Situating the Performer and the Instrument in a Rich Social Context with PESI Extended System

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ABSTRACT

In this paper we present our solutions to the design challenges of facilitating awareness of actions and development of self-identities within *The notion of Participatory Enacting Sonic Interaction* (PESI) project. The PESI system is a modular framework for participatory music making with three performers. We present a brief technical overview, design considerations and revisions resulting from a user study conducted during the system's development. Through the development process of the PESI project a design approach we term: Non-Behaviourally Restrictive Digital Technology became apparent. In this approach, the shifting focus that embodied agents have in relation to the environment is accounted for and the development of sound-action relationships are encouraged. This is achieved through providing mappings relating to individual sensor values and movement information from motion tracking data. Our approach to the implementation of the PESI system can shift the collaborative music activity to a more engaging and active experience.

1. INTRODUCTION

Designing systems in which social interaction is the primary focus is challenging as it requires consideration of additional factors along side the social interaction. An awareness and understanding of the evolving nature of the performer-instrument relationship within specific contexts and cultures is needed to inform how these relationships may be facilitated through the technology. The idea of performance ecosystems helps to address these design challenges by emphasising how social factors effect and facilitate changes in the function of technology and music. Through the consideration of performance ecosystems, we highlight the importance of usage in technology which allows for the blurring of phenomenological and epistemic distinctions between acoustic and digital technology [1,2]. In blurring these traditionally held distinctions, we are able to focus directly on investigating the ideas of social interaction in collaborative music. Through investigating these ideas, we have implemented our own system that is capable of supporting collaborative and creative activities in group music practices.

This paper presents our design approach to *The notion of Participatory Enacting Sonic Interaction* (PESI) project, a modular framework for participative music making with three performers. The project incorporates new generation mobile phones and group motion tracking technology to create an environment in which performers' individual and social actions contribute to and affect the sonic output. We have briefly presented previous versions of the PESI system in [3–5]. The system has been developed on the iOS platform along with the use of the Microsoft Kinect System. Mobile phones enable individual action within the system and the Kinect system tracks participants, enabling augmentation of the social space within the system. The result is that the PESI system can facilitate group music practices that exploit social action in combination with the use of everyday devices for allowing musical action.

Compared to other approaches based upon analysis of social behaviours within musical practice, such as [6] and the EU-ICT SIEMPRE project, [1] the PESI project instead has focused on facilitating social action through technology within a musical context. As such, the design challenges of the PESI system relate to the ideas of awareness and mutual engagement within Human Computer Interaction (HCI). Finding solutions to these challenges has guided the design and development process, and in doing so, we have identified a design approach which we call: behaviourally non-restrictive digital technology.

This paper begins with an overview of related work on the performance ecosystem approach. Section 3 presents the design challenges and section 4 provides an technical and design overview of the PESI system. Section 5 outlines our idea of behaviourally non-restrictive digital technology, which is discussed in section 6, where the approach is compared with the work described in section 2. The paper is concluded in section 7.

2. RELATED WORK

2.1 Ecological Perspectives Towards Music

The ecological perspective has been used within the design and implementation of interactive digital music systems as

[1] http://siempre.infomus.org/

a way to contextualise and investigate relationships that develop when using these systems [7–11]. One approach, which has been given notable attention, is that of performance ecosystems. Based on ideas suggested by Simon Waters [12], a performance ecosystem is a tool to understand current musical activity. The central idea is that "understanding music making as a complex dynamic system puts it in terms of the process of creation, but also its consolidation into culture specifically as a social practice embodying behaviours, beliefs and actions" [12]. Here music making is seen as an activity that produces artefacts as well as being part of social practice.

Two projects that embrace the performance ecosystem perspective are the Audible Eco-Systemic Interface (AESI) project [7] and in 'Infra-instruments' [8]. Within both these projects the notion and design practices of interaction within interactive systems are questioned. The AESI project questions the performers' role in interactive systems. In many interactive systems the performer is the person providing external conditions that the dynamic behaviour of a system is driven by. The system is depended on the performer. Within the AESI project the need for a performer is removed. The relationship of performer, instrument and environment is reduced to only being between the instrument and the environment. This is accomplished through a feedback loop in which the system generates the controls from analysis of its ambient surroundings.

