Towards Related-Dedicated Input Devices for Parametrically Rich Mechatronic Musical Instruments

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ABSTRACT
In the recent years, mechatronic musical instruments (MMI) have become increasingly parametrically rich. Researchers have developed different interaction strategies to negotiate the challenge of interfacing with each of the MMI's high-resolution parameters in real time. While mapping strategies hold an important aspect of the musical interaction paradigm for MMI, attention on dedicated input devices to perform these instruments live should not be neglected. This paper presents the findings of a user study conducted with participants possessing specialized musicianship skills for MMI music performance and composition. Study participants are given three musical tasks to complete using a mechatronic chordophone with high dimensionality of control via different musical input interfaces (one input device at a time). This representative user study reveals the features of related-dedicated input controllers, how they compare against the typical MIDI keyboard/sequencer paradigm in human-MMI interaction, and provide an indication of the musical function that expert users prefer for each input interface.

Author Keywords
human-robot interaction; wearable sensor interface; musical robotics; mechatronic musical instruments; user study

ACM Classification
H.5.2 [Information Interfaces and Presentation] User Interfaces—Evaluation/methodology, H.5.2 [Information Interfaces and Presentation] User Interfaces --- Input devices and strategies

1. INTRODUCTION
In recent years, mechatronic musical instruments (MMI) have become increasingly parametrically rich [16]. This increase in the number of user accessible parameters presents the potential of greater amounts of musical expression to composers and performers [18]. While many early musical robots presented users with a small number of discrete parameters, some current systems allow for many continuous parameters to be affected [6]. Consequently, this increase in parameters comes with an increase in the level of difficulty of interfacing with each of the high-resolution parameters in real time, in the context that the MMIs behaves like a musical instrument rather than as an autonomous agent. This is one of the major challenges facing users and creators of parametrically dense mechatronic musical instruments. To address this problem, new control systems, which include new custom input devices as well as mapping strategies between a human performer and a parametrically-dense MMI, must be explored. While mapping strategies hold an important aspect of the musical interaction paradigm for MMI, attention on related-dedicated input devices to perform these instruments live should not be neglected. A recent user study on using new mechatronic musical instruments conducted by Murphy et al. expert users revealed that there exists a need for related-dedicated human-to-mechatronic input interfaces [10]. Two questions emerged when designing these new specialized musical interfaces:

1. How does new custom input devices, specifically gestural controllers, compare to the conventional control paradigm of MIDI keyboard and sequencer in this human-mechatronic musical interaction?
2. What are the key factors that contribute towards the compelling musical interactions, mediated by dedicated input devices, between the composer/performer and the new mechatronic musical instruments?

To answer these questions, a user study is conducted. The main goal of the study is to gather information from users pertaining to their experiences in using different musical interfaces to control parametrically dense mechatronic musical instruments. An enhanced understanding of users' experiences will provide an indication to which device performs best in compositional and performative contexts, together with insights into the key factors that afford intuitive, idiomatic, and highly embodied live interactions between human and MMIs in a digital musical instrument model. Consequently, this will facilitate research in the design, development, and evaluation of new musical interfaces for new mechatronic musical instruments in composition and live performance.

This paper begins with a brief introduction to recent trends in MMIs and interaction strategies. Thereafter, the user study design, protocol, procedure, and results are described in the following sections. Finally, this paper concludes with a discussion and describes future works that may arise.

2. INTERACTING WITH MECHATRONIC MUSICAL INSTRUMENTS
The majority of existent research in human-robot musical interaction remains limited to mapping schemes rather than the input devices [15, 18]. While researchers in the field have created specialized input devices to control mechatronic musical instruments [6, 7], most of these devices are developed for use with mechatronic instruments that are parametrically simple and are designed from an idiosyncratic perspective [4]. To address this issue, one can turn to the literature of design guidelines and principles for digital musical instruments (DMIs) as described in [2, 5, 12]. While some of the design guidelines for the input module of digital musical instruments may be transferable, parametrically rich mechatronic musical instruments pose a set of new considerations. The output module of DMIs is typically computer-based sound synthesis and thus does not have an embodied relation to its input [9]. As such, researchers have proposed to design controllers of DMIs with "sufficiently convincing gestural control affordances to overcome any concern about authenticity in performance whilst providing the potential for highly nuanced, expressive, embodied music performances" [11].

