Alternate Fabrication Approaches for Tangible Knobs on Capacitive Commodity Devices

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ABSTRACT
After decades of research and practice, the tangible interface community still contemplates the question of what tangibles might look and act like as they grow common. This paper discusses some fabrication techniques and commercial examples of a class of tangibles embodied as cylinders, wheels, or knobs that can function with mass-market multi-touch devices. We consider laser cut knobs, 3D printed knobs, and support these with several simple applications, as well as trajectories toward more applied uses. We also discuss interoperability with Microsoft Surface Dials and consider future implications of our current work.

ACM Classification Keywords
H.5.m Information Interfaces and Presentation (e.g. HCI): Miscellaneous; H.6.2 User Interfaces: Input/Output Strategies

Author Keywords
Tangible user interfaces; capacitive touch screens; passive knobs; dials; 3D printing; laser cutting; pattern classification

INTRODUCTION
As the number of publications investigating tangible interfaces approaches 3000 (per the ACM and IEEE Digital Libraries), many researchers, practitioners, educators, commercial startups, students, and beyond are increasingly contemplating the question of what tangibles might look and act like as they grow common. Might they be general purpose, special purpose, or some combination of function? May they most often be built or bought? May they best be fabricated using laser cutter, 3D printer, by hand, or in some other fashion? We suspect a likely answer is "yes, and ..." As illustrated by the activities of TEI, DIY, Maker Spaces, Internet of Things, among others, momentum on all of these fronts and many more currently exists, and we imagine this is likely to continue.

Regarding specialized forms, perhaps a majority of publications to date explore distinctive physical forms. From a general tangibles perspective, cubes, cylinders/knobs/dials/wheels, marbles/spheres, and several other geometrical forms have recurred as common patterns not only in the tangibles literature, but also going back hundreds or thousands of years, from clay accounting tokens [16] to Froebel's gifts [5], and far beyond.

Commercial industry has, especially of late, introduced many mass-market variations upon dials: fixed, like SGI's Dial Boxes [22]; wired, like Griffin's PowerMate [21]; and wireless, like Microsoft Surface Dials [14], Dell Canvas totens [4], and many others. This makes the present seem an interesting moment to explore synergies between community and commercial forms.

Figure 1. Fabricated and commercially available tangibles. Laser cut knob (left); 3D printed knob (center), Surface Surface Dial (right).

While some might aspire for a single standard to emerge, seeking possibilities and interoperability between many different variants may be attractive. In resonance with several academic and commercial approaches, we illustrate some platforms that work on commodity multi-touch devices that inter operate with custom and commercially available knobs; and introduce variations on knobs fabricated by laser cutters, 3D printers, and variations upon commercial forms. Following the success of TUIO (`www.tuio.org`), we explore OSC [23] and TUIO variants as a low-level protocol, while hoping to join others in considering what higher level data descriptions and protocols might look like.

BACKGROUND AND RELATED WORK
Tangible interfaces represent a subfield of human-computer interaction (HCI) concerned with approaches for giving physical, interactively manipulable form to digital information. The topic is also referred to as tangible user interfaces (TUIs) [8], in the context of research investigating tangible interaction.

A number of tangible-enabled systems employ dial-like tangibles as representations and controls for cyberphysical associations. The use of knobs in computational systems has a long history. The electromechanical interfaces of the 1946 ENIAC computer incorporated hundreds of radial input dials [6]. The mid-1950s SAGE system [2], Sutherland's 1960s SketchPad system [17], and many other early graphical interfaces prominently incorporated interaction via mechanical dials. These early uses employed permanently mounted physical dials that were either statically mapped to specific digital functions, or reassigned by the GUIs to which they were coupled.

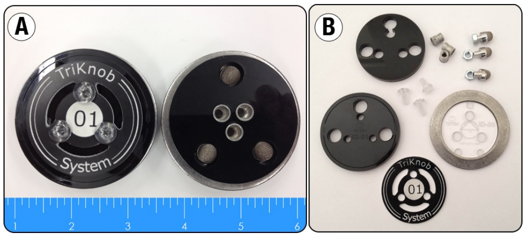


Figure 2. a) Detail of the top (left) and bottom (right) of a laser cut knob; and b) the parts that compose a knob.

