Sensor-Specific Strategies for Mapping Gesticular Control to Digital Music Instruments

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Abstract

Recent developments in 3D gesticular control systems as human-computer interfacing peripherals have changed what may be realized as a digital music instrument (DMI), with profound implications for the directions and potentials of future pervasive computing. Before these applications can form a substrate for creative expression, however, knowledge about our ability to cooperate with them must be rendered in a practical form, one that can serve as a basis for fluency of manipulation by it's future virtuosos. This work analyses the specific level of development regarding the integration of music synthesis software with the Leap Motion Controller® and presents a methodical course toward advancement of the art built upon the careful analysis of effective mapping strategies for DMI systems.

1. Introduction

We commence this study with an analytic deconstruction of the Leap Motion Controller. Subsequently we examine the concept of a DMI to establish a narrow basis of comparison, permitting us to separate what is useful or valuable from what is superfluous. This study adopts the GOMS (Goals, Operators, Methods, and Selection rules) information processor model for evaluation of human-computer interaction in addition to ergonomic considerations described by Fitts' law, and the relation between DMI object and environment encapsulated by the notion of affordances. We present a Leap Motion inspired DMI of our own creation based on these specified metrics and finally we posit a reasoned trajectory for DMI technology; laying the foundation for future work.

2. Leap Motion Controller

The Leap Motion Controller is a relatively new consumer-grade sensor designed principally for registering gestures performed by the fingers or hand(s) with respect to relative position, for use as input to general-purpose software applications. The Leap Motion aims to provide a high degree of granularity, facilitating a sensitivity to actions imperceptible to its predecessors. As the vast majority of musical instruments are directly manipulated by hand the utility of this device as a DMI controller is compelling.

The working mechanism of the sensor consists of two charge-coupled device (CCD) cameras in addition to three infrared light-emitting diodes projected over a limited field of view described by an approximate 61 cubic centimeters. Manufacturer documentation asserts a sensor accuracy, with respect to the detection of fingertip position, of roughly 0.01 mm, though extensive testing has established a degree of accuracy of approximately 2.5 mm, with an average precision of 1.2 mm [6]. In terms of repeatability the sensor averaged not more than 0.17 mm of exactitude. Finally in the determination of movement toward discrete positions on a path, the standard deviation was less than 0.7 mm per axis (x, y, z). [5]

Hand tracking within the circumscribed field of vision for the device is highly accurate. In this working area there are three distinct tracking modalities: *Robust*, *Low Resource* and *Auto Orientation*. The performance levels can be configured to: **High Precision**, with a frame frequency of $\approx$ 50 frames per second (FPS) of data and a corresponding delay of $\approx$ 20 milliseconds (ms) as applied to computer music**;** to **Balanced Tracking**, with data FPS of $\approx$ 100, and a delay of $\approx$ 10 ms**;** and **High Speed**, which entails a perceptible loss of precision but a reduction in delay to $\approx$ 5 ms ($\approx$ 200 FPS)[6]. These figures feature prominently in the Methods-Time Measurement (MTM) analysis of each DMI system with respect to the GOMS model.

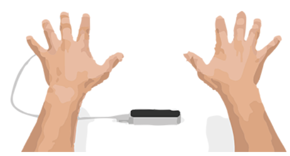

Figure 1: Conception of a simple Leap Motion DMI

3. Methodology

3.1 Digital Music Instruments

The term digital musical instrument (DMI) can be understood to mean a control surface and a computer-generated sound unit, which drives the music synthesizer. It should be noted that both units are independent modules related to each other by mapping strategies. The sensor serves as the gestural controller, which processes the physical behaviour of the performer, generating input for the DMI. The sound producing component involves a synthesis algorithm and it's associated parameters. The mapping strategy is the crux of the device; it is the interlocuteur between output of the general controller and the input to the sound unit. [3]

The distinction between gestural controller and sound generation module is where DMIs diverge from acoustic instruments wherein the gestural interface is inseparably bound to, and often defines, the sound production unit. The concept of a DMI is analogous to the disassembling of an acoustic instrument, such that one might separate the functionality of the gestural interface and the sound generator, thus freeing them for alternative methods of combination and modification. Thus the traditional correlation between action and sound in a DMI is irrelevant.