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In the case of MMIs, the sound producing mechanisms are constrained by the mechanical and physical limits of their responsible actuators. Furthermore, there is a physical and visual causality between the movements of the actuators and their sonic outcomes. Consequently, two main mapping directions can be derived when considering the features of MMIs:

1. Since the sound-producing mechanisms of MMIs are obvious and visible, there is freedom to utilize more abstract mapping schemes. This results in interactive performance systems, in which the MMIs may seem to be autonomous or "intelligent" as described in [4].
2. Because of the physical and visual causality that is apparent to the user, more explicit mapping schemes that correlate the user's actions to the actuators are required to achieve an intuitive and expressive control of the MMIs.

3. USER STUDY DESIGN

This user study is designed to gather information from users pertaining to their experiences in using different musical interfaces to control a parametrically dense mechatronic musical instrument. As described later in the following sections, study participants are given three musical tasks to complete using a mechatronic chordophone with high dimensionality of control via different musical input interfaces (one input device at a time). Thereafter, a series of questions are posed to gain insights into their interaction experience afforded by the musical input interfaces.

This study was conducted with approval from the Standing Committee of the Human Ethics Committee at Victoria University of Wellington.

3.1 Participants

Due to the specialized nature of the study, participants would require specific musicianship skills to provide insightful feedback. Drawing upon Murphy et al.'s user study on using new MMIs [10], participants with the following musicianship are gathered via email correspondence:

1. Familiarity with electronic music composition tools such as digital audio workstation (DAW) software and musical interfaces that may be classified as new interfaces for musical expression;
2. Familiarity with electroacoustic and synthetic composition techniques;
3. Experience in working with musical mechatronic instruments.

In total, six participants (four males and two females, aged between 25 to 34) took part in this user study.

3.2 Study Protocol

Four criteria are identified from Shackel's criteria for usability of HCI systems [14] and Pressing's cybernetics of the control interface [13] to be key characteristics of a related-dedicated input controller for parametrically rich mechatronic musical instruments, and are used to facilitate the evaluation of users' experience in controlling a parametrically-rich MMI with different input controllers. The four criteria are:

1. **Ease of use**: the efficiency and effectiveness of how one can accomplish musical tasks;
2. **Immediacy**: the extent of translation from intention to the execution;
3. **Access to control multiplicity**: the ability to simultaneously access and modify a range of sound-shaping parameters to alter the sonic output;
4. **Precision**: the extent to which one's control inputs affect the sonic outcome within just-noticeable-difference threshold.

Similar to the dimension space used to evaluate digital musical instruments [1] and collaborative musical performance systems [3] proposed by Birnbaum et al. and Hattwick and Wanderley respectively, this study utilizes a dimension space representation, with the proposed four criteria as axes, to visualize user experience in controlling parametrically rich MMIs with different musical interfaces. While previous dimension space representations utilize a more subjective and qualitative measurement of each axis, this study extends the representation model and utilizes a five-point Likert scale [8] to measure users' attitudes towards each criterion: one denotes the least and five denotes the most. A glossary of the definitions for each criterion is provided to the study participants, and an explanation of each term is provided at the beginning of the study.

3.3 Study Procedure

In this user study, the participants utilize three different musical interfaces to interact with *Swivel 2*, a six-stringed mechatronic chordophone as shown in **Figure 1**. The tools used in this study are: 1) a ubiquitous MIDI keyboard controller, 2) MIDI sequencer in Ableton Live 9, and 3) *g.qin*, a custom gestural controller that measure the three-dimensional orientation and physical dynamics of the fingers and wrist of the left hand. No other gestural controllers were included because the goal of this study is a comparison between the gestural control paradigm and the typical MIDI keyboard/sequencer paradigm.

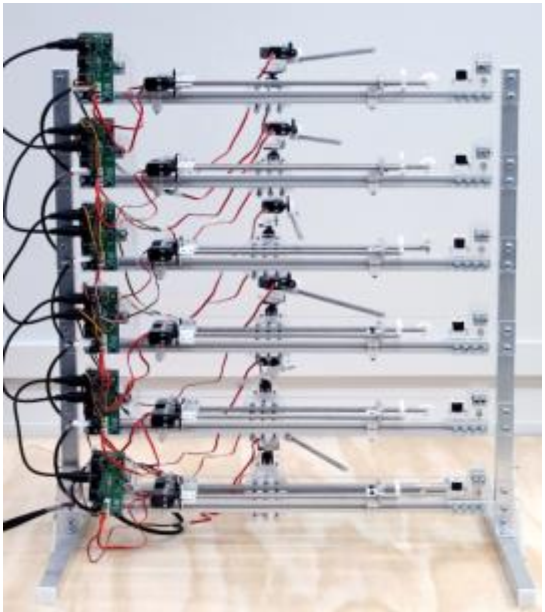

Figure 1. *Swivel 2*, a parametrically rich mechatronic chordophone.

