Constraining Movement as a Basis for DMI Design and Performance

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ABSTRACT

In this paper we describe the application of a movement-based design process for digital musical instruments (DMIs) which led to the development of a prototype DMI named the Twister. The development is described in two parts. Firstly, we consider the design of the interface or physical controller. Following this we describe the development of a specific sonic character, mapping approach and performance. In both these parts an explicit consideration of the type of movement we would like the device to engender in performance drove the design choices. By considering these two parts separately we draw attention to two different levels at which movement might be considered in the design of DMIs; at a general level of ranges of movement in the creation of the controller and a more specific, but still quite open, level in the creation of the final instrument and a particular performance. In light of the results of this process the limitations of existing representations of movement within the DMI design discourse is discussed. Further, the utility of a movement focused design approach is discussed.

Keywords

Movement-based design, gesture, DMI performance, design

1. INTRODUCTION

A central theme within the NIME literature is that of gesture and the manner in which new interfaces might engage the body in performance. Prior examination of the role of movement in DMI design has focused on the development of descriptive models of gesture [4], the 'expressive' quality of movement [5], and the notion of musician effort [20]. Where research has explicitly considered the design of movement it has tended to be in relation to very specific applications that make use of open-handed gesture [13], the sonification of dance movement [25], or to situations where the design space is first constrained by either a focus on some specific sensor technology or the augmentation of an existing interaction style [6]. Although the role of the body and human movement in musical interaction has been the focus of prior study, there has been comparatively little consideration of how insights gained from this work might inform design practice. Though many idiosyncratic approaches are evident in the literature - approaches that often result in instruments that involve the body in engaging and novel ways - a more general movement-based design method has not been proposed.

When playing an acoustic instrument the instrumentalist must excite some element into vibration, and then possibly manipulate it in some manner so as to control its vibration. And, this excitation and manipulation is achieved through bodily movement. Of course, the situation in the case of DMIs differs. With the replacement of a physically vibrating object (a string, membrane or column of air) with an electronic sound engine (an electronic synthesiser or computer capable of generating sound) the requirement to supply excitation energy is removed and also the manner in which the sonic result can be manipulated expands greatly. A synthesiser or electronic sound engine may have dozens of individually adjustable parameters. It becomes thus a challenge for the DMI designer, to conceive a coherent model for the requirement of bodily movement on a technology-based instrument.

Designers of DMIs have tended to side step this challenge. Rather than designing movement explicitly, DMI development has more often utilised paradigms of interaction based on established traditional artefacts, or moved through small steps of incremental change toward new modes of interaction, guided by the opportunities offered by technological development. By focusing, for example, on technological aspects such as sensor choice, the design space can be adequately constrained without the need to explicitly consider the instrumentalist's movement at any deeper level than an acceptance that knobs are turned and sliders slid. And indeed ergonomic principals of ease-of-use and anthropometrics can aid in the layout of said controls. Further, existing instruments or electronic equipment, e.g. piano keyboards and mixing desk consoles, can be used as familiar templates for design.

In this paper we examined how a designer can design for performer movement explicitly. Our interest lay in examining how a focus on movement first and foremost might drive the design process i.e. that all choices of material, size, shape, sensing and sonic character would be based on the desire to support specific movement in use. Our motivation for this stance stems from the proposition that irrespective of the theoretical background that prompts a greater consideration of the role of the body and physicality in musical performance - be it an embodied approach to cognition, a dissatisfaction with the styles of movement encouraged by existing DMIs, or a recognition of the embodied nature of musical skill - a designer must possess an ability to design explicitly for specific qualities of movement in order to exploit this theoretical viewpoint in design.

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2. BACKGROUND

As with DMI design, product design research has focused on the opportunities and challenges presented by the transition from analogue mechanical control, toward the digitally mediated control of computation enabled devices. Electronics and digital computation have enabled behaviour that requires a rethinking of how users interact with products. As product designers integrate this technology, new challenges arise in terms of designing the physical engagement.

