control systems for these instruments has been lacking, meaning that the use of these expressive new instruments has largely being left to the builders of the instruments themselves, or other especially skilled users. This paper proposes a new framework for the control of mechatronic musical instruments that is designed to afford an intuitive interaction for all users. This design allows for more aesthetic exploration of mechatronic instruments as well as expanding the potential demographic of users. This framework explores the potential of new iPad applications that offer high level control parameters and gestures, for the real-time interaction with mechatronic instruments in both performance and installation settings without assuming prior mechanical knowledge of the user.**

This paper discusses the current state of the field and the need for this new framework. It then demonstrates and explains three case studies that have being developed by the authors as examples of this new framework.

Keywords— Control Systems, Mechatronics, Musical Robotics, Touch Interfaces, Control Framework, Interaction Design, Installation Audience Interaction Introduction (*Heading 1*)

I. Introduction

Mechatronic musical instruments have recently seen a period of rapid development in their functionality and musically expressive qualities. However, this development has often taken part purely on the instrument side, with significantly less development taking place on the control system side of the instruments. In order for mechatronic instruments to be used by a wide range of composers and performers, as well as non-expert users in an installation setting, the authors recognise a need for development in the user control systems for mechatronic instruments.

This paper begins with an assessment of the field of mechatronic instrument development, and the use of iPad applications as instruments and expressive musical tools. The development of custom iPad applications as musical interfaces is a key aspect of the new framework. Following this, the paper goes on to discuss the motivation for developing the proposed framework. After discussion of the motivating factors, the framework itself is introduced with detail provided of how the framework operates, and why each element and communication method was chosen. Finally, the paper provides three case-studies, each of which has implemented the proposed framework. These case studies include: *speaker.motion*, a mechatronic loudspeaker; *Carme*, a mechatronic string ensemble; and *mecha.space*, a control system for spatialised mechatronic percussion instruments. The paper concludes with discussion of the future direction of the framework.

II. Related Works

A. IPad and IPhone as interfaces

In the past decade the increased commercial popularity of multi-touch products has seen interfaces of this type begin to gain popularity as performance interfaces for live electronic music. In particular Apple's iPad and iPhone have proved a popular interface to develop new applications for musical expression. This popularity might be attributed to a number of factors: they have a relatively low purchase cost; their multi-touch technology is fast, accurate and reliable, particularly when compared to early large-scale multi touch tables; they require no calibration; and they are not affected by stage lighting. This set of factors make these commercial touch interfaces well-suited platforms with great potential for exploration as a musical interface.

Many artists and developers from the NIME (New Interfaces for Musical Expression), an impor community have built expressive interfaces using this platform. Ge Wang's Magic Flute [1] and Magic Fiddle [2] are new instruments conceptually based on the design of an acoustic flute and fiddle. They were designed to fully utilize the capabilities of the tablet and smart phone technologies. Their control systems include: touch events, accelerometers, breath control (through microphone input), and GPS location. Even though these instruments are designed to replicate pre-existing acoustic instruments, they also extend their capabilities through utilizing the features of the new technology. For example, the potential for multi-user networked performance. There is also a vast array of synthesis applications written for touch screens that are used by the novice user, as well as by professional musicians, such as the Arturia iMini, Moog Minmoog and the Korg iMS-20.

A further trend in the use of portable touch-screen technologies is as a control interface (rather than a full instrument). Many music software programs are now capable of receiving control information from touch interfaces. For example, the Logic Remote app allows direct communication with Logic Pro X, a popular digital audio workstation (DAW) that allows for comprehensive editing of audio. This extends the Logic Pro X control interface for recording, mixing and performance purposes. Rather than generate audio on the app itself, the app uses the technology embedded in the iPad to send communication data back to the computer to control Logic Pro X. There are also multiple control interfaces available to interact directly with Ableton Live, another popular DAW, in both studio and performance settings, many of which are graphical representations of popular hardware interfaces.