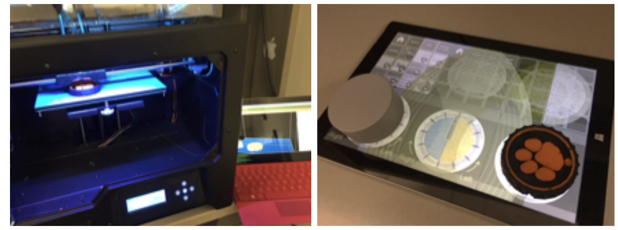


Figure 3. (left) 3D printer fabricating knob. (right) Microsoft Dial and 3D printed knob operating a control interface.

Among systems conceived as tangible interfaces, tagged handles offered interchangeable, tracked knob-like elements with haptic feedback, often used in audio contexts [10, 11, 15]. Where tagged handles were "labeled" with radial arrays of shapes and textures, the wheels of Strata/ICC [19] and tangible query interfaces [18] labeled tokens with static text and visuals, and applied these to parametric navigation of diverse datasets. Where [11, 19, 18] structured knobs interaction around fixed mechanical constraints, Sensetable and ReacTable allowed tangibles to be sensed and graphically mediated through continuous manipulation across interactive tabletops [10, 15]. More recently, research including SLAP widgets [20] and FacetStreams [9], have evolved the visual, domain application, and implementational strategies. In other variations, the smartwatch-based tokens of [1] employ new commodity platforms toward the realization of active knob-like tokens.

Among the most common applications, tangible interfaces have engaged elementary education [12], art and music [10], and DIY/Maker Movement [13]. Many tangible interfaces have also engaged scientific applications [1]. We aim to balance our sample applications among these contexts.

DESIGNING THE KNOBS

Our research group has a long history in developing tangible interfaces. Some of these have involved electro-mechanical systems. In recent years, we have also emphasized general-purpose, reproducible approaches allowing multiple knobs to be assembled faster and more uniformly than the manually fabricated ones.

Our present knobs are sensed by commodity, widespread hardware platforms that are capable of capacitive sensing, such as tablets, laptops, and smart-phones; eliminating the necessity of custom-built or special-purpose hardware. Our design incorporates constellations of three touch points, sometimes using stylus tips, sometimes flat conductive rubber; that may be rigid or pliable. The pattern defined by each knob allows them to be uniquely identified. Position and direction can also be sensed by the underlying software. More recently, we have started to explore and integrate commercial variations, such as the Microsoft Surface Dial.

Shape, Size, Materials and Context

Our knobs have been designed considering design criteria within [7]: shape, size, materials, and usage context.

In terms of shape, the use of cylindrical objects such as dials, knobs, and wheels in computational systems has a long history, including in the TUIs realm; This informed our design choice for round knobs with a flat top and bottom, indicating the affordance of rotation.

The knobs' size is comfortably held by most teenagers and adults, while also being suitable and safe for children, with the possible exception of the very young. Knobs are ~6 cm in diameter.

Capacitive sensing requires designing knobs in which some or all components are conductive. We use acrylic sheets, wood, and metal shims when fabricating with laser cutters and acrylonitrile butadiene styrene (ABS), or conductive polylactic acid (PLA) thermoplastic when 3D printing.

In the next sections, we present our laser cut and 3D printed knobs, together with associated TUI prototypes.

Design and engineering considerations

Fabricating passive knobs requires careful design and engineering decisions. To distinguish capacitive objects from finger-touches, spatial [3] or temporal [24] multiplexing is typically used. The more common of these, and the one we employ, is spatial multiplexing. Here, two or more conductive, capacitively coupled points are positioned in a distinct constellation relative to each other. Different systems employ different numbers of contact points. This number is associated with trade-offs including the physical size, distinguishable IDs, number of concurrent tokens, error-resilience, required physical pressure, materials and fabrication technologies employed, and mobile vs. fixtured use.