3.2 Gesture

In this paper, the term gesture is used in a broad sense to mean any human action used to stimulate the sensor. In order to devise new DMIs, it is important to start by analyzing the characteristics of the actions that will be captured. For instance, the human hand is ideal for fine motor control owing to its dexterity; thus the basic starting point for studying performance gestures is effective movements, the actions that performers make in order to generate sounds. We hold the *instrumental* gesture to be a movement intended to effect the control surface of the sensor, with forms and dynamics that can be mastered by the subject.

3.3 Feedback

The signal acquisition system must account for the physiological characteristics as well as the context-specific function of the instrument, to a large extent this is determined by the visual, auditory, and tactile-kinesthetic feedback presented to the performer. The characteristics of feedback can be described as follows: **Primary:** visual, auditory, and tactile-kinesthetic; **Secondary:** sound response from the instrument; **Passive:** physical characteristics of the system; and **Active:** produced by the system in response to a user action.

These feedback metrics are important in acoustic performance and are therefore necessary in gestural interfaces that simulate the control surfaces of such instruments. In our case the gesture does not involve physical contact with the device and there is no *imminent* need to provide the user with tactile or force feedback, although it has been shown that feedback can significantly effect the usability of "open-air" DMI controllers.

3.4 Mapping

Between the acquisition system, responsible for analyzing and capturing the unique gesture characteristics of the user, and the synthesizer, employed in the generation of the sound response, is the relationship that maps these inputs to appropriate parameters known commonly in digital music as mapping. Traditional input channels, e.g the velocity of a cellist's bow or the pressure exerted on a percussion mallet, provide a 1:1 correspondence as the relationship to the synthesis algorithm is determined by the physical attributes of the system. The mapping strategy is the essence of the instrument. This characteristic is not obvious to the creator of the DMI nor to the user; it must be selected on the basis of receptivity to the action by the input device and a logically comprehensible association in the mind of the performer.

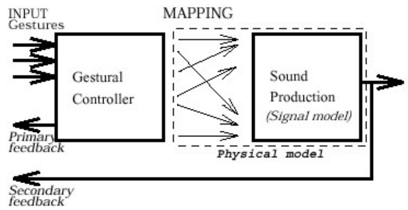

Figure 2: Graphical representation of parameter mapping [3]

4. Results

4.1 Procrustean Instrument

It is reasonable that engineers would initially attempt to replicate more familiar instruments by adapting them to the Leap Motion framework as a barometer of effectiveness, to examine the extent to which this new platform conforms to currently established expectations of DMIs.

Since historically the piano keyboard has dominated large swaths of the input mechanisms we do well to consider the effects of Leap Motion integration into this traditional framework. One interesting study sought to perform just such an integration of the Leap Motion with a virtual keyboard [5]. In order to provide tactile feedback to the user, they created an arrangement with a sheet of glass placed atop the sensor, in an effort to simulate the kinesthetic experience of the keys; moreover, the glass was demarcated to appear as a piano keyboard.

It was found that problems emerged with respect the degree of subtly in tracking input. In the case of two fingers placed in close proximity, the Leap Motion was insufficiently sensitive to distinguish each stimulus separately. When the Leap Motion pianist sounds a note he would be required to pay undue attention to the cleavage of his fingers for this system to adequately identify the intended input. Furthermore, with a digit depressing a particular note, there exists the potential that the systems inherent instability might loose track of that input and in recovery generate a false positive. At other times the input was wholly ignored by the sensor creating a false negative.