Within the field of Human Computer Interaction (HCI) a similar development has occurred, albeit from a different starting point. The movement of computing from the primarily PC centred paradigm toward what is termed 'ubiquitous computing' has resulted in the need to reconsider at many levels the manner in which human and computer interact [24]. Much work has focused on the social and cognitive aspects of this new paradigm. Recently a greater interest in the role of the body and physicality has emerged.

This is evident in the development of Tangible User Interface (TUI) and Tangible Interaction, approaches that have influence on DMI and NIME design also [1]. Though several different emphases are evident within TUI research a common thread is, 'the desire to design ways of physically interacting with computers that fit with our innate abilities' [3]. Though the notion of innateness is problematic [21][19], the statement denotes the dissatisfaction that developed around traditional methods of HCI, be that the WIMP [1] model on PCs or the prevalence of simple button pushing on digital devices. In contrast, it emphasises the desire to explore a much wider notion of physicality that goes beyond these approaches.

Interestingly however, although notions of physicality, human movement and action are intrinsic to the field of tangible interaction, there has until recently been little direct reference to physical movement in much of the research within this field. By 'direct' we mean that few researchers have considered movement explicitly. This may partly be explained by the originally data centred approach of TUI research, which focused on the physical representation of data [22] and lead to systems which, while involving the movement of objects, rarely considered the quality of the movement as important.

It also arguably reflects the tacit nature of movement knowledge and the difficult nature of explicitly describing and prescribing human movement. A designer will often find that their tacit and embodied knowledge of movement allows them to arrive at a solution without ever explicitly considering the quality or type of movement that the interface will require. For example, in the development of the TUI based musical device 'music bottles' [9] at no point do the developers describe the movement of the user. The act of lifting up a small bottle, removing the cork, and placing it back on a table is one that does not benefit from a detailed description of the movement. However, in making use of this style of interaction, the designers have relied upon their tacit knowledge of movement.

The reacTable [14] is also noteworthy in this regard. Although it is presented as an example of a TUI by the authors there is no explicit discussion of the interaction in terms of the qualities of the user's movement. The interface, consisting of pucks and a horizontal surface, defines the range of movement in a manner that is easily understood by users and designers alike without a need to attempt to analyse in any detail the movements: we have all placed an object on a table. In summary, the tangible interaction approach allows for an expanded consideration of the possibilities for the role of movement in interaction. It does not however necessarily require the explicit consideration of the quality or range of movement and further, does not necessarily lead to a richer use of movement than in the case of say WIMP based interfaces.

[1]In human computer interaction, WIMP stands for 'windows, icons, menus, pointer' denoting a style of interaction using these elements of the user interface.

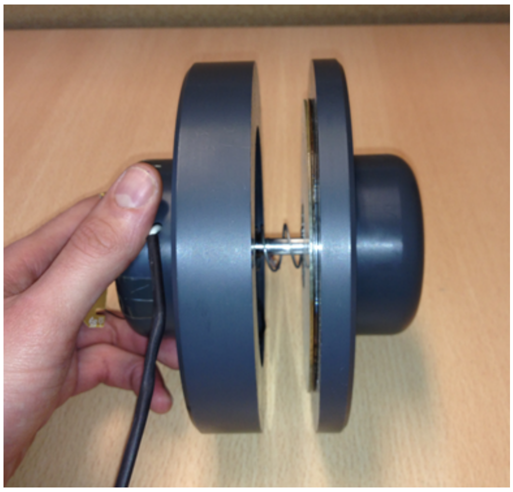

Figure 1: The Twister

2.1 Movement Based Design

In recent years the term 'movement based interaction' has been used to describe approaches to interaction that emphasise the role of human movement, irrespective of whether that emphasis stems from an embodied, enactive, tangible, aesthetic or other viewpoint. In the introduction to the special issue of Personal and Ubiquitous Computing on movement based interaction, the editors called on designers to 'think further about the role of the body, and how bodily movement can and should be used in real use contexts' [17]. A recurring theme within this field is the idea that in order to exploit movement within design fully a designer needs to have an embodied understanding of movement and that the designer needs to move. Klooster emphasises the view that designers need to be physically engaged in the act of movement exploration as part of the design process [15]. Essentially, they argue that 'the designers body needs to be educated'.