Similarly, the Infra-instruments project draws comparisons to and diverges from the approaches used within the development of 'hyper' and 'meta' instruments. Hyper and meta instruments are approaches that extend traditional instruments' interactive capabilities, expressive nature and virtuosity through the addition of sensors. Instead of extending the instrument, Bowers and Archer see value in simplifying and limiting the interaction. Their approach creates a space within the performance setting for the additional capabilities of computers [8].

The ecological perspective has also been taken by [9–11] to investigate the relationships between performers and spectators of interactive digital music system performances. Their research has highlighted considerations within the design of digital musical instruments (DMIs) to improve spectator experience within these performances. The improvement of experiences with DMIs and music technology is also a concern within the area of embodied music cognition and mediation [13]. Whilst not explicitly drawing upon ecological ideas, the focus is upon how we interact with music. The ideas developed within the field of embodied music cognition have been used to inform the development of an interface exploring musical experience and creativity [14]. The Musical Paint Machine extends the performance space of a player so that the sonic output of the instrument is visually represented. In this way, additional feedback modalities are introduced to the player as a method of stimulating creativity.

2.2 Blurring Distinctions Between Instruments

The works presented have followed Waters' main ideas on performance ecosystems; however, work by Green has extended these ideas further towards musical creation. Green emphasises the influence that social factors have in the use of technology and musical practice. When players and instruments are situated within a social world *'the categorical distinctions between the acoustic and the digital dissipate somewhat, and that such differences in practice are contingent upon the shifting intersections between the technical and social'* [2]. Thus the influence that social factors have on the usage of technology results in the distinctions [2] between acoustic and digital being blurred.

Accounting for relationships between the different parts of a system, from a conceptual stand point, is one of the main challenges in adopting an ecological perspective. In adopting Greens contingency view on musical instruments we can direct our own focus towards the consideration of social factors and their influences on the design of interactive systems. In the following section we briefly address these challenges in the PESI project by considering and accounting for the performers' relationship to the technology and to each other within the design of the system.

3. DESIGN CHALLENGES

To account for forms of embodied interaction in the implementation of the PESI system we have investigated the design challenges surrounding the role of meaning in relation to collaborative interactive systems. This has directed our focus to concerns relating to intersubjectivity, and the design of technology that facilitates co-operative processes.

Intersubjectivity is the way in which two people can share understanding of the world, or how meaning can be shared between two people [15–17]. To establish and allow for intersubjectivity within a collaborative system, users need to be able to interpret and understand the action of others. This is required for a communication flow to be established, thus enabling collaboration within the activity. Similarly participants need to be aware of what others are doing or have done, also known as having public awareness of actions [18]. Facilitating awareness in collaborative systems is very important in allowing for multiple users to interact with each other. This is emphasised by both the fields of HCI [15] and Computer-Supported Collaborative Work (CSCW) [18]. Awareness of actions is also an important design feature in facilitating mutual engagement, allowing for a more socially engaging experience [19, 20].

Issues of awareness within areas of HCI and CSCW and in research into mutual engagement in social music have mainly focused on activities in which participants are not co-located. Within the PESI system the participants are co-located, to account for this we extended the ideas of awareness and mutual engagement through considering the experiences of individual users. We draw on ideas of optimal experience, Flow [21], for this.

The exact conditions for achieving a Flow state are still being investigated, however, a key component of obtaining a Flow state within an activity is the maintenance of ones own personal identity [21]. The importance of self-identity within optimal experiences has prompted us to ex-

[2] These are the phenomenological and epistemic distinctions between acoustic and digital instrument technology [1]