This short list of examples shows that portable multi-touch technologies have quickly found their place as expressive interfaces both in the NIME community and in the commercial realm. The widespread adaptation of this technology makes these interfaces a desirable platform to work with in the context of the goals of the framework presented in this paper, as it has a high potential for other members of the mechatronic community to adopt and develop the proposed framework.

B. The Mechatronic Instrument Field

A main driver for research in the mechatronic musical field has been affording musical expressivity through their design. This has created a proliferation of control parameters and complexity in these systems, affording more expressivity. However, this has made the composer-mechatronic system interaction more complex and difficult. Rapid developments made in the design of these instrument systems have not been matched in the control systems, which as Jim Murphy identifies, means that '[t]o compose for these systems in their current state is to manually direct every action that the robot undertakes. To write music in this manner is quite time-consuming, requiring much actuator management rather than higher-level musical composition.' [3]

The common control solution that most designers of mechatronic systems use is to implement a custom MIDI communication framework. The MIDI communication protocol has its benefits as it is widely used (particularly in music communities), with many commercial hardware controls available, as well as many software systems that can output MIDI. The protocol is reliable, versatile, common among musicians, and simplistic, which makes it well suited to communicating control parameters to a musical mechatronic system.

However, the commercial hardware MIDI controllers available are often ill-suited to controlling the specific range of parameters that are afforded by complex mechatronic systems. The keyboard design paradigm that many MIDI keyboards are based on offers a fine degree of control over discrete pitches, with dynamics, polyphony and physical tactility all important design features. However, in many cases, this design paradigm doesn't match the specific needs of a complex mechatronic system.

This lack of suited hardware controllers often mean that composers use software to generate MIDI to control a mechatronic system, which is more customisable than its hardware counterparts. This method has its benefits, as composers can carefully control many different parameters at once by transcribing MIDI messages, and then playing their compositions back. This also makes compositions repeatable, and mechatronic builders can implement communication frameworks that can be catered for. A good example of this is Godfried-Willem Raes's research with the Logos Foundation, who have developed a large robot orchestra, and provide a comprehensive MIDI manual for each of their robotic instruments. [4]

C. Bespoke Hardware Controllers for Mechatronic Systems

There are very few examples of custom-built hardware controllers used to communicate with mechatronic instruments. Jordan Hochenbaum and Owen Vallis have designed a large multi-touch interface called Bricktable, which they used to control Ajay Kapur's MahaDeviBot, a twelve-armed percussion robot. [5] The touch interface sent positional and rotational data of tangible objects that were placed on the touch surface to MahaDeviBot, controlling rhythms and intensity of each strike. Bricktable was not specifically designed to control mechatronic systems, however, they were able to customise the user interaction to control the MahaDeviBot.

Ajay Kapur has also interacted with mechatronic systems in his piece Digital Sankirna. The work is for Kapur's own ESitar [6], a custom built hyperinstrument, that combines a sitar with sensors that detect different aspects of the performers movement and behaviour; and for the Machine Orchestra [7], a mixed ensemble of human and robotic performers developed at the California Institute of the Arts. Through using data from the sensors on the ESitar, as well as real-time analysis of his ESitar performance, streams of quick notes are distributed throughout the robotic ensemble, creating ripples of percussive strikes to accompany his sitar playing.

In a 2013 interview with the LAWeekly, Trimpin described an iOS application he has developed that allows the user to control an ensemble of his mechatronic sound sculptures [8]. The application allows for different MIDI sequences to be sent to different instruments, allowing for the control of an ensemble from one point. The application itself is specific to Trimpin's creations, and as such, not widely adaptable for other systems.

