# Do We Speak Sensor? Cultural Constraints of Embodied Interaction

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## ABSTRACT

This paper explores the role of materiality in Digital Musical Instruments and questions the influence of tacit understandings of sensor technology. Existing research investigates the use of gesture, physical interaction and subsequent parameter mapping. We suggest that a tacit knowledge of the 'sensor layer' brings with it definitions, understandings and expectations that forge and guide our approach to interaction. We argue that the influence of technology starts before a sound is made, and comes from not only intuition of material properties, but also received notions of what technology can and should do. On encountering an instrument with obvious sensors, a potential performer will attempt to predict what the sensors do and what the designer intends for them to do, becoming influenced by a machine centered understanding of interaction and not a solely material centred one. The paper presents an observational study of interaction using non-functional prototype instruments designed to explore fundamental ideas and understandings of instrumental interaction in the digital realm. We will show that this understanding influences both gestural language and ability to characterise an expected sonic/musical response.

## Author Keywords

tactile interaction, tacit understanding, musical gesture, digital musical instruments, NIME, sensor technology

## CCS Concepts

•**Applied computing** → **Sound and music computing;** •**Human-centered computing** → *Interaction design theory, concepts and paradigms;*

## 1. INTRODUCTION

Designers of digital musical instruments (DMIs) spend considerable effort identifying new sensor technologies and incorporating them into their instrument designs [14]. Sensors, together with mapping relationships, constitute some of the principal concerns of many NIME creators [22].

However, excessive focus on sensors and mappings carries risks for the designer, particularly falling into a viewpoint that considers the available affordances from a technology-centred viewpoint rather than a player-centred one [19]. Put another way, a technology-centred viewpoint might ask *what the instrument can do* rather than *what the performer can do with the instrument.*

That digital sensors can influence not only the designer but also the performer is well established. Magnusson [12] has observed that performers interacting with DMIs explore their constraints as much as they engage with their affordances. It has been shown that technological and material factors guide patterns of human interaction [4, 18], and that the limited richness of sensor inputs on a DMI can lead to a progressive reduction in the variety of performance gestures [9] as well as to appropriating behaviours [8, 23].

Although some aspects of performer adaptation to an instrument might be explained by their reaction to the instrument's responsive behaviour, we propose that material factors of the instrument can guide their expectations before the first sound is made. In particular, we hypothesise that the very existence of an exposed sensor, even in the absence of any functionality, biases performers toward a technology-centred way of thinking in which the sensing capabilities of the device, rather than the gesture language of the body, comes to the foreground.

To test this hypothesis, we conducted a study of three non-functional prototypes [17], investigating the performer's tacit understanding of interaction with each material and their expectation of the sonic response. The results are presented alongside a general discussion of the use of non-functional prototypes as a DMI research tool.

## 2. BACKGROUND

Many authors have discussed the danger of limited or unintuitive mappings [20, 12], going beyond the affordances of technology, to explore and expose their constraints. Jack et al. [9] highlight the reductive nature of the commonly found "input-output" model of DMIs, reducing the dimensionality of rich gestural interaction through limitations in the sensor layer. Magnusson [12] builds on Gibson [7], suggesting that playing an instrument is a form of exploring its constraints. Armitage [1] reviews numerous Digital Musical Instrument design frameworks and taxonomies, however very few discuss the subject of materiality. Magnusson [11] calls for DMI luthiers to "acknowledge the theoretical, cultural and social context in which all tools are designed - and this implies an awareness by designers of the responsibilities they have in terms of aesthetic and cultural influence".

### 2.1 Embodied Interaction

Magnusson [11] discusses the 'symbolic' relationship we have with digital music instruments through the very nature of their design, describing them as epistemic tools. The paper references Davis Beard [2], stating "the instrument becomes an expression in itself, an externalisation of knowledge in a form that is not symbolic but material".

Müller [16] also discusses the 'symbolic' nature of DMIs



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questioning the design stage, and highlighting phenomenological considerations of embodiment via 'skill acquisition' through experience with an instrument, linking perception and action "where action demands perception and perception effects and informs action".