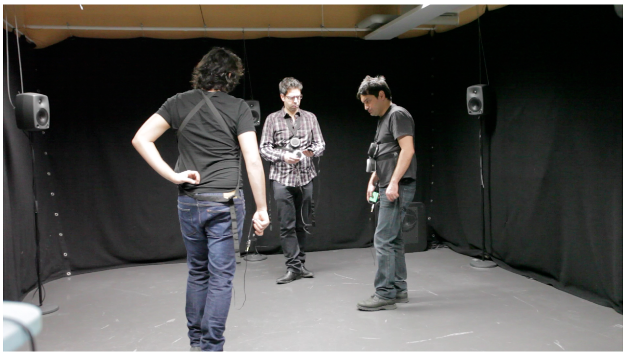

Figure 1. Three musicians using the PESI system in a free form improvisation.

tend ideas of awareness and mutual engagement so that users area able to retain the ability to develop and act through their own self-identities within the system. This requires enabling users to be identifiable as other identities within the system, and that these identities can be influenced by others, through a their own self identities [21]. It also requires that each user be able to detach themselves, and their actions, from the overall interactive system.

We believe that facilitating the building of identities aids in, and strengthens, awareness within collaborative systems of co-located participants. Therefore, the design challenges of the PESI system are focusing on facilitating both awareness of actions, and allowing users to create their own identities within the system.

4. THE PESI SYSTEM

In the PESI system mobile devices run custom software that allows for them to be used as musical instruments that are usable within an improvised musical group performance [4]. The relationship and interaction between the performer and their mobile instrument is extended into the physical and social space through the use of motion tracking software and group analysis.

4.1 Technical Justifications

From the start of the project, the PESI system was designed with a modular structure. The modular structure aided in development by allowing for rapid system reconfiguration as well as the testing of ideas. This structure also makes the system more accessible to others to modify or to extend for their own uses. In that concern, we used readily available technology: Apple iPhones as the mobile phones, Microsoft Kinect as the motion tracking system and Pure Data [3] for the sound synthesis.

Including mobile phones allows us to emphasise the role of social communication within the system as they represent communication within our society. iPhones also have the additional benefit of being association with music practice. iDevices are largely connected with music listening as well as music production through the ever increasing number of musical applications available on the platform. They also contain the technology required by the PESI system: sensor input feedback mechanisms, enriched computational possibilities for sound processing and wireless communication.

The decision to use the Microsoft Kinect system within the PESI system was determined in a similar manner to the iPhones. The Kinect system is a cultural object that is primarily used within games that require whole body interaction. It allows us to emphasise the playful nature of the system as well as being able to visual track and allow for detailed evaluation of a group of people.

Pure data was the audio programming language of choice for the PESI system's sound synthesis. The primary reason pure data was chosen over other audio programming languages is due to its portability. The development of Libpd [4] has made it possible to run Pure Data on many different platforms. Within the PESI system this meant that the same sound synthesis patch can run on both iPhones and Laptop Computer. It also sufficiently fulfils the sound synthesis needs of the PESI system.

4.2 The Initial System and the Design Outcomes Arising from it's User Study

Development of the PESI system has gone through multiple iterations. Work began on a simple system in which only mobile phone instruments were augmented with relational parameters generated from a Microsoft Kinect system. Through a user test we were able to assess the effect extending the controls into the social domain had on the playability of the mobile phone instrument [3]. This resulted in an extension of the system, to allow for further ideas relating to development of the mobile phone instruments to be explored and implemented.

Figure 2. A group of three participants taking part in first user study of the PESI system.

The first user study used an initial simple system implementation and was primarily conducted to gain insight into the effect socially control parameters had on the interaction. 21 participants: 8 female and 13 male, aged 25-48 were involved in the study. Test participants were divided into 7 groups of three players, each group participated in a separate session (see Fig. 2). In each session we asked the users to use the system in two scenarios. In the first

[3] `http://puredata.info/`

[4] `http://libpd.cc`

scenario there were no social parameters effecting the mobile instruments, in the second scenario, a parameter calculated from the average distance between group members altered an amplitude distortion effect. The evaluation of the user test included a quantitative survey and qualitative interviews. We presented our findings in detail in [3].