Jensen et al. [11] present several design methods based around an approach they term 'designing actions before product'. The authors cite the desire to be explicit about actions before linking them to physical design solutions. Their approach takes observation of existing examples of rich human movement from craft traditions as a starting point. The designer then seeks to isolate qualities of the actions that might be of interest to, or applicable to, another context.

2.2 A Movement Based Design Process

A complete description of the various movement-based design approaches that have been described is beyond the scope of this paper. However, in reviewing the work of movement-based designers four activities can be seen to be commonly used:

1. Observation and Analysis of existing movement
2. Exploration of Movement
3. Devising Movement

4. Product or System Actualisation

These activities fulfil specific requirements for movement-based design. Observation and analysis of movement lead to an understanding of the qualities of movement that typify a situation, and can also highlight relationships between an existing product and the movement style that it encourages. The exploration of movement exemplifies the embodied approach to understanding movement as argued for by Hummels and others [8]. Activities Three and Four move directly toward design and the creation of a system or object. The emphasis on movement is maintained by explicitly attempting to design actions and movement before considering the product's features. The features are then designed to encourage or require the intended movement quality in use.

Based on this observation we decided to explore movement-based design of a DMI using these four activities as the basis of the design process. In order to support the observation and exploration activities we chose to use Laban Movement Analysis (LMA) [7] as a framework. Our decision to use LMA was influenced by previous work within DMI development which explored the Effort and phrasing aspects of the framework [2][23].

3. THE TWISTER

In designing the Twister we began first by analyzing the movement of several clips of violin and no-input-mixer performance using LMA. Our focus here was on the different qualities of movement that were displayed and how the interfaces' physical characteristics encouraged or constrained movement qualities. From this analysis two movement qualities were chosen for further exploration.

- *Carving.* A specific quality of movement defined in LMA as part of the Shape category. A Mode of Shape Change that is environment motivated and molds with the environment. It is adaptive, 3-dimensional, uses rotary function. Both mover and environment (space, other person, etc) are changed in Carving movement.
- *Interfaces and physical boundaries:* It was interesting to note how certain interface elements set very definite constraints on the useful movement whilst others allow the limitations of the body to define the constraints. e.g. a simple linear potentiometer with 120mm of travel versus a rotary encoder that can be turned continuously.

Following the selection of these two qualities the first author engaged in a physical exploration of different Shape and carving actions using a range of different Efforts and scales. The hands-only approach of Jensen et al [11] was found useful as part of this process.

This process of movement exploration, which led to the definition of a two handed action with a range of Effort variations, also generated very definite ideas as to the form and features of the instrument. In order to encourage the two hands to act simultaneously, the instrument needed to be an object that was grasped and held in both hands. It needed to allow the distance between the hands to vary whilst keeping the palms facing each other and encouraging the hands to rotate in opposite directions.

In order to explore the notion of challenging boundaries it was decided that the limits of the rotational aspect of the Carving movement should be set by the performer's body, and not by the interface. This suggested the rotation should be continuous. The device was first sketched and then a 3D model of the prototype was created. A physical prototype was then created in ABS plastic. Following this the metal bearings, shaft, spring and keyways were fitted.

4. TECHNICAL DESCRIPTION

The Twister interface consists of two flat cylindrical discs, each with a smaller diameter raised cylindrical section that acts as a handle and allows it to be gripped easily. The two discs are attached to a shaft or axle which allows one side to rotate freely with respect to the other. One of the discs can also slide along the axle thereby varying the distance between the two discs between 18 mm and 0 mm. A light spring maintains the distance of 18mm between the discs when no force is applied. The movement suggested the physical form for the Twister, and also the main elements of the sensing system. An optical encoder was integrated to sense the change in angular displacement between the two sides of the device. A short-range infra-red sensor was used to sense the distance between the two hemispheres. These two sensors, coupled with the physical mechanism, allow for the combined pressing and twisting movement which characterise the Carving action to be captured. Two buttons were added as a simple way to exploit the fingers of the hand that is gripping the disc. The associated circuitry was integrated into the handle of the device. A cable exits from the side to carry the sensor signals to an arduino.