Tuuri et al. [18] explores embodied control, questioning how "technologies actually control our moving bodies and transform our lived spaces". The author uses the term 'human-technology choreographies' to perform a theoretical analysis of the multidimensional aspects that reside within embodied interaction. The paper outlines three dimensions of embodied control. Two of their domains are particularly relevant to this research: (1) Instrumental Control - How designs harness body gestures and movements as instruments in control surfaces in HCI; (2) Experiential Control - How designs participate in constituting a feeling of being controlled and a feeling of being in control.

## 2.2 Enactivism and Enactive Design

Wessel [21] and Essl and O'Modhrain [5] propose an 'enactive' approach to the design of new tangible musical instruments, stating the design theory to "retain the familiar tactile aspect of the interaction so that the performer can take advantage of tacit knowledge gained through experience with such phenomena in the real world". Momeni [15] explores the themes of enactive approaches, control intimacy and tactile interaction. Bennett and O'Modhrain [3] investigate tangible enactive interfaces, seeking to compare and combine concepts found within enactive design and Tangible User Interfaces (TUIs). The authors use Fishkin's [6] taxonomy, which uses concepts of embodiment and metaphor [10] to classify TUIs. The idea of embodiment requires an actual output (which is beyond the scope of this study), however there is some fruit in his concept of metaphor, which "looks at how the use of the interface can relate through metaphor to a real-world concept". Bennet and O'Modhrain [3] state "Enactive interfaces are desirable because they allow the user to utilise their pre-conceived knowledge of interacting with the world when using the interface".

While Bennet and O'Modhrain highlight the power of this 'preconceived knowledge' as a point of leverage in enactive interfaces, we question if these same preconceptions of interaction when applied to the 'sensor layer' found within many DMIs, are what hold back the variety and creativity of interaction with sensor-based objects.

# 3. METHODOLOGY

To understand how the materiality of an unfamiliar instrument shapes engagement, we conducted a study involving three non-functional prototype instruments [17]. It was considered that functionality would guide participants into ways of interaction defined by epistemic considerations, beyond the materiality of the interface. This form of experimentation will highlight the tacit knowledge of participants, before any 'symbolic' language can be exchanged. Pierce and Paulos [17] discuss the use of non-functional prototypes. Their concept of "imagined firsthand use" enables a greater focus on the cultural constraints of embodied interaction prior to the influence of actual 'soundmaking'.

## 3.1 The Instruments

Three prototype instruments were built for the study (Fig 1). All three are the same size and shape, and styled in a similar way. #1 has a surface made from wood, #2 a surface made from malleable rubber and #3 has a large 2-axis capacitive touch sensor made from a printed circuit board derived from [13] embedded in it.

**Figure 1: Non-functional prototype instruments. Clockwise from right: #1 (wood), #2 (foam rubber), #3 (capacitive sensor)**

## 3.2 Experiment Design & Implementation

### 3.2.1 Participants

The instruments were tested by a group of twelve participants (nine male / three female). All participants were doctoral candidates or post doctoral researchers in the department of Electrical Engineering and Computer Science at Queen Mary University of London. Nine participants played a musical instrument, experience ranging from 1 to 27 years, all of whom were familiar with Digital Musical Instruments. The three non-musicians and had taken a module focusing on sound recording and production techniques.

### 3.2.2 Procedure

Participants were given 5 minutes to explore each instrument prototype, which were presented in a randomised order. Participants were told:

*"These are prototypes Digital Musical Instruments. Currently they are non-functioning and have no intended functionality or expected mode/s of operation. Spend 5 minutes interacting with each prototype, considering the two following questions: What gestures or techniques would you use to play these instruments? What subsequent sonic/musical response would you expect from each gesture?"*

### 3.2.3 Data collection and Interviews

Each session was audio and video recorded to facilitate thematic analysis. The session ended with a short focused interview (5 minutes) where the participants were asked to discuss their experience with each instrument.

Two key areas of interest were targeted. First, the type and number of unique gestures used. Second, the imagined sonic/musical response to each gesture.

# 4. RESULTS

## 4.1 Gestural Interaction

Table 1 presents a summary of unique gestures used with each instrument prototype, and the prevalence of their use within the participant group.

