Adding Z-Depth and Pressure Expressivity to Tangible Tabletop Surfaces

Jordan Hochenbaum[1]
New Zealand School of Music[1]
PO Box 2332
Wellington, New Zealand
hochenjord@myvuw.ac.nz

Ajay Kapur[1, 2]
California Institute of the Arts[2]
24700 McBean Parkway
Valencia, California, 91355
akapur@calarts.edu

ABSTRACT
This paper presents the SmartFiducial, a wireless tangible object that facilitates additional modes of expressivity for vision-based tabletop surfaces. Using infrared proximity sensing and resistive based force-sensors, the SmartFiducial affords users unique, and highly gestural inputs. Furthermore, the SmartFiducial incorporates additional customizable pushbutton switches. Using XBee radio frequency (RF) wireless transmission, the SmartFiducial establishes bipolar communication with a host computer. This paper describes the design and implementation of the SmartFiducial, as well as an exploratory use in a musical context.

Keywords
Fiducial, Tangible Interface, Multi-touch, Sensors, Gesture, Haptics, Bricktable, Proximity Sensing

1. INTRODUCTION
Musicians have long been intrigued by gestural interfaces since the invention of the Theremin in the early 20th century [2]. This has led to the exploration of pressure-based input sensing for expressive musical interaction. Realizing the potential expressivity of gestural interaction in musical contexts, researches have developed a number of hands-free and pressure based interfaces, exploring several sensing technologies. These include laser controllers such as Hasan, Yu, and Paradiso's work on the the Termenova [3], Wiley's Multi-Laser Gestural Interface [14], Murphy's force-sensing resistor based controller the Helio [10], and countless others.

Concurrently, the last few years has seen an explosion of interest in musical tangible interaction including the Reactable [7], the Bricktable [4, 5], Block Jam [11], and the Audiopad [13]. The Microsoft Secondlight project [6] is an interesting example of adding additional input freedom to tabletop surfaces by alternating projection quickly between two independent diffuse surfaces (the tabletop and ones above the tabletop). While Secondlight can track tangibles and gesture above the surface, it lacks distance tracking above the surface. Tangible surfaces can undoubtedly provide users with extremely dynamic interaction, however they lack the gestural qualities of non-contact and pressure based interfaces.

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The SmartFiducial is an attempt to provide the best of both worlds—offering and expanding upon the traditional *x,y*, and *rotational* modes of interaction afforded by tabletop surfaces, while providing the gestural expressivity and sensatory affordances experienced from hands free and pressure based interaction.

The remainder of this paper is organized as follows. The Implementation section is divided into two subsections; the first describes the physical design and technology embedded within the SmartFiducial, and the second describes the use of the SmartFiducial with an interactive musical application. The Discussion section details the various design considerations and affordances of the SmartFiducial.

2. IMPLEMENTATION
The SmartFiducial offers users multiple degrees of freedom and expressivity. In this section, we describe the hardware design of the SmartFiducial that enable these input freedoms, as well as our exploratory software implementation of using SmartFiducial's in a musical setting. Figure 1 below provides a general overview of the SmartFiducial tracking system, which is further expounded upon in the following section.

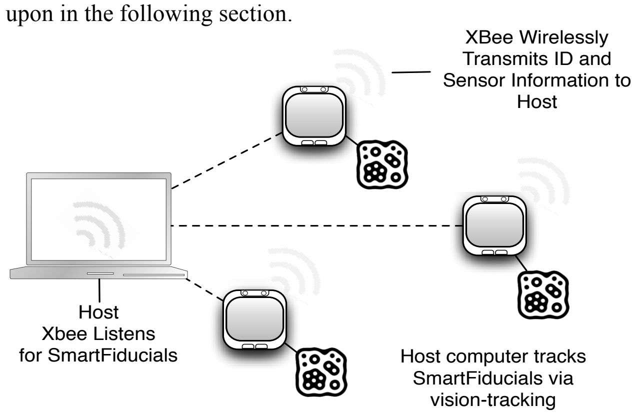

Figure 1 – SmartFiducial System Overview Diagram

2.1 Hardware

2.1.1 Vision Tracking
X, *Y* and *Rotation* tracking is achieved using a custom version of the open-source vision tracking software CCV (Community Core Vision). CCV implements the *libfidtrack* engine developed for the reacTIVision system [8]. More information on the vision tracking systems communication can be found in section 2.1.5.