5. EVALUATION & REFINEMENT

A user study was carried out that explored the manner in which naive users manipulate the device. In this study the device was not connected to any sound generator. The central question was whether it did in fact invite Carving movement in use. The study showed that the interface did naturally invite the Carving. Participants also suggested possible sound mappings. Several unexpected actions were suggested as possible music producing gestures. A recurring suggestion was the use of tilt and also shaking as a control parameter. Based on these suggestions a three axis accelerometer was added to the interface to enable the detection of these parameters.

6. PERFORMANCE DEVELOPMENT

The Twister was used in a live performance viewable at `http://vimeo.com/75591098`. Hereafter, we offer a description of the process behind the creation of the performance. We will do this by trying to offer an insight of the mental processes that facilitated the development of the performance. This analysis is, however, not strictly made by using tools borrowed from the field of musicology. Rather, we offer a framework for the analysis that focuses on justifying the choices made according to either technical constraints and/or aesthetic issues.

6.1 Defining Affordances and Constraints

The first step towards the creation of the performance was the study of the Twister interface's characteristics. This process was formalised in a process whereby the first author interviewed and guided the second through the discovery of the instrument's features and capabilities. The intention here was to place the emphasis on considering action first. The first author asked the second to respond to the following:

- Please list off and demonstrate as many different actions that you feel the device supports.
- Please perform two fast, energetic actions
- Please perform two long slow gradual actions.

Table 1: List of affordances for the Twister

Gesture	Sensor
clockwise and anti-clockwise rotation	optical encoder
two buttons	momentary switches
shaking	accelerometers
opening and closing of the discs	Infrared sensor

- Please perform two actions that combine a range of sudden and gradual movements (about 20 seconds).

Using Norman's words this process aimed at finding *'the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used'* : the affordances [18].

However, it is important to stress that the list of the DMI's affordances was confined to those actions that were felt would be useful for the purpose of the performance and to which the device could respond, i.e. that could be detected by the sensors. The list of these *utilitarian affordances* is therefore defined here by the combination of gesture and actuators as presented in Table 1. It should be noted that the list provided in the table includes highly subjective affordances of the Twister and that different performers could have expanded or reduced the provided list. In particular the list includes actions that are limited to a very defined section of the kinesphere surrounding the performer (i.e. hand movements close to the performer's chest) and that performers more inclined to 'dancerly' or open movements could easily expand on the list offered here.

6.2 Sonic Character

6.2.1 Sound Generation vs Event Controller

Before delving into the mapping problem (connecting gesture-data to sound output), it was useful to just play with the device while imagining possible sounds. This simple, playful and imaginative exercise helped in answering a more serious issue: should the device control parameters of a sound generating mechanism (e.g. a carrier frequency, modulation frequency and so on for an FM synth) or instead focus on the triggering of pre-recorded loops, events etc? or both? The answer is, of course, completely subjective but it is required in order to progress in the development of the performance. For the purpose of the performance presented here, the device was intended to be used primarily as a controller of events.

6.2.2 Instrument(s) sound design

Having decided that the Twister will control events, the next step involves deciding what kind of events. Two elements influenced the choice. On one hand, we have a limited sets of actions (see Table 1). On the other hand, the composer felt the urge to have control over multiple sounds simultaneously in order to facilitate the creation of a vertical/multi-layered dimension in the music performance (multi-voicing). The compromise between these two elements was achieved by assigning to each button a synthesizer (synth 2 and 3) and a further synth (synth 1) to the opening and closing action. The quality of the sounds generated by these three synthesizer was influenced by the quality of the movement that would trigger them. More precisely the opening and closing movement suggested long notes with amplitude curves reflecting the sound produced by an accordion. Conversely, the action of pushing the two buttons was suggesting amplitude curves of short notes as originating from a kalimba.