There are three sections to this study. In the first section, the participants answer questions about their background in using new musical interfaces and MMI. In the second section, participants are asked to perform several musical tasks with the MMI using one of the musical interfaces presented to them in a random order to minimize the learning effect. There are three tasks in total: the first task requires the participants to "jam" with the presented interface to familiarize themselves and perform as if in a live performance scenario; the second task is to perform a musical phrase that contains a slide from one position to another, picking the string, and damping the string; the third task is to perform a specified musical phrase as shown in **Figure 2**. Thereafter, they are asked to provide short answers and rating (one to five, least to most) with regard to their experience with the musical interface used to complete the requested musical tasks. This section is repeated for the remaining two musical interfaces. In the final section of the study, participants are asked to compare and contrast their experience between the three musical interfaces presented and provide a ranking for each device in each criterion, along with explanations for their evaluation.

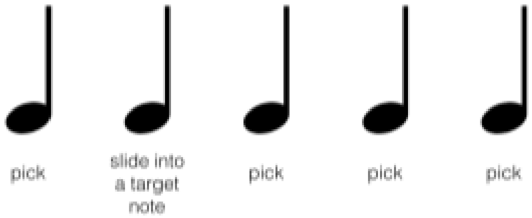

Figure 2. Task 3: Pick the string on the first pick, slide into the target note on the second beat (no pick), and pick on the following third, fourth and fifth beat.

3.4 Setup

This study was conducted in a studio at Victoria University of Wellington. A MacBook Pro laptop running Ableton Live 9 DAW and custom software was used to transmit MIDI data to *Swivel 2*. Table 1 shows the mapping scheme employed by each device in this user study. In Ableton Live 9 DAW, MIDI-clips in session view are used as the MIDI sequencer: study participants control Swivel 2's parameters using the envelope tracks (via mouse and keyboard) of a MIDI clip as shown in **Figure 3**.

Figure 3. Envelope tracks of a MIDI clip controlling *Swivel 2*'s picking. Study participants access a drop-down menu, highlighted in green, to select the envelope track corresponding to *Swivel 2*'s parameters.

Table 1: Mapping schemes of the three musical interfaces used in user study.

Input			Output
Keyboard	*g.qin*	Ableton	*Swivel 2*
Note on	Single-tap on trackpad	Envelope track of controller 7 (trigger when value $v_{t-1} \neq v_t$)	String picker
Assignable button #1	No assignment	Envelope track of controller 9 (127 = not damped, 0 = damped)	String damper
Note (discrete) + pitchbend (offset note, bipolar, continuous)	Yaw orientation of left hand	Envelope track of pitchbend	Fretting Position
Modulation Wheel	Hand posture (fist = fully clamped, open = not clamped)	Envelope track of controller 8	Fretting Strength

A ubiquitous keyboard (M-Audio Axiom 252) is connected to the laptop with a custom Max/MSP patch that maps the controls of the keyboard to the parameters of Swivel 2. *g.qin*, as illustrated in **Figure 4**, sends physical gesture data of the left hand wirelessly via Bluetooth. The data is mapped in another custom Max/MSP patch to control the actuators of *Swivel 2*. The range for each parameter was restricted such that the values resulted in musically sensible and mechanically safe output.

Figure 4. ***g.qin, a gestural controller that measures the metacarpophalangeal joint's range of motion (ROM) of all fingers (except the little finger) and the wrist, together with linear acceleration of the instrumentalist's left hand.***

4. USER STUDY FINDINGS

This section presents the findings gathered from users' feedback of the four criteria for each of the musical interfaces provided and concludes with the findings from the final section of the survey questionnaire that addresses participants' comparison of the three musical controllers as a dedicated controller for parametrically-rich mechatronic musical instruments.

4.1 MIDI Sequencer in Ableton Live 9

Figure 5 shows the dimension space representation of study participants' evaluation of MIDI sequencer in Ableton Live 9 DAW as a related-dedicated input controller for *Swivel 2*. The dimension space representation reveals that users find the device's ease of use, immediacy of control, and access to control multiplicity to be low and precision to be high. Findings on each criterion are described below.