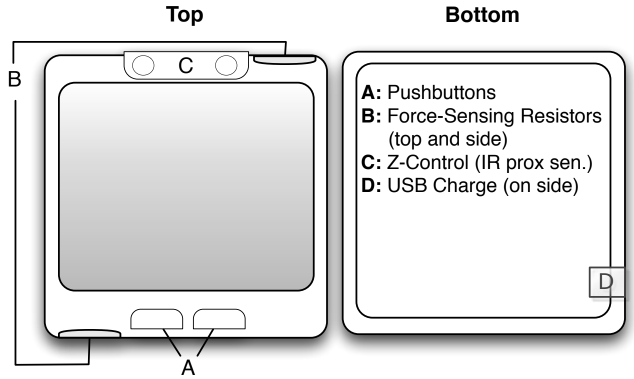

Figure 2: SmartFiducial Hardware Design Layout

2.1.2 Z-Depth

In addition to *x*, *y*, and *rotation* information captured by the vision tracking system, the SmartFiducial enhances the traditional 2D optical tracking system into a three-dimensional space. *Z-depth* input freedom is achieved by a short-range Sharp *GP2D120XJOOF* infrared (IR) proximity sensor embedded on the top face of the SmartFiducial (Figure 2, item C). The *GP2D120XJOOF* has an active sensing range of approximately 3cm – 40cm, providing users with a coverage area capable of highly expressive gesture sensing.

2.1.3 Pressure Sensitivity

The SmartFiducial also provides pressure-based gestural input via two Force-Sensing Resistors (FSR's), on the sides of the SmartFiducial, as pictured in Figure 2, item B.

2.1.4 Wireless Transmission

Embedded within the SmartFiducial is an Arduino Funnel IO[1] (Fio) equipped with an XBee wireless transmission module. XBee utilizes the ZigBee communication protocol, operates at 2.4GHz radio frequency, and exhibits extremely low power-consumption properties. This makes XBee an excellent candidate for wireless serial communication between the SmartFiducial and a host computer. Additionally, the XBee provides each SmartFiducial with a unique identifier, tied to its fiducial ID.

Data is received wirelessly via and XBee connected to the host machine, and is parsed by our custom version of CCV. CCV then sends out the ID and sensor data to other client applications using a custom implementation of the TUIO[2] protocol [9] that supports our additional data.

```
/tuio/smartFid set sId id x y z a X Y A m r f F b B
```

sId	Session ID	int32
id	Fiducial ID	int32
x, y, z	Position	float32
a	Angle	float32
X, Y	Velocity Vector (motion speed & direction)	float32
A	Rotation velocity vector (rotation speed & direction)	float32
m	Motion Acceleration	float32
r	Rotation Acceleration	float32
f, F	Pressure	float32
b, B	Button-state	int32

Figure 3: SmartFiducial TUIO Protocol Specification

[1] The Arduino Funnel IO is an Atmega based microprocessor designed by Shigeru Kobayash

[2] TUIO is a UDP based data-communication protocol, built around Open Sound Control (OSC) [15]

Additionally, we have implemented a basic algorithm in the SmartFiducial firmware to only broadcast new data when input is detected. This optimization helps to reduce the amount of data being transferred in larger system use-cases and scenarios, and can optionally be turned off in the firmware if constant streaming is preferred.

Once CCV receives new data bundles from the connected Xbee, it first checks to make sure that the SmartFiducials ID is present in the list of active fiducials being tracked by the vision system, before broadcasting a new TUIO message. This prevents the SmartFiducials sensor data from being transmitted when not active on the tabletop surface, however, this can optionally be turned off if off-surface interaction is desired. Although the SmartFiducial messages include all information present in standard TUIO fiducial ("/2Dobj") messages, CCV also broadcasts the SmartFiducial as part of its regular fiducial message broadcasting. Lastly, support for the SmartFiducial has been added into the standard C++ TUIO client implementation allowing easy integration into custom software applications. We are currently working to include support for the SmartFiducial in other TUIO client implementations (Java, Processing, openFrameworks, Max/MSP, Pure Data, etc) however, the SmartFiducial data can still be accessed cross-platform via any OSC receiver application or library.