III. Motivation

As discussed in Section 2, the authors felt that portable multi-touch devices offered a great range of potential for development as a control interface for musical expression. In particular the iPad is well suited with its larger screen size, its reliability and its ease of use, especially in configuring communications over a wireless network. Furthermore, it is also a multi-functioning affordable tool that many users may already own. This was a significant factor in the decision of which design platform to implement for this new framework. It needed to be something that would allow control in multiple performance settings without requiring new hardware for each different mechatronic system. Mechatronic musical instruments themselves often require significant set up and time, and incorporate a lot of hardware to set up, so the control interface needed to be something that could be incorporated in the system without significantly adding to the complexity of the overall system.

Another factor was considering the potential for use by users coming from multiple backgrounds. It was important that there is the both the potential for nuanced, complex control that will allow an experienced performer to become highly proficient and use the platform for sophisticated musical performance; as well as being able to be implemented in an installation setting where a novice user could quickly engage with the system. This would allow them to interact with a mechatronic instrument, quickly but with enough complexity to create meaningfully musical gestural relationships.

The authors also felt that it was imperative for the development of the mechatronic musical field to develop the control elements of the robot/human interaction, to fully explore the possibilities that this research can afford.

IV. Framework Overview

The new framework developed by the authors can be broken into three major parts. The first is the control interface, which takes the form of custom iPad apps. Though each individual system has its own app developed specifically for it, there are many common features that allow the apps to fit easily within the wider frameworks. This also means that in building each new application the structure for the iOS code, can be used for each app, significantly reducing the time needed to develop each new app. The apps all send OSC data out over a wireless network, which is setup through a configuration screen that allows the user to input the IP address and port number for communication to be sent. Depending on the needs of the application, this screen can also feature other configurable settings as needed.

The OSC (Open Sound Control) [9] protocol was chosen for its ease in customisation. Each application can easily implement its own protocol based on the control data needed for the particular systems. The OSC data is then received in a customisable Max/MSP patch [10]. The Max patch essentially works as a protocol translator - receiving OSC data and translating it to the appropriate MIDI data that is needed to control the mechatronic instrument. Depending on the needs of the performance and the system, the Max patch might also generate further musical information. For example, in the mecha.space system, the Max patch also generates sequences of MIDI information that can be sent as loops to the instruments. The control interface then triggers each loop to start, and determines which instruments should play which parts of the sequence.

Max/MSP was chosen for its ease of use both in receiving OSC data and sending MIDI data, but also for its potential to be used to generate complex musical information be it in the form of audio or MIDI data. As has being identified in Section 2, MIDI is the most common control protocol implemented by mechatronic musical instruments. It was a goal of the framework to be compatible with both future and past mechatronic instruments and the use of the MIDI protocol ensures this is possible. The full framework is displayed in diagrammatic form below.

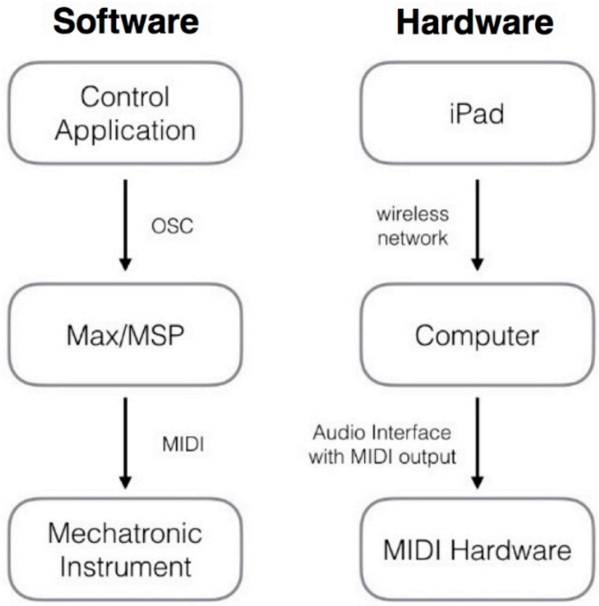

Fig. 1. Overview of New Framework

V. Case Studies

The following section will outline three case studies developed by the authors that are examples of the proposed framework. Each of these systems has being developed for both performance and installation settings. They all feature customised versions of each element of the framework built off common base foundations and communication protocols.