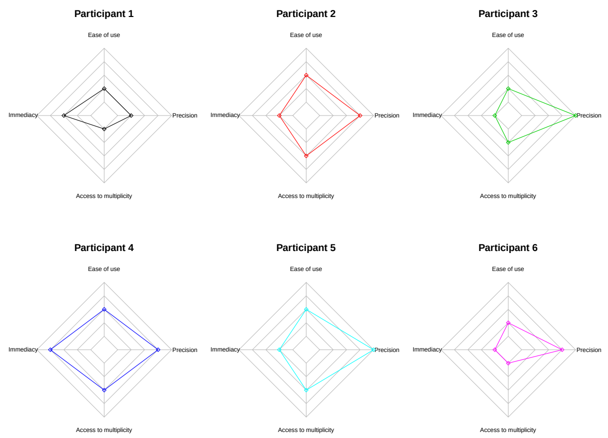

Figure 5. Dimension space representation of users' responses on the four criteria of MIDI sequencer in Ableton Live 9 dedicated input controller for *Swivel 2*.

With regards to ease of use, most users attribute the low ease of use to the cumbersomeness to perform a musical gesture. Three participants, #3, #5, and #6, share similar sentiments on the efficiency and effectiveness of completing musical tasks, commenting that "many parameters must be programmed to generate a simple musical phrase"; "having to control all parameters that lead to a single musical action separately is very difficult"; and "each parameter has to be controlled individually and you cannot view the other parameters...".

On the immediacy to translate intention to execution, study participants were asked: "...did this interface afford immediate control over *Swivel 2*, requiring relatively little translation of your intended action between your execution of the action and its output?"

While most participants (N = 5) gave a rating of ≤ 3 for the immediacy of control, participant #4 gave a rating response of 4. Upon examining participant #4's comments, it appears that participant #4 may have misunderstood what was being asked: "the programmed controls were executed in time". Most of the participants felt that a substantial amount of time was required to generate the desired output, commenting that "the control takes a lot of time to enact" and "it felt like it took a long time to get the (musical) gestures going...".

In terms of the accessibility to control multiple parameters simultaneously to modify the sonic output of the mechatronic instrument, all participants gave a rating of ≤ 3. Participant #2 (rating = 2) commented that "it did give me access to the parameter, but it would not work well for live performance without extensive pre-programming", and participant #4 (rating = 3) noted that the separation of controls made the interface non-intuitive.

All the users felt that the interface afforded precision (rating > 3). Notably, "very precise, and repeatable control over all parameters" and "...found it very precise for pitch control, but less for plucking and dampening" were some of the feedback received.

From the users' feedback, a potential role of the MIDI sequencer in the creative musical process of MMIs seems more likely to be suited for offline composition and controlling live performance on a meso musical timescale, rather than performing it live as one would with an acoustic instrument. Therefore, it is deemed unsuitable in the context of this study, which goal is to find effective live performance interface schemes.

4.2 Ubiquitous MIDI Keyboard

The dimension space representation of users' evaluation with regard to the ubiquitous MIDI keyboard as a dedicated input controller, as seen in **Figure 6**, reveals that most users (N = 5) find the keyboard effective and efficient in executing musical tasks, provides a direct translation of intention to execution, provides sufficient access to multiplicity of control, but does not perform well in precision. Further details of each criterion are described below.

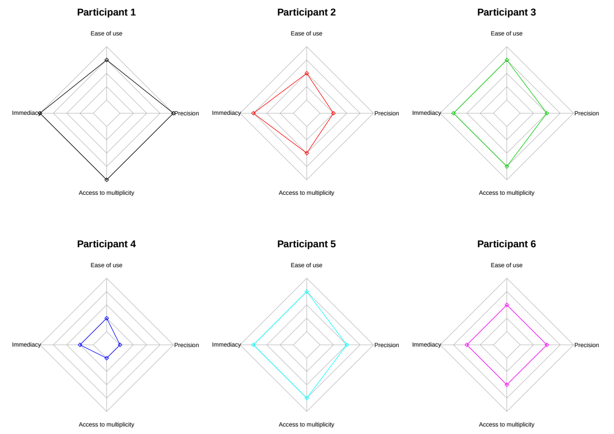

Figure 6. Dimension space representation of users' responses on the four criteria of ubiquitous MIDI keyboard controller as dedicated input controller for *Swivel 2*.