2.1.5 Serial Protocol

Figure 4 below outlines the serial-protocol developed for SmartFiducial communication. All data is sent to the vision tracking software in 6-byte message bundles.

Fiducial ID has a resolution of 8-bits, yielding support for 255 unique fiducial IDs. All analog sensors (*Z-depth* and *Pressure Sensitivity*) retain full 10-bit resolution, while digital inputs (buttons) use 1-bit respectively. An additional 2-bits (bits 0 and 1 in byte5) are reserved for two additional digital sensors in the future. Lastly, the most significant bit (MSB) in each of the six-bytes is reserved as a special alignment bit, which is checked in CCV in order to ensure robustness and reliability of the wireless serial communication.

Byte	Bit 7	Bits 6–0
Byte0	1	FID
Byte1	0	FID, Z
Byte2	0	Z, FSR1
Byte3	0	FSR1
Byte4	0	FSR2
Byte5	0	FSR2, B1, B2, D1, D2

Figure 4: Overview of the SmartFiducial Serial Protocol

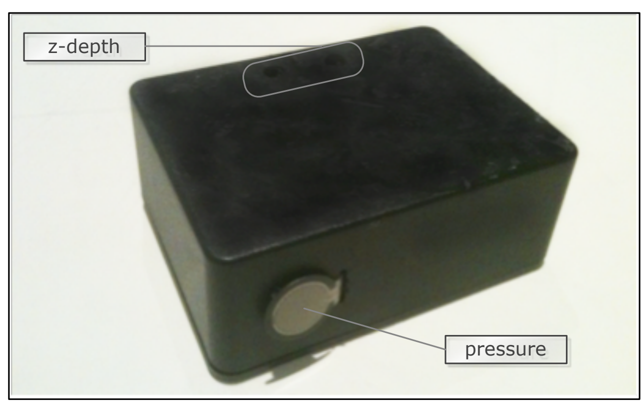

Figure 5: SmartFiducial Prototype (buttons 1 & 2 not pictured)

2.2 Software

In order to begin exploring the unique interactions afforded by the SmartFiducial, we have developed a basic wavetable synthesizer sequencer called *Turbine* (Figure 6). When a SmartFiducial is placed on the tabletop surface, sixteen "nodes" are created around the object. Each node represents a sixteenth note in a one-bar sequence, and dragging the node away from the SmartFiducial changes the pitch of the step. Using the z-depth sensing, the user is able to gesturally morph between the wavetables single-cycle waveforms, creating highly expressive, complex oscillations. Visual feedback is provided to the user via a soft Gaussian circle emitting from underneath the SmartFiducial. Currently the circle grows larger in size as the user nears the SmartFiducials proximity sensor, although the visual feedback may change as we continue to add more functionality to Turbine. In the future, we hope to expand Turbine's functionality, including the interaction between multiple SmartFiducials as well as regular fiducial objects acting as sound modifiers, effects, and other types of intermediaries.