A. *speaker.motion*

speaker.motion is a mechatronic loudspeaker system that allows dynamic repositioning of the loudspeaker in real-time [11]. The loudspeaker can be fully rotated in either direction indefinitely, as well as, tilted 180 degrees. This allows its directionality to be manipulated to create complex spatial patterns and trajectories, as well as, activating the physical space in varying ways. The speaker.motion iPad application was designed so a performer or installation user could intuitively control the angle and tilt of the loudspeaker in real-time. The full speaker.motion system features four loudspeaker units each of which can be controlled independently and simultaneously by the app.

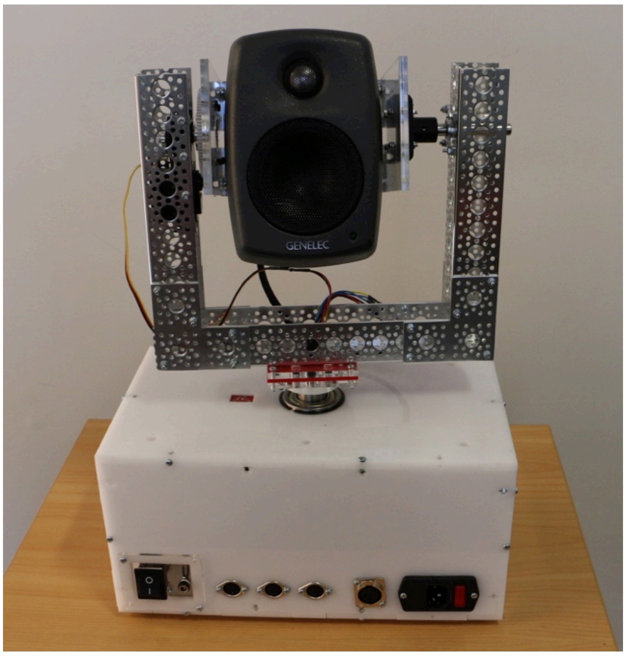

Fig. 2. *speaker.motion* mechatronic loudspeaker.

The design of the iPad app was driven by the intention of maintaining highly intuitive gestural relationships between the movement of the speaker and the physical movement the user performs. The app shows graphical representations of all four loudspeakers displayed as a series of consecutive circles. The user interacts by moving a small ball around the graphical space representing the directionality with which the speaker should aim itself. The radial movement is very intuitive as the position inside the circle that the ball is placed directly correlates to the radial direction of the loudspeaker. The tilt is controlled by the balls distance from the centre of the circle. The outer most circle will cause the speaker to tilt towards the floor, the inner circle will cause the speaker to tilt directly up, and all other positions are calculated therein.

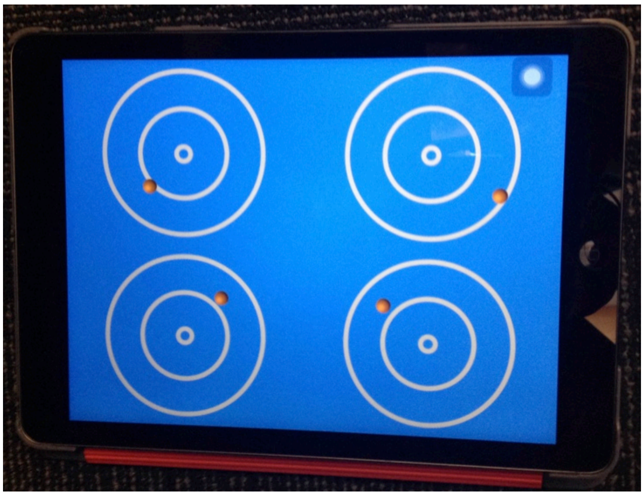

Fig. 3. The speaker.motion iPad Application

The speaker.motion iPad application and its implementation of the proposed framework means that the mechatronic loudspeakers can be interacted with in a gestural and intuitive way by performers or non-expert installation users. The direct mapping of the app to the physical movements of the loudspeaker themselves means that the instruments can be used easily by musicians and other users without any understanding of how the mechanics of the system works. The proposed framework removes the need for specialised knowledge in interacting with this mechatronic ensemble and opens speaker.motion up as an expressive tool to a much wider and more diverse range of users in both performance and installations settings.