In conducting this user study two design issues were highlighted. The first issue related to the average distance value of the group, participants found it was very hard to perceive and understand. Using the individual distance parameters between participants was much more understandable. We believe this is due to the fact that the interaction is obscured when using an average distance parameter. The behaviour is only revealed when the group synchronises, causing the actions to not be publicly available when the group is not synchronised. Thus, the difficulties in perception of the distance parameter's effect on the sound. We believe this is due to a breakdown of awareness from the lack of public availability of the actions relating to this parameter.

As an additional step we chose to reinforce and separate the interaction controlled by social parameters and individuals. For this, we decided to have the mobile instruments only controllable by the person playing it, and use an extended system for socially controlled sound synthesis. These became the *on-body* and *in-space* components of the PESI system respectively (see section 4.3).

The second issue was a technical problem that arose due to occlusion. Occlusion occurred when one or more participants blocked the Kinect's view of another participant and resulted in the Kinect temporarily losing track of the occluded participant.

The main problem that occlusion caused was technical. Within our implementation of the final PESI system there is a requirement to track the identities of performers. For the initial user test we were able to mitigate the problem that occlusion caused by removing the need to user IDs. This was not possible with the final implementation as IDs were required to ensure sonic cohesion between the *on-body* and *in-space* components .

Each user is assigned a unique ID value by the Kinect system, when the Kinect loses track of a user the ID is unassigned. Once the user reappears a new ID is assigned to that user. Thus, when occlusion occurred, a new ID is assigned by the Kinect to the occluded performer causing the PESI system to miss match the sound synthesis between the *on-body* and *in-space* components causing a breakdown in sonic cohesion. This further compounds the problems of awareness, particularly relating to self-identify within the system.

The issues relating to occlusion and social mapping that arose from the user study indicated that the system had not provided solutions to the design challenges mentioned in section 3, particularly those relating to awareness. However, in revealing these problems potential solutions were also presented, for example: not using average distance mappings and developing methods to prevent or at least reduce occlusion. These solutions where implemented when refining and continuing the development of the system, which we assessed in a second user study (see section 4.3.3).

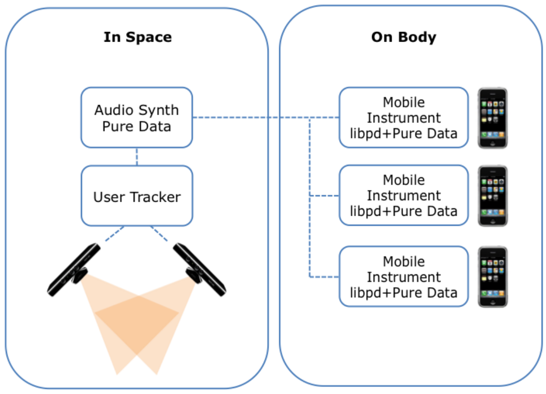

Figure 3. PESI extended system module diagram.

4.3 Design Report

The current system has two main parts: *on-body* and *in-space* components (see Fig. 3) [4, 5].

4.3.1 The on-body Component

The *on-body* component consists of a custom native iOS application built with Objective-C and using Libpd, designed to run on iPhones. This component also includes portable speakers that are directly connected to the mobile phones. Running the sound synthesis on the mobile phone allowed for the co-location of the performer's action and sonic results, reinforcing the embodiment of the interaction. Accelerometer, gyroscope and touch data are retrieved from the sensors in the mobile phone. This data is used to generate the parameters for the sound synthesis modules.

The design of the mobile instruments were based upon participants' comments from the initial systems' user test. The performers have a choice between three different sound modules. Only one module can be played at a time, however, it is possible to switch between each module when playing the mobile phone instrument. Each module has its own sonic characteristics, associated colour and a 'tuning' system that lets users alter static parameters within the instrument for further customisation.

The first instrument *Green* switches between pulse-width modulation (PWM) or wave shaping of a square wave depending on the orientation of the device. The tuning system allows for manipulation of two constant square waves with PWM. Tilt controls frequency and touch controls timbre. The second, *Red*, and third, *Blue*, instruments are based upon a granular synth. Tilting the X axis accelerometer controls the grain playback in both, however, in the *Red* instrument tilting the Y axis accelerometer changes the grain size. The Y axis on the touch screen allows for the playback pitch of the *Blue* instrument to be controlled. The tuning system in both allows for changing default settings within the granular synth in each instrument. For detailed technical descriptions of each instrument see [5].