Two other broader technical constraints shape the functionality of capacitive tags. First, multi-touch capacitive screens typically incorporate a number of constraints relative to their anticipated use and function. For example, most capacitive tablets presently support a maximum of ~10 simultaneous sensed touches, and are presently tuned to sense contacts of sizes comparable to fingertips. Second, any system that relies upon electromechanical connections is influenced by a variety of properties that govern the quality of electrical contact. A phenomenon known as switch bounce occurs whenever mechanical jitter causes intermittent disconnection of the circuit [2]. This temporary loss of contact is known to cause glitches in systems that inadequately filter this form of noise. The mapping and filtering employed by capacitive multi-touch devices to transform analog field input into 2D events introduces analogous artifacts. This is compounded by several challenges. First, some present multi-touch capacitive surfaces are glass, which may be scratched by metal. Second, especially if more than three conductive tags are utilized, simple geometry and

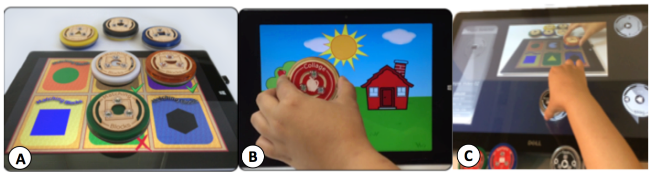


Figure 4. (a) Matching Blocks application. (b) Creating scene with the Collage software (c) Knob used with the VideoPlayer application.

mechanics suggests all points may not be in constant contact with the sensing surface.

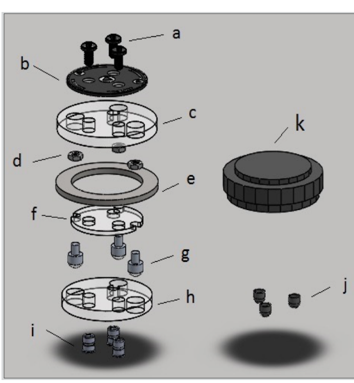
LASER CUT KNOBS

Fig 2 depicts a knob fabricated with a laser cutter. In our approach, we sandwich a central conductive ring, used to establish electrical contact with a user's hand, with non-conductive layers. These outer layers support human legibility (the upper visually-inscribed layer) and computational legibility (the lower layer). The lower layer structures a constellation of touch points, realized as threaded conductive mesh stylus tips. The pattern described by these tips is defined by an acrylic guide piece that is positioned within the internal circumference of the metallic ring. The non-conductive layers also serve as mechanical fixture plates for connecting the ensemble structure together. The pieces are held together by three pairs of rivets and screws.

The small size of the pieces employed suggests this design can be replicated with most laser cutters, as well as other fabrication tools (e.g., CNC mills and routers, water jets, etc.) from a variety of materials. Figure 5 lists the parts involved.

3D PRINTED KNOBS

While our first-generation approach seemed altogether effective, the fabrication and assembly of the multiple components could be laborious, our design was sometimes heavy, and not all groups have access to laser cutters. The rise of 3D printers interested us in their potential as an alternative approach. 3D printing, also known as *additive manufacturing*, offers a new platform for creating knobs and tangibles in general. The three-dimensional body of a knob is generated by "slicing" the virtual model into two-dimensional segments and then printing the actual object layer by layer.



	Name
a	*(3) Polycarbonate Screw*
b	Lasermax Acrylic
c	*Upper Acrylic*
d	(3) Steel Hex Nut
e	*Steel Shim*
f	Center Acrylic
g	*(3) Fiber Tips*
h	Lower Acrylic
i	*(3) Rivet Nut*
j	Rubber Tips
k	*Token Body*

Figure 5. Comparison between laser cut and 3D printed knobs. Laser cut knobs require nine distinct parts while 3D printed only two.

Fabrication of 3D printed knob requires no external tools, and can be printed on-site within an hour. The level of complexity of a 3D printed knob design is limited to that of one's 3D printer and CAD (Computer Aided Design) skills.

In terms of the number of components, our laser cut design requires the assembly of nine distinct components, while the 3D printed counterpart (in its simplest form) consists of only two distinct components and four parts in total. Figure 5 shows a comparison between the number of parts required by each design and fabrication technology.