Gestures used with the wooden prototype were primarily percussive in nature, such as tapping/beating with fingers or sticks (used by 10 of the 12 participants). The tactility of the material elicited gestures such as scraping (using fingernails on the wooden surface), swiping (fast finger movements with minimal pressure), sliding (slower finger

| Gesture | Wooden | Rubber | Sensor |
|---|---|---|---|
| Tap/beat with Fingers | 10 | 4 | 1 |
| Scrape | 8 | - | - |
| Waving/Turning in air | 5 | 1 | 2 |
| Push/Press | 2 | 12 | 1 |
| Swipe | 2 | 1 | 12 |
| Beat with sticks | 1 | 2 | - |
| Touch (single location) | 1 | - | 10 |
| Rub | 1 | - | - |
| Slide | 1 | - | - |
| Drag | - | 2 | 9 |
| Stroke | - | 1 | - |
| Bow | - | - | 1 |
| Strum | - | - | 1 |
| Shake | - | - | 1 |
| Add Patch Pins | - | - | 1 |

**Table 1: Unique gestures used with each instrument prototype. Numbers indicate the number of participants who used each gesture**

movements with minimal pressure) and rubbing (continuous finger movements with minimal pressure). The majority of participants cited the wooden nature of the interface as the main rational for their interaction, commenting "wood is intended to be hit", "the grain of the wood implied an interaction strategy", and "I would like to use the natural properties of the wood".

Gestures used with the rubber prototype fostered a much more 'pressure' based approach to interaction, with a high prevalence of push and press gestures. There was some evidence of percussive gestures such as tapping and beating. 4 participants experimented with drag (slow finger movement with pressure), stoke (slow finger movements with no pressure) and swipe (fast finger movement with no pressure) gestures, however with much lower frequency. Participants commented that "the texture makes you want to enjoy the sensation", "the surface invites me to interact with it" and subsequently "the behaviour of the material lent to interaction". Others commented that "the tactility makes me want to push", and that "you look at that and know you can press it". The material fostered constraints: "I wouldn't want to scrape this one", "this absorbs vibration so I wouldn't have so much precision", and affordances: "I would imagine this to be velocity sensitive".

Gestures used with the sensor prototype were primarily pressure-less actions in two dimensional space. Swipe and touch gestures were much more prevalent with this instrument than with the wooden and rubber prototypes, and there was a reduction in the number of taping/beating gestures. A theme of fragility emerged, with participants reluctant to impart pressure or force on the surface of the instrument, commenting "I don't feel as comfortable to hit this one", "It looks like something electronic that can be broken easily", "It feels more delicate", "I wouldn't hit this as I don't want to break it". Many participants used terms such as 'mappings', 'XY location' and 'multi touch': "it looks like something that can track my fingers", "I feel like swiping or scrolling", "I would be inclined to use touch more than pressure", "I feel like defining precise points". These notions of interaction firmly defined both expectation of functionality and subsequent gestural interaction with participants stating that "It looks like a touch pad", and "it appears to me more as a controller". In general the interface was likened to a "smartphone screen" and referred to more as a controller than an instrument.

One participant predicted the presence of gyroscopic and acceleration based sensor technology in all three instruments, which led to some free movement in 3D space.

## 4.2 Imagined Sonic Response

Table 2 presents a summary of the imagined sonic/musical response elicited by each instrument.

| Sound | Wooden | Rubber | Sensor |
|---|---|---|---|
| Percussive Sounds | 11 | 7 | 1 |
| Piano/Keyboard | 1 | 1 | - |
| Synthetic Sounds | 2 | 3 | 3 |
| Organic/Natural | 3 | - | - |
| Any Sounds | 1 | 1 | 3 |
| Scratchy Noises | 1 | - | - |
| Timbral changes | 1 | 4 | 1 |
| Dynamic Changes | 1 | 5 | 1 |
| Filtering | 1 | 2 | 2 |
| Smooth Sounds | 1 | - | - |
| Amp/Freq.mod/Pitch bend | 1 | 1 | - |
| Pitch Changes | - | 3 | 2 |
| Pitched Sounds/Tones | 1 | 2 | 1 |
| Envelope (ADSR) | - | 2 | 2 |
| Wind Instruments | - | 1 | - |
| Samples/Loops | - | 2 | 7 |
| Guitar/Piano/Harp/String | - | 1 | 4 |
| Sequencer | - | - | 2 |
| Theremin | - | - | 2 |
| Bowed/Bent Sounds | - | - | 1 |
| Electronic Sounds | - | - | 1 |
| Pads/Continuous Sounds | 1 | - | 1 |
| Physical Model | - | - | 1 |
| Between Analogue/Digital | - | 1 | 1 |
| Gain/Pitch Slider | - | - | 2 |
| Effect Trigger | - | - | 1 |
| X/Y - Pitch/Dynamics | - | - | 2 |
| X/Y - Timbre/Amp | - | - | 1 |