Having defined the amplitude shape of the sound generated by each individual synthesizer, the attention moved on to the pitch for the notes. The constrained movements that the device afforded was thought to be insufficient for the precise trigger of several individual notes. Therefore, it was felt that the note generating process could be left to a random generator algorithm bounded to specific rules[2]. The closing and opening movement and the buttons were then confined to the enabling of the start and stop function of this algorithm.

6.3 Mapping

6.3.1 Creating a sound-to-gesture vocabulary

The number of useful gestures discovered represents the starting point for the subsequent development of a musical gesture vocabulary. This vocabulary links gestures to potential sounds by means of metaphors and it forms the basis of what will be then used for the appropriate coding of the mapping. The vocabulary is built by taking into account gestures but also combinations of gestures. The way the data retrieved is manipulated enables the mapping between action and sound.

The software used for the data manipulation was MAX 6. Sounds and effects were generated and triggered in Ableton Live. Hereafter is the list of actions described in terms of metaphors and technical implementation & mapping.

Music Box: The continuous rotation speed of the disc was mapped to the tempo of the random generator unit connected to synth 1. The two discs must be in open position. The action providing this data resembles the movement required to act upon a music box for which the faster you rotate its wheel the faster the notes are played.

Accordion: The distance between the discs controls the volume for the Ableton channel strip hosting synth 1 and continuously receiving midi notes from the random generator unit. A close position mutes the sound. The open position maximises the volume of the channels strip. This open and closing movement resembled the one used to play an accordion.

Pointillism: The two buttons control the start/stop function for the random generator units connected to synth 2 and 3 respectively. The pushed position triggered the start command. The released position triggered the stop command. These actions helped to add to the sonic palette. The sonic attributes of these synth are in contrast with the slow attack notes from synth 1 and work as 'pointillistic' decoration to the main melody lines built by synth 1.

Voices: By default, when opening the discs the random generator units for synth 1, 2 and 3 generate random notes from the Cm7 chord with random velocity. When closing the discs, it is possible to rotate the two in opposite directions. The angle of this rotation is measured and mapped to a fifth up or down every +/-15°of rotation as showed in Table 2. Thus, the sequence closing-rotating-opening triggers the random notes from the selected chord.

Shaking: The data retrieved from the three axis accelerometer was converted to polar form and the magnitude used to control the shaking effect. The effect is a combination of distortion and delay lines added in an auxiliary track in Ableton Live. The shaking movement controls the threshold parameter of the gate (input of the auxiliary) which opens and

[2]see next Section.

Figure 2: A stop-frame sequence of the carving gesture.

Table 2: Angle to Chord Mapping.

Angle	Chord
0°< angle < 15°	Cm7
15°< angle < 30°	Gm7
30°< angle < 45°	Dm7
0°< angle < -15°	Fm7
-15°< angle < -30°	Bbm7

closes itself according to the magnitude and thus creates a distorted rattling effect (a metaphor for the movement originating it). The mapping of the magnitude to the threshold parameter is mediated by a physics emulator object (pmpd library) which smoothes the oscillation between values with a spring motion that reinforces the rattling metaphor.

Tilting: The Y axis accelerometer value was used to retrieve the inclination of the Twister over one axis only. This function was enabled in order to discern in which mode the data originating from the rotational movement of the discs would be interpreted. The two modes were: 'Voices' (see above) and 'Carving' (see below).

Carving: The carving movement is depicted in Figure 2 and it includes a combination of closing, tilting and rotating actions. The carving mode is enabled when the Y tilting value is above 350°and the discs are closed. When the Y tilting is below 350°and discs are closed data is instead used for the 'Chord selection'. Once the tilting value is above the given threshold, tilting data is used to control the gain of the send faders of each synth connected to a dedicated auxiliary track in Ableton Live. The auxiliary track include a combination of delay and grain effects. These effects are then controlled by a macro parameter that has been mapped to the angle of rotation performed. The resulting sonic output is a gradual deformation of the ongoing music which now seems to be squeeze and crashed. Similarly the body gradually contorts to force itself, and the Twister, in a carving gesture.