On using the MIDI keyboard controller, with the exception of participant #4, users generally find it efficient and effective to complete musical tasks. While participant #3 (rating = 3) found that even though the interaction afforded by having a physical controller was easy, the unrelated design of the keyboard to *Swivel 2* (a chordophone) affected the experience to be less straight-forward: participant #4 commented that "it is difficult to control the slide consistently". Difficult experiences from other users included "...parameters on the modulation wheel and pitch bend were difficult" and "damping and lifting the fretter take some thought".

With immediacy in translating intention to execution, as expected, most users (N = 5) gave a response rating of > 3, and provided similar explanations such as "musical phrases can be played easily" and "the translation is easy". Participant #6 (rating = 3) commented, "the translation is immediate but the nature of keyboard controllers dictates some mappings that are not very intuitive". Participant #4 found that the execution of the intention is more complex than the mechanical action being produced.

Most users agreed that the keyboard provided access (rating > 3, N = 5) to a range of output parameters for shaping the sonic outcome and allowed for fair precision (response rating > 3, N = 5) to repeat musical tasks within recognition threshold for *Swivel 2*. One user felt that the "small space of the pitch and mod wheels makes them less precise, thus repeatability would be an issue", while another user found the keyboard controller to provide "less accuracy for controlling bends, and lifting the fretter".

Although most users gave a generally favorable response about the device, participant #4 did not. The overall response of participant #4 suggests that participant #4 may not be keyboard-trained. From the participants' feedback, a potential role of the MIDI keyboard controller in the creative musical process of MMIs seems more likely to be suited for more conventional musical outcomes such as playing melodies that fit within Western musical scales and tunings. The favorable responses towards MIDI keyboard controller may be due to its ubiquity in the electronic music community, despite its differences in playing schema when compared with *Swivel 2*: MIDI keyboard's vertical movement for pitch bend controller to slide fretter's position, versus *Swivel 2*'s horizontal movement. Hence, due to its non-intuitiveness, unrelated design to *Swivel 2*, and fair precision, the MIDI keyboard controller may not be suitable in a live performance scenario.

4.3 Custom Gestural Controller — *g.qin*

As illustrated in **Figure 7**, all users felt that *g.qin* can be a related dedicated input controller for *Swivel 2*. Their feedback on how *g.qin* measures with the four criteria is discussed below.

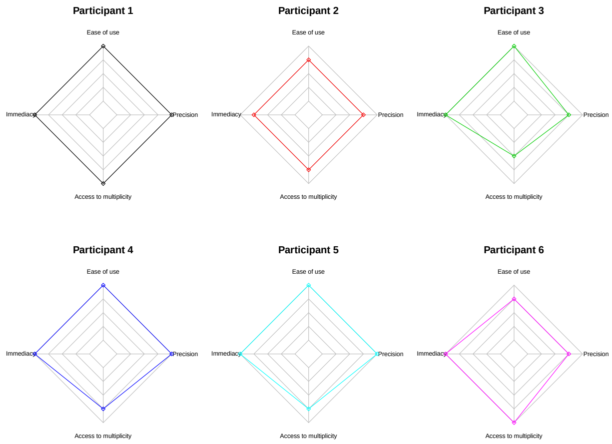

Figure 7. Dimension space representation of users' responses on the four criteria of the new physical gesture acquisition system, *g.qin*, as dedicated input controller for *Swivel 2*.

All study participants found *g.qin* to be efficient and effective in completing the three musical tasks (N = 5, response rating > 4), and that its embodied relation to the actuators of Swivel 2 affords immediate translation of intention to execution (N = 5, response rating > 4). Almost all users (N = 5) described this ease of use and immediacy as "intuitive" and attribute this experience to the "highly correlated" motions of *Swivel 2*'s actuators and their actions. One user mentioned that the "visual and intuitive connection between hand movements and fretter positioning is very helpful". Another user commented that the system consisting of *Swivel 2* and *g.qin* is "quick to learn".

In the domain of accessing multiple controls, it is reflected in the users' response ratings (N = 5, > 4) that the compromise to exclude damping was negligible and did not hinder their ability to produce their desired sonic outcomes with *Swivel 2*. One user commented that "the mapping area (physical space) translated well to the performance space", while another participant commented that *g.qin* provided "very good control over pitch slides and quick gestural behavior".

With regard to its precision in producing outcomes within just-noticeable-difference threshold, all users responded that the control of pitch sliding was "very precise", with one user mentioning that this was so even with the "the speed of transition and the curve of pitch slide", as well as the fretter's final position. On the other hand, two users shared the sentiment that finding exact pitch location was "a little harder". On this account, *g.qin* received an overall response rating of > 4 from all study participants.