An acoustic instruments demands a high degree of nuance, the representation of these input parameters are inseparable from the internal representation of the mode of play that a musician demands of a device which replicates their characteristics. If instead of attempting to force an acoustic instrument to fit a digital mold we adapt our gestures and mapping strategies to the idiosyncrasies of the input mechanism, we can create a meaningful and satisfying experience for the user.

4.2 Sensor-Specific DMI Mapping

The Leap Motion offers an enticing model with which to break from the commonly accepted keyboard input convention, thereby creating an opportunity for sound to map more naturally to representations found in the physical world.

We took advantage of the repeatability with which the hand-opening gesture registers a positive identification by the Leap Motion sensor based on the SDK. Using this as a basis, we sought to conjoin this action to a logically relevant sound. The distinctive and long sustaining high-pitched *ping* sound of a bell or cymbal was selected with regard to the conceptual link between the opening of a closed fist and the accompanying sonification which can be afforded by the resonance evoked through the intentional dropping of a hard object onto a tempered sheet of metal, a cymbal or bell.

In our system the opening of a closed fist evokes the sound of a bell which resonates until the fist is closed. Under conditions of field testing the delay was virtually imperceptible to the performer. Using the *Processing* programming language to transmit the Leap Motion data via *Open Sound Control*, a protocol for communication between a sound-synthesizer and a computer, to *SuperCollider*, an environment and programming language for real-time audio synthesis and algorithmic composition, we were able to achieve the desired effect. This framework is based on a proof of concept demonstrated by the work of Gene Kogan [2].

This instrument was tested against popular DMIs from the Leap Motion Airspace App Store amongst a group of 10 Computer Science graduate students in an effort to evaluate the effectiveness of the conceptual mapping system as opposed to the replication of traditional instruments [4] and [1]. It was unanimously determined that the reinforcement provided by the 'replica models' constituted a dramatic departure from the typical behaviour the impersonated instruments would be expected to demonstrate through their physical counterparts. The 'beating' motion associated with percussion is fraught with ambiguities, described by participants as beset by "significant" latency and a "highly irratic" mapping policy, leading inexorably to a sense of disillusionment. Alternatively the open palm gesture sonified by the ringing bell was described by such words as "intuitive" and even "natural".

5. Discussion

The open-palm gesture was selected on the basis of dependable recognition by the sensor. This characteristic and *not* analogy to the antecedent instrument must be the criteria for mapping strategy of sensor controlled DMIs. The bell sound was chosen on the basis of psychological mapping and our perception of it's generalizable internal representation in the mind of the users.

It was found that our device has relatively low barriers to entry but lacks sustainability, i.e. it is easy to "play with" for a while but like a toy rapidly looses it's appeal. This stands in stark contrast to traditional instruments which are initially very difficult to play but become more interesting in direct proportion to the amount of time devoted to practice.

Video game controllers offer an interesting model, with a relatively stable interface, techniques developed on one platform are transferable between games and systems; resulting in a suitable environment for aficionados to hone their skills. Applying a similar pattern to sensor-based DMI design would likely improve retention.

6. Conclusion

Each DMI which integrates the functionality of alternative input mechanisms such as the Leap Motion controller merits commendation for advancing the avant-garde of musical expression. The reconstitution of traditional instruments with adaptations for sensor technology serve as an important metric with which to access the sensitivity of these devices. However, the utility of these hybrid creations should not be overemphasized as the true creative capacity of sensor technology lies not in the adaptation of antiquated paradigms but in the re-envisioning of the fundamental framework for digital instrumentation.

7. Future Work

Reinforcement is the key. The musician adjusts his play by what is reinforced through auditory, tactile and visual response. The fusion between Leap Motion and pervasive devices such as Oculus VR® gives credence to the idea that fully immerse DMI experiences are not far on the horizon, providing a high level of reinforcement for performers.

8. Acknowledgments

Without the substantial contribution of [6], this study would not have been possible. [5] deserve special mention. We would like to recognize Gene Kogan for providing a proof of concept upon which our instrument was based.

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