Three different 3D printers were used in the fabrication of our knobs: The mono-extruder Lulzbot Taz, the dual-extruder Makerbot Replicator 2X, and a Voxel8 machine (`www.voxel8.com`). With the Lulzbot and Makerbot, we used conductive PLA for the body of knobs. With the Voxel8 knobs were fabricated with non-conductive ABS; 3D printed "wires" made of conductive silver ink coupled the touch of a user to the capacitive display. The silver ink also has the capacity of connecting embedded hardware. Figure 3 shows a knob being 3D printed. For customization, an acrylic ring and a faceplate were added to the 3D printed knobs.

SAMPLE APPLICATIONS

Several small applications have been developed to demonstrate the knobs. All three applications presented here have been tested on Microsoft Surface tablets, Lenovo laptops with capacitive touch screens, and Dell 27" multi-touch displays.

Matching Blocks, Collage, and VideoPlayer

The *Matching Blocks* application, depicted in Figure 4(a), was inspired by children's toys that require fitting objects, eg. blocks of wood into corresponding slots. The goal is to match the geometric figures of knobs with the figures on the GUI. Visual and auditory feedback is given in response to the actions of the user. Six distinct knobs are used by application. Faceplates made of balsa, a type of soft wood, were added for decoration. The knobs' body is made of acrylic of a variety of colors in an attempt to appeal to children's eyes.

The *Collage* application works as a set of stamps, as shown in figure 4(b). Each stamp is represented by a knob. Users can stamp the images anywhere on screen, any number of times. First users "stamp" a background then they add different elements to the scene such as a house, a dog, trees or apples. The wooden knobs used by *Collage* are slightly lighter than the acrylic ones, requiring users to apply pressure for detection. This turned out to be a feature for our application by emulating more realistically a real rubber stamp.

The *VideoPlayer*, shown in figure 4(c), is a TUI for video playback. Some knobs are containers of video files and others are playback controls. Besides detection and identification, the rotation of knobs controls discrete and continuous variables. We explore a combination of finger touches and knob actions. A video can be moved around by touch, but can only be controlled by using one of the physical knobs.

TUIO PROTOCOL

TUIO is an open framework that defines a common protocol and API for tangible multi-touch surfaces. We use a slightly modified version of the TUIO 2.0 protocol for 2D tokens. Our version better suits our needs without any additional parameters. A typical message is encoded as follows:

/tuios/tok s i x y a p

Here *'s'* is a knob id; *'i'* is the pattern id of the knob; *'x,y'* position of the knob on the screen; *'a'* current angle of a knob, and *'p'* a boolean indicating if a knob is placed on screen.

COMMERCIAL KNOBS

Recent mass-market commercial variations of knobs such as the Microsoft Surface Dials [14] and Dell Canvas' totens [4], with their native integration with the Windows 10 operating system, motivated us to seek interoperability between these devices and our platforms.

We are interested in integration achieved purely by software, or by performing small modifications. We have integrated *unmodified* Microsoft Dials to our applications running on Microsoft Surface Studio machines, and *slightly modified* Dials running on any Windows 10 machine. Our modification includes adding the pattern of touch points to the Dials. Figure 3 depicts a tablet using a Microsoft Dial as a control knob.

CONCLUSION AND FUTURE WORK

We have introduced our work on variations of knobs fabricated with laser cutters, 3D printers, and commercial forms. We showed prototypes that work on mass-market multi-touch systems, capable of interoperability with custom-made and commercial dial devices. We do not perceive any single technology as intrinsically better; instead, we see the future populated by combinations and hybrids of these and other variations. Currently, our work focuses on *passive* knobs but we hope to soon integrate *active* ones; either by fabricating custom active knobs, integrating and modifying commercial variations, or integrating knobs and higher level data description protocols already existing and under development in the tangibles research community.

We look forward not only to the opportunity of sharing our work but also to prospects for working with other research groups; giving, receiving feedback, forging partnerships and, in this manner, contribute to the lively tangibles community.

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