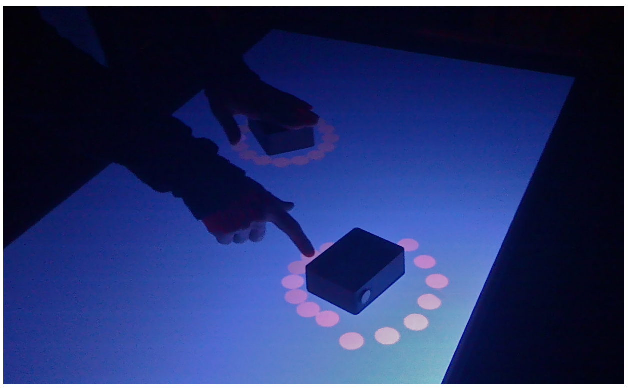

Figure 6: Two SmartFiducials being used with Turbine

3. DISCUSSION

3.1 Spatial Relationships and Tangible Interfaces

Because tangible surface interaction happens along the *xy plane*, input interaction is often a result of 2D spatial manipulation of the objects and the resulting relationships to both the tabletop surface and/or other objects. Once a tangible is placed within this location-dependent context however, e.g. when actions are tied to specific *xy* coordinates on the surface, the *x* and *y* input freedoms are no longer useable (without changing the set relationships). In this situation, the only user-interaction possible is by rotating the object, or interacting with a virtual parameter displayed on the surface itself (assuming the surface is also touch-enabled). Although manipulating on screen parameters can often be effective for input, it poses many user interface (UI) challenges (clogging the UI, dealing with movable UI elements tied to the fiducials….etc) and is often less than ideal. Additionally, proximity sensing and pressure based input offer a wide range of affordances not possible by other means, as further discussed in the following section. Thus, the addition of z-depth proximity sensing and pressure sensitivity on the SmartFiducial allows tangible interaction to be more expressive in this situation, and other scenarios in the following ways:

- Adding complementary modes of input that can be utilized independently or simultaneously with traditional *x,y*, and *rotational* tangible interaction
- Beginning to address the loss of input modes in situations where the object must be placed in specific locations or when *xy* spatial relationships and movement are primary means of surface interaction.

This greatly strengthens the ability of having dynamic relationships possible between tangible objects and the surface, and also between tangible objects and neighboring objects.

3.2 New Affordances for Tabletop Interaction

Affordance theory, originally proposed by perceptual psychology pioneer J.J. Gibson introduces the idea that the potential utility of an object is based on the perceived qualities of the object by the subject [1]. Whereas previous work in vision-based tangible tabletop surfaces has given users a set of interaction affordances defined by spatial relationships within a 2D environment, the SmartFiducial not only extends these affordances into the third dimension, but also offers additional affordances, governed by the unique cognitive notions of gesture based input. The following are a few of the interaction affordances that we have discovered through our initial experimentation with the SmartFiducial:

- Z-Depth proximity sensing may provide a more natural means of exploring 3D virtual environments on tabletop surfaces compared to traditional 2D interfaces.
- Both pressure sensitivity and proximity sensing offer the user new means of highly gestural continuous control. These are very different than common touch-based input gestures such as pinching, zooming…etc
- Pressure sensitivity is not only gestural but may afford the user more tactile interaction and control over traditional tangible interaction, especially when in combination with other interaction techniques (for example, utilizing the pressure sensors simultaneously with moving and/or rotating the objects on the surface).
- Proximity and pressure sensors lend themselves particular well to the application of a parameter modifier, non-dependent on the tabletop surfaces GUI

Additionally, the design of the SmartFiducial is influenced by Donald Normans application of Affordance Theory to the field of Design, and Human Computer Interaction (HCI) [12]. In accord with Normans idea that the design of an object can be such that it suggests potential usage, our qualitative use of SmartFiducials has matured in its design in ways we believe optimize the SmartFiducial to be naturally used, without previous experience. This includes the interaction design decision to place the IR proximity sensor on the top of the SmartFiducial, and the pressure sensors both on the sides of the SmartFiducial, typically where users tend to grip the object. While of course there will always be a familiarization stage between the user and the software running on the tabletop surface, our initial exploratory testing showed that when the users knew there was a distance sensor on the top and pressure sensors on the sides, they were able to very naturally exert a high-level of control and nuance in the use of the inputs.

4. CONCLUSION

Building upon previous vision-based tangible surface interaction techniques (offering *x,y* and *rotational* modes of input freedoms), the SmartFiducial is a novel tangible object which offers a new level of gesture and tactile affordances to tangible tabletop interaction. While we present an initial exploratory application of these new input freedoms in the creative music realm (Turbine), we believe the potentials afforded by the SmartFiducial can greatly enhance the user-experience when interacting with tangible tabletop surfaces across many disciplines and fields.

We are currently developing the Turbine synthesis engine to more thoroughly examine the affordances of the SmartFiducial in musical contexts. In the future we are particularly interested in conducting user-studies that explore our preliminary findings and experiences with the SmartFiducial (sections 3.1 and 3.2), and will also hopefully illuminate new use cases and affordances of the SmartFiducial.

Additionally, we are excited to finally release the SmartFiducial and our branch of CCV out into the community and see how others interpret and apply the new input freedoms.

5. ACKNOWLEDGMENTS

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