B. Carme

Carme [12] is an application designed to control The Polus Ensemble [13], an ensemble of mechatronic, bowed string sculptures. The ensemble contains six instruments, each with a single string that is excited by a rotating bowing wheel mechanism. The design of the bowing mechanism allows for the control of the speed of rotation of the wheel, direction of rotation, and the pressure of the bow onto the string through controlling the swing arm that rotates perpendicular to the bowing wheel.

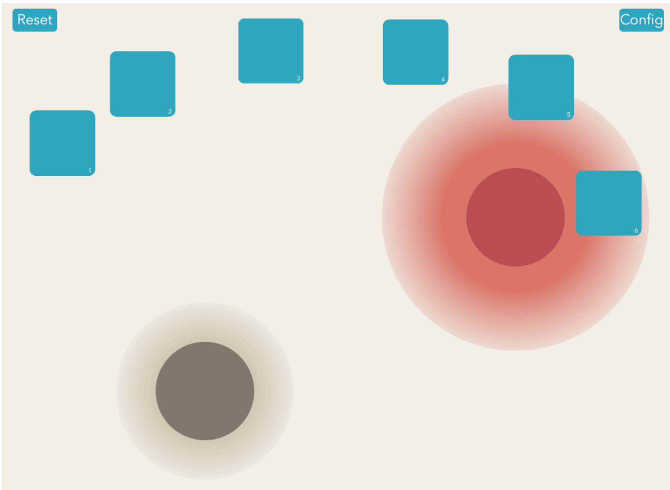

Fig. 4. The Carme Application User Interaface.

Due to each unit having four raw control parameters, high-level musical behaviours were abstracted to allow a more intuitive interaction. This means if a user wanted to create a continuous note, they would not have to set the direction of the arm and adjust the speed, as well as, control the speed of the bowing wheel. Instead these behaviours offer abstract control parameters like intensity, which are interpreted in the Max/MSP application to control these parameters accordingly.

Circles and squares represent musical behaviours and the instruments of the Polus Ensemble respectively on the iPad user interface. By dragging a musical behaviour in close proximity to an instrument, the relevant behaviour is performed by the instrument. This design can easily be customised to have any amount of instruments and behaviours on the screen, catering to the specific mechatronic system. This behaviour is only triggered when the shapes overlap. The degree of proximity is used to control a parameter within the behaviour. An example would be the intensity of a continuous note.

Fig. 5. Polus Ensemble controlled by Carme, the iPad app.

Each shape is not fixed in space and may be grouped in any way. This allows for an interesting approach to organising sound, as sculptures can be spatially grouped together to create chords, or separated to make small sections in the ensemble. Using a spreading gesture with two fingers can alter the size of the behaviours. This allows for the influence of a behaviour to dilate and cover a large space. By making the behaviours larger, the user can have finer control over the proximity, as the resolution is effectively higher.

While to some degree, this approach of high-level musical behaviours abandons the possibility of fine-grained control over every possible control parameter; it has the benefit that it greatly simplifies the user experience, while still allowing for complex behaviours to result. This design choice was informed by the two different complexities that exist in The Polus Ensemble: controlling multiple instruments at once that are spread out through space, while treating them as one mechatronic system; and the multiple parameters of control that each sculpture presents.

Through using this framework, the complexities of the ensemble can be controlled in a nuanced way, which is both intuitive, and doesn't require a full understanding of how each of the units need to behave in order control musical behaviour.