4.3.2 The in-space Component

The idea behind the *in-space* component was to use a generated layer of sound, related but, external to the perform-

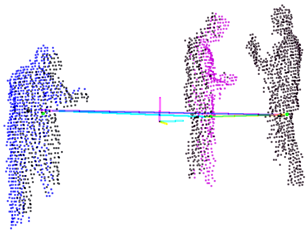

Figure 4. Point-cloud image generated by two Kinect sensor bars showing the motion tracking of three performers.

ers individual mobile instruments. Through this layer the social interactions within the system are represented and manifest as sounds.

The *in-space* component is based around a central control module that receives sensor information from a multi-user motion tracking system as well as from each mobile phone. This information is used to control the sound synthesis of the *in-space* component. The multi-user motion tracking system has been built with two kinect sensor bars (see Fig. 4), the OpenNI [5] library with Processing [6] and openFrameworks. [7] Multiple Kinects were used as single Kinect solutions to occlusion proved unreliable, two Kinects provided a robust solution to the ID switching by dramatically reducing occlusion within the system.

This system continuously tracks the spatial positions of three performers. From their positional information, relative distances between performers, velocity, acceleration and alignment are calculated. Sensor data from the motion tracking system and each mobile phones is sent to the central control module via Open Sound Control (OSC). [8] A robust network module was developed that managed the connections between each component in the system. This module allows the central control unit to re-establish connections, sort sensor information and track the devices that the information was sent from.

The sensor data from the mobile phones is used to generate identical copies of the sounds being played by the performers within the *in-space* component. These sounds are then processed with a granular synth, controlled by socially generated parameters and played back over a multichannel speaker ring that surrounds the performers. The processed sounds are associated to the instrument they have been produced from, thus are unique to each individual performer, to further reinforce the idea of self-identity.

The granular synthesis is mapped as follows (from the perspective of a performer using the system): the grain size and density vary depending on the distance to one performer and the frequency range of the playback scales exponentially depending on the distance to the second performer. The speed of an individuals movement within the space controls the amplitude of the synth. For further technical details see [5].

[5] http://openni.org/
[6] http://processing.org/
[7] http://www.openframeworks.cc/
[8] http://opensoundcontrol.org/

4.3.3 A User Study of the Current System

We invited three skilled-musicians for a user test jam session with the current PESI system (see Fig. 5). Similar to the previous user test, the evaluation was based on survey and interview analysis. Detailed findings from this user study were presented in [5]. In summary, musicians comments and feedback were positive regarding the *on-body* and *in-space* component; especially for the sound characteristics and the responsiveness of each module. This was supported with the following comments directly quoted from participants:

> *" ...pretty impressive... I liked the idea of the extended system. It gives a nice ambient and supporting feeling that you have sound around you...."*

> *".... I have been using sensor based instruments more with traditional music and tonal structures . It would actually be very interesting to implement this system for a traditional kind of music that you could improvise with. The system is actually quite interactive and the instrument is very good. You can do all kinds of stuff with small gestures. This system could be open to all kinds of directions.... "*

Figure 5. Skilled musicians performing with the current version of the PESI system in the user test jam session.

5. BEHAVIOURALLY NON-RESTRICTIVE DIGITAL TECHNOLOGY

In solving the design issues which occurred in the various stages of the PESI system's development, an idea arose, which we term: Behaviourally Non-Restrictive Digital Technology (BNDT). For the *in-space* component of the PESI system to operate, performers are not required to direct or focus their attention towards it or make explicit changes to their behaviour. Yet similarly users are able to act through the *in-space* component when their attention is directed towards it. When attention is directed towards this component, it is able to reveal itself to participants, in relation to theirs as well as other users' actions, allowing them to determine how they wish to deal with it. This can be leaving the system in ones peripheral perceptions or developing couplings with it.