Similar to the ubiquitous MIDI keyboard, the new physical gesture acquisition system measures very close to the four criteria of a related-dedicated input controller for new mechatronic musical instruments with a high number of output parameters. Preliminary speculation of this may be attributed towards the device's ability to transduce the performer-instrument relationship.

5. INTERDEVICE COMPARISON

The previous section presented the study participants' experience when utilizing the MIDI Sequencer in Ableton Live 9, a ubiquitous keyboard controller, and *g.qin* to control *Swivel 2*. In this section, a comparison of the different devices is presented based on the final section of the survey questionnaire that serves to gather users' feedback on how one device compares to the other, their preferred way of interfacing with *Swivel 2*, and general questions about customized controllers, which are presented below. A dimension space representation summary is shown in **Figure 8**.

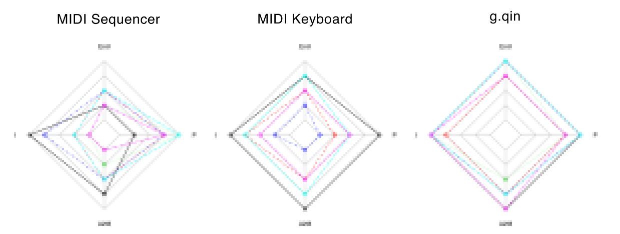

Figure 8. Dimension space representation of users' responses on the four criteria by input controllers. Clockwise: EoU represents ease of use, P represents precision, A2M represents access to multiplicity of control, and I represents immediacy.

All of the study participants concur that *g.qin* is their preferred way of interacting with *Swivel 2*, with many users attributing their choice mainly to the intuitive and embodied relation of input gestures and sonic outcome. One user mentioned that the interaction between the performer and *Swivel 2* "is visually interesting for an audience". The users' comments on their preference among the three devices presented support the intuition that the four criteria established are qualities of a related-dedicated input controller for parametrically-rich MMIs. These comments include: "... to create a more interactive performance and embodied performance..."; "access is not as important as ease of use and immediacy in live performance"; "the immediacy and precision of *g.qin* make it best suited for live performance"; and "I felt a strong connection between my gestures and the movements of *Swivel 2*. These were largely lost with both other interfaces.".

When asked "what would be a more intuitive musical interface for controlling *Swivel 2*", most participants suggested similar gestural interfaces that directly capture body movements or position in space such as Wii Remote[1] and the Laser Harp (described in [17]). Finally, users were asked if "a controller interface customized to be used with *Swivel 2* would be more intuitive than a general-purpose interface". All study participants agreed that it would, with one participant stating that "to explore the idiosyncrasies of *Swivel 2*, the controller needs to be well suited at controlling the movement of the fretting arm... this means that a grid based mapping of pitch is often not suited to controlling and exploring the musical capabilities of *Swivel 2*".

6. CONCLUSION

The findings of the user study presented in this paper further support the need for related-dedicated input devices and revealed that the common way of interacting with MMIs via MIDI keyboards and sequencer still has its place in the advent of parametrically rich MMIs. Particularly, users have indicated that the MIDI sequencer is likely suited for offline composition and controlling live performance on a meso musical timescale; the MIDI keyboard to be suited for more conventional musical outcomes such as playing melodies that fit within Western musical scales and tunings; and, the gestural controller to be suited for controlling *Swivel 2* more closely to the traditional performer-instrument relationship — affording the performance of the MMI like a musical instrument, and exploring beyond conventional musical outcomes.

The user study also indicates that potential related-dedicated input controllers have high level of ease of use, immediacy, access to multiplicity of control, and precision. In addition, the actions required of the user possess an embodied relation with the MMI, enabling intuitive interaction and quicker exploration of musical ideas. This can be explained by the similarity between this gestural input-MMI system and the performer's relationship to traditional musical instruments, as described by Pressing:

> *"Traditional instruments have a nearly one-to-one response between actions of the performer and the resulting sound, a stimulus-response model fits well. Interaction between the person and the instrument takes place through the aural [visual] feedback loop and the performer makes decisions on that basis in real-time."[13]*

While this user study is limited to a specific MMI of an instrument-family and only three input devices, the insights gained from this study with regards to the characteristics of a specialized controller for parametrically rich MMI should serve as a guide for researchers and developers interested in developing MMI-specific input devices. Developers of MMI-specified input controllers should also conduct user studies to evaluate these new MMI performance systems, just as one would with DMIs. Future studies will include more users, different parametrically rich MMIs, and different new musical gestural controllers.

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