C. *mecha.space*

mecha.space developed out of ideas about spatialisation in live electronic music. One of the focuses of research in acousmatic music is the dynamic spatialisation of sound across loudspeaker arrays. mecha.space seeks to explore these concepts of the spatialisation of musical ideas through an array of sound generators in the mechatronic realm.

The mecha.space application was designed for user interaction with a spatialised mechatronic percussion ensemble in both performance and installation settings. The graphical user interface allows the user to drag visual depictions of the physical instruments, represented as red squares into the space to coincide with where those instruments have been placed in the concert hall. Once satisfied that the instrument objects are placed correctly in the virtual space the user can 'lock' their positions so they aren't accidentally moved in further interactions. The user may then tap on the instrument object to send a single hit note to that particular instrument, or interact with a separate set of objects, represented by green circles to start a rhythmic sequence and dictate how this sequence is spread throughout the physical instruments. The user can dynamically change the size of the circle, ranging from very small, to taking up the full screen and the system is able to recognise which instruments fall within the scope of the object. Any instrument falling within the scope of the object will play the rhythmic sequence. The velocity, or loudness of each particular instrument is determined by its position within the object relative to the centre. Instruments on the edge of the objects parameter will receive only a low velocity and therefore play much quieter, instruments positioned right in the centre of the object will play at full loudness capabilities.

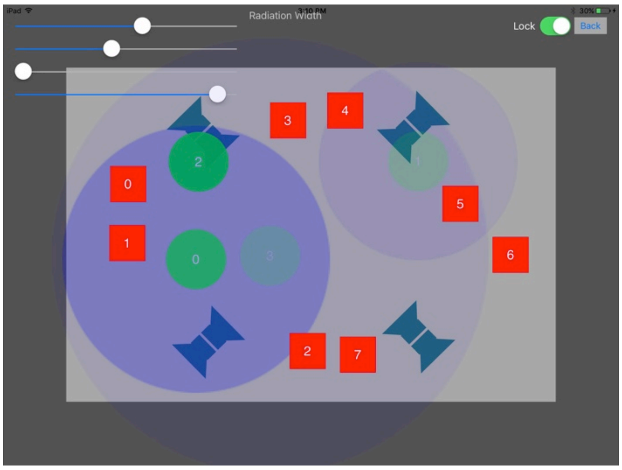

Fig. 6. The mecha.space iPad Application

In following with the proposed framework the mecha.space application has a start-up screen where the user can enter the details of the desired network and port to connect to. The data about the instruments is then sent out via OSC messages over the network. For a tap received on an instrument object a single message is sent with an ID corresponding to the instruments tapped. For the sequencing objects a message is sent for each instrument that falls within its scope, the message contains two ID tags, one for the instrument and one for the object. The message also contains a percentage value that will correspond to the velocity value, the percentage of how close to the centre of the object it is, therefore dictating the amplitude with which that instrument is played.

The sequencing takes place in Max/MSP where the MIDI data is produced. The user can easily create rhythms to sequence within Max that can be played by the mechatronic percussion ensemble. While mecha.space was designed to work with specific mechatronic percussion instruments, a major advantage of the framework is that it could very quickly and easily be adjusted for use with any mechatronic instruments that are controlled with MIDI.

VI. CONCLUSIONS AND FUTURE WORK

The strength of developing this framework lies in the ability to control multiple mechatronic instruments in a customisable, intuitive, and convenient way for a range of users from expert to novice. This expands the possibilities of these exciting new mechatronic systems to users beyond the very small group of expert builders and makers. It also gives these users a convenient, flexible, and powerful way of interacting with their own mechatronic systems.

Future developments for this framework will be directed towards expanding the existing applications to other mechatronic systems. This will lead to development of how these touch interfaces can be interacted with in different modes to suit different systems. Also, the authors will be researching streamlining and providing a standard package of software which will allow for the quick customization of parameters and features so that many different mechatronic systems will be quickly compatible.

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