We see the approach of BNDT as a method of accounting for the differing modes of use and shifting of focus that occurs between embodied agents and the environment [15]. The shifting of focus can also be related to the ideas of identity creation, discussed in section 3, as the design of the system allows for the detachment of the user from the system. In allowing for detachment and coupling, users are able to reconfigure their focus and understanding of the system - which we believe aids in the development of identities within the system.

However, accounting for differing modes is only one part of our idea of BNDT. Actions are still an important part of our investigation into design solutions surrounding the ideas of intersubjectivity and awareness within collaborative digital music systems.

5.1 Being Social in the World

Actions themselves are not a kind of act, they are instead properties of individuals at times [22], and are grounded in our movements. We effect objects around us by moving our bodies and we are able to produce different movements to fit a large range of circumstances. The effect these movements will have is also generally understood, as the results of movements are dependent upon the context and situation in which they occur [22].

An important idea relating to the understanding of actions within the context in which they arise from, is the notion of accountability. The notion of accountability is a fundamental feature of the ethnomethodological perspective, and is concerned with what is available to members as situated practice. Members being those who have common sense understandings relating to the situation [15]. In particular, situated practice is the context in which the action arises and thus can be part of the means by which action can be interpreted. Therefore, actions relating to situated practice are understood as normal, rational action by members. The availability of these actions depends on them being able to be observed by members and reported upon: observable-and-reportable [15].

The methods of understanding an action are also the methods for engagement with it. As such being competent with an action requires that it is engaged in ways that are recognised by members. Therefore, an action is needed to be organised in such a way that it is understood as being rational within the context it has emerged from. In the case of the PESI project, the focus was on the sound and action relationships that occur in the context of music.

5.2 Musical Gestures

The relationship between sound and action is being investigated within the field of musical gesture, which focuses on classifying musically related actions. Within this field actions are separated into two categories: sound-producing and sound-accompanying. [23]

Sound-producing actions are the actions used in the process of making sound. Godøy et al. [23] make a distinction between excitation action - which triggers the sound, and modulation action - which modifies the sound. Sound-accompanying actions are the other types of actions which are performed along to sound/music, but are not part of its production; for example playing air guitar or tracing the dynamics of the music. Sound-accompanying actions normally have a readily observable sound matching feature to them [23]. Within the PESI system we have primarily concerning ourselves with sound-producing gestures. However, we also accept the need to be aware of all musically related action that may arise within the PESI system.

One of the main aesthetic considerations we had in relation to the system was that it would not be using traditional acoustic instrument sounds. The sounds being used would be synthesised to create new sounds, to be interacted with and used within a musical context. Therefore, we encountered the problem of there being no established sound-action relationships for the sounds being synthesised with the PESI system. This required the design of new sound-action relationships for the PESI system.

We see sound-action relationships as inherently cultural. Associations of gestures that relate to the production of specific sounds are developed through the combination of cultural practice and physical constraints of the musical instrument [13]. This adds an additional level of complexity if we were to design new sound-action relationships. Instead we have continued to follow our idea of BNDT and decided to not predefine any sound-action, or musical gestures within the system. Instead we have used movement mappings to sound parameters.

5.3 No-predefined Gestures

We facilitate action through allowing movements to have an effect within the system. Performers can develop their own actions through the movements that the system can track. By combining motion tracking information with sensor data from mobile phones it is possible for many movements - both individual (through moving the mobile device) and social (through movement in space) to be used to generate sound responses. Actions can then arise in response to the sounds, caused through individual and social movements, and through this, gestures are able to be developed by performers within the system. We believe that this is possible when the resulting actions are made publicly available, allowing for all actions to be interpreted and accounted within the interaction.

In having no-predefined gestures, the idea of BNDT is further enforced, and the interaction is able to become fully situated, aiding in the potential for adoption into practice. As a further result of our approach we see the possibility to investigate formations of musical gestures from movement within a controlled and traceable environment. Our research interest lies in a similar direction to [24] in that it does not to look for stated understanding of gesture, but to understand how movements are actually employed in the interfaces that researchers have built.