**Table 2: Imagined sonic/musical response from each instrument prototype. Numbers indicate the number of participants referring to each category**

The wooden prototype elicited predominantly percussive expectations, with 11 participants suggesting it to be a percussive instrument. Overall, the expectation was of natural acoustic sounds, which were linked by most to the materiality of the surface. As the instruments were stated to be 'digital instrument', 6 participants highlighted synthesis based features such as filtering and frequency modulation, 4 of whom used these terms within the remit of percussion based interaction. Overall the materiality shone through with participants commenting: "I get an organic feeling", "being made of wood it should sound natural" and that "it should sound woody".

The rubber surfaced instrument featured a range of imagined responses, with percussive and sustained morphologies exemplified. The malleable nature of the surface featured heavily in the sonic expectations, with direct parallels made between tactile interaction and modulation of sonic parameters. An overall theme of 'shaping' sound through tactile interaction emerged from all participants. Expectation tended to reside within a more electronic paradigm, with less reference to 'natural' or 'acoustic' sounds.

The sensor prototype elicited much more 'controller' based responses, with 10 participants perceiving it as a control surface rather than an instrument. 7 participants imagined the instrument as a trigger for samples, commenting "the interface looks more electronic", "It looks like a digital instrument" or "this is more like a controller for digital stuff". Only 3 participants referenced an actual type or family of sound, commenting that it could sound like 'anything' or 'nothing specific'. 9 participants used synthesis type terminology (pitch, amplitude, envelope, timbre) in their description, however no direct 'sound' was imagined or described. Participants stated: "It's ambiguous", "Anything could happen with this one", "It doesn't inspire any specific sound", "I don't feel like this would have its own sound" and "I have a less clear idea of what it would sound like".

# 5. DISCUSSION

## 5.1 Materiality in DMI design

It is clear from the study that materiality plays a huge role in expectation of both gestural interaction and sonic response in DMIs. The wood and rubber prototypes evoked categorically different responses, with one seen as percussive and the other pressure based. This understanding influenced not only the choice of gesture used, but assumptions of what they would sound like. In many cases participants drew an explicit analogy between the natural sound of the material and the kind of sound the instrument should make. This conclusion was strengthened by the fact that the sensor prototype was seen not to have a natural sound at all. The difference in response between the wood, rubber and sensor based instruments show that our assessment of potential gesture is guided by the playing surface, and beyond this our expectation of what the instrument does and how it sounds is fundamentally linked to material considerations.

## 5.2 A machine-centered approach to DMIs

The outcome of the study highlights a limitation in relation to explicit sensor technology, which we attribute to a 'machine centered' approach to instrumental interaction. Participants exhibited a very different understanding of the sensor prototype, becoming preoccupied with the kind of spatial representation they assumed the digital sensor would produce. The prototype was seen as a controller and not an instrument, and promoted XY-based thinking adopted from smartphones rather than acoustic instruments. This understanding was also evident in the actions of a few participants who assumed the prototypes might contain accelerometers or gyroscopes, which subsequently influenced their gestures. Notions of fragility, lack of feedback, and a two dimensional pattern of interaction underpinned many responses. The instrumental gestures used with the wood and rubber prototypes gave way to notions of basic control, mappings and triggering; losing sight of control intimacy, gestural richness, and sonic nuance, as desired by many writers and researchers in the field.

## 5.3 Non-functional prototypes

The use of non-functional prototypes as an experimental methodology has proven to be fruitful. The ability to separate the expectations of a technology from the reality of using a technology has enabled an assessment of the tacit cultural elements that underpin our understandings and influence our subsequent actions. This paper shows the value of the approach in the context of DMI and NIME design. The use of a non-functional prototype design stage in NIME development could afford an indication of what kinds of performance techniques are likely to emerge, which could be reinforced of deliberately thwarted in the development of elements such as sensor choice, placement and mappings.

# 6. ACKNOWLEDGMENTS

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