6.4 Structuring and Sequencing

Each word in the previously described dictionary can be considered as a unit with distinct characteristics. The 'Accordion' and 'Pointillism' provide a fairly large sound palette. Their combined use allowed for the adding in complexity and density. The 'Shaking' and 'Carving' allow for the building of tension. The 'Music Box' allows for relentlessness. The 'Voices' unit allows for modulation to a different key signature.

The performance presented in the video accompanying this paper is improvised and it follows a ternary form ABA'. This was possible due to the 'Voices' unit which allowed to modulate to several key signatures. Sound intensity and density followed a bell shape curve. The 'Accordion', 'Music Box' and 'Pointillism' units are introduced gradually and mixed throughout the performance. The apex of tension is created in the central part of the performance by combining shaking and carving.

All these units, which originated from a reasoning of the links between action and sounds, were available to the performer who needs to present them in an structured manner at performance time. Thus, the structure is thought in terms of gestures and sound at the same time and it could be scored by displacing units vertically and across the temporal line (horizontal) to depict time of intervention. This would then be a sort of graphical score or storyboard of the kind of what illustrated , for example, in [16, p. 106-107].

7. DISCUSSION & CONCLUSION

The Twister interface was deliberately kept simple in order for us to focus on the design process and examine whether it was useful to target specific movement qualities as the basis for design. Our experience suggests that this approach is useful. The device did invite the movement quality that it was intended to. Further, considering how the sound mapping might encourage certain actions was seen as a useful starting point in the further development of the DMI.

Central to the design approach was the use of LMA as a typology of terms that refer to specific aspects of movement. LMA is but one of many different framework for movement description. Prior work has focused on the Effort and Phrasing aspects of LMA [2]. Here we found it useful to look at the Space and Shape elements and consider how the different types of Shaping might suggest interaction. What is apparent from our limited exploration of LMA however is the need to familiarise ourselves better with the nuances of this rich and detailed approach to movement description. Being able to refer to aspects of movement explicitly defined in a framework such as LMA, and to differentiate between various actions according to clearly defined qualities is essential if movement is to become a design material. The interface described here is not what one might expect to emerge from a movement centred design process. It does not require large exaggerated 'dancerly' movements. This reflects our desire to explore design process and theory as opposed to simply attempting to develop what we might personally feel to be instruments that epitomise physicality.

The second author did not find it necessary to refer to LMA in defining the actions that would underpin the development of the Twister as a complete DMI. We see here the need for several different representations of movement at different stages of the design process. LMA is beneficial in the initial stages of identifying ranges of movement, in terms of body part usage, spatial aspects etc. Within the NIME literature musicians' movement has tended to be most often considered in terms of a functional taxonomy of gesture. This description however does not fully capture the qualities of movement. It does not describe movement in movement terms. Our work with LMA suggests that a shift toward describing movement in terms of how the body actually changes, its shape, use of space, and the dynamics of this change, might better inform design.

In any approach where the aim is to design the actions before product the designer must note that it is never possible to fully prescribe the movement that will be evident in performance. This of course is dependent upon the intentions and preferences of the performer. However, as with Jensen [10], we have found that an explicit focus on action is a rich starting point for design. It forces the designer to consider how the interface will require and encourage certain movement qualities whilst constraining or prohibiting others. Through repeated applications of a movement-based design process we believe that a designer should develop a clearer understanding of how to design for movement and how design choices effect possible movement. As stated earlier this approach appears beneficial both in the early stage of considering the interfaces's physical characteristics and also in the development of action-sound coupling [12]. Here we have attempted to add to the notion of action-sound coupling by considering what we see as the preceding problem of action-interface coupling, an area that we feel has been somewhat neglected in the NIME literature to this point.

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