6. DISCUSSIONS

When we compare the PESI system to the work discussed in section 2, we can highlight many common themes. Comparing to the work of Di Scipio [7] and the AESI system, both the PESI system and the AESI system have a focus on the performer and their role within the system. However, unlike the AESI system which questions if the performer is even needed, we take the opposite approach in which the performer's role is strengthened becoming an integral part of the PESI system.

Our approach to having no-predefined gestures could be seen as following Bowers and Archer's [8] ideas relating to infra-instruments. In only focusing on movements our overall mapping strategies have been reduced and somewhat restricted - like those of infra-instruments. We have also allowed for greater flexibility within the social practices of the PESI system, as well as providing space for the technology and computing that enables and enhances the musical activity.

Comparing the work of the PESI project to that of Gurevich and Trevino, Gurevich and Cavan Fyans and Cavan Fyans et al. [9–11] and their work directed towards spectator experience, we can see benefit in having actions publicly available. However, we can foresee a potential challenge faced by spectators of the PESI system. This is due to actions being created within the use of the PESI system. Those who are not a part of the improvised practice may struggle from a spectators stand point to grasp or understand the actions within the system, as they would not be members of the practice. This is a side-effect for primarily focusing on facilitating improvised musical practice and not on performances that feature spectators.

The musical paint machine takes the biggest depart from the ideas we have been using with the PESI system. This is because it has been designed to investigate musical practice, musical gesture, Flow and stimulation of creativity [14]. Here, an element that has not been part of our designs within the PESI system has been used: the addition of multi-modal feedback. Within the PESI system we have only focused on sonic feedback; however, the sonic feedback within the PESI system also provides information on social actions of the group, not just on each individuals personal action. We do see some parallels to the idea of behaviourally non-restrictive digital technology within the musical paint machine project. When using the musical paint machine one can chose their focus between the instrument and the feedback provided by the musical paint machine. This is similar to the PESI system, however, performers can chose between the social, personal or neither to direct their focus.

We acknowledge that there has been little discussion surrounding the sounds and music the system creates. Music itself is an aesthetic form and throughout the design of the system we have drawn upon our own aesthetic preferences to drive the development of the sound synthesis within the system. In theory, we see, our approaches implying a generality in assigning sound mappings to the interaction as the suitably of such mappings is determined through the emergent action-meaning relationship that, we believe, we have facilitated within the PESI system. The effect this has on aesthetic preferences within a social context requires further exploration and experimentation.

7. CONCLUSIONS

In this paper we presented our solutions to the design challenges that were faced within the development of the PESI extended system. In viewing the technology and practices that relate to music from an ecological perspective, the relationships between performers themselves and their instruments became our focus. Drawing upon work within the fields of HCI, CSCW and research into Flow the need to account for awareness and creation of identities were identified as key considerations when designing the PESI system.

Two evaluations were carried out at different stages in the PESI systems development. It was identified within the first evaluation that relational parameters between all three group members were not as perceivable. We hypothesise this was due to the actions of an individual no longer being publicly available due to the other group members obscuring a single members contribution. Within the development of the *in-space* component these considerations where accounted for and solutions were implemented. Relational parameters were relational between each group member but never related to the whole group. This was done to allow for better public availability of actions as well as to enable a stronger development of self-identity within the system. The results from the second evaluation support our design choices.

Through the development of the PESI system we developed an idea of non-behaviourally restrictive digital technology. Within this approach, the shifting focus that embodied agents have in relation to the environment is accounted for, and sound-action relationships are encouraged to be developed through providing mappings relating to individual sensor values and movement information from motion tracking data. Through the situatedness of the performer and instrument, we believe that musical gestures will arise that could not have been anticipated within the design of the system due to the influence social factors have on the usage of the mobile instruments. When discussing these ideas in relation to the related works discussed within section 2 the ideas we have developed can be see within many of these projects.

The contextualisation of sounds within social settings is still an open question within the PESI system and within collaborative digital music systems. Further investigation into the idea of behaviourally non-restrictive digital technology is also required, not only within the design of digital music systems, but in a wider context of digital technology. Both these points are to be considered within further work on the PESI system which will be moving to focus upon long-term movement behaviour between performers.

Acknowledgments

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