Mechamagnets: Tactile Mechanisms with Embedded Magnets

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Figure 1: Mechamagnet widgets.

Abstract
This paper presents Mechamagnets, a technique to rapidly prototype tactile mechanisms for tangible interfaces. We demonstrate how to embed different passive tactile mechanisms in physical systems through a combination of magnets and digitally fabricated parts. We also discuss how DIY materials and 3-axis magnetometers can instrument Mechamagnet interfaces into functional prototypes.

Author Keywords
Tactile; Magnets; Rapid Prototyping; Digital Fabrication; Tangible Interaction.

Introduction
Advances in digital fabrication have enabled designers to rapidly prototype physical parts for tangible interfaces—however, integrating mechanisms into these parts is still a complex process. This is compounded by the steep learning curve that many design novices face while learning computer-aided design (CAD) [7]. Mechanisms, however, are vital in making functional physical prototypes for tangible interfaces. In this investigation, we focus on passive mechanisms that also deliver tactile textures (tactile mechanisms). Tactile feedback is a ubiquitous part of our interactions with physical interfaces; the ‘click’ of flicking a light switch, or the resistance of turning a door knob, accompanies our use of these objects. They play an important role in informing and guiding our actions [6].
We hypothesize that as a material paired with digital fabrication, magnets are capable of affording a wide range of tactile mechanisms, along with simplifying the process of embedding such mechanisms in tangible interactive systems. In this paper, we describe *Mechamagnets*, a work-in-progress exploring the affordances of magnets in creating passive tactile mechanisms for tangible interfaces. We demonstrate how embedding different configurations of an identical magnetic unit can give 3D printed widgets different tactile mechanisms, as well as afford physical actuation. We also outline methods of instrumenting *Mechamagnet* interfaces into functional prototypes.

**Related Work**

*Mechamagnets* is informed and inspired by research on magnets for tangible interfaces, as well as research on prototyping functional physical interfaces. Magnets come in a variety of forms (sheets, discs, powder etc.), and they can be easily integrated with different partner materials (paper, plastic, liquids etc.). This diversity makes it an ideal material for physical prototyping. Magnets and magnetic forces have been used in various ways in the development of tangible interactive systems. Researchers have demonstrated how to create haptic textures and expressions through the use of magnets [12,13]. Combinations of static- and electro-magnets have also been used as visual and tactile cues to guide user actions [8,11]. Magnets have also been explored as a form of tangible input, in combination with hall effect sensors and 3-axes magnetometers [1,2,4,10,11]. This paper extends the body of work by demonstrating how similar magnetic units can be configured and embedded in 3D printed parts to create functional physical widgets with different tactile textures and mechanisms.

Embedding pre-manufactured mechanisms and electronic parts is a common way to prototype tangible interactive systems. This is a complicated process, as the designer has to build around off-the-shelf parts. *Makers’ Marks* [9] expedites this process for designers through a computer vision system which creates inserts and recesses for electronics in a physical form. Physical computing platforms such as the *Calder* toolkit [3] offer designers a range of sensors and actuators which can be easily programmed and attached onto physical models for functional testing. However, while these systems mitigate the integration of electronics, they restrict designers to the form, structure and tactile mechanisms offered by existing components.

**Mechamagnets: Design Exploration**

We started by exploring the design space of embedded magnets as tactile mechanisms in digitally fabricated assemblies. We used a specific static magnet in this investigation: 3mm by 3mm cylindrical neodymium magnets (Figure 2). Different mechanisms were created from varying the polarity and spatial arrangements of this same magnet unit. All other parts were fabricated by a desktop fused deposition modelling (FDM) 3D printer in polylactide (PLA) plastic (Figure 3). To embed the magnets, holes with a negative tolerance were modelled in the 3D printed parts. Magnets are pressed into these holes, resulting in a snug fit (Figure 4). We developed a variety of widgets from this exploration.
Tactile mechanisms for input

For this initial exploration, we focused on replicating the tactile textures and mechanisms found in common physical input interfaces.

1. **Toggle switch** (Figure 5A): The switch is constrained to rotate about a hinge, while a set of attracting magnets hold its state. When pressed with sufficient force, the switch flips into its new position, resulting in a satisfying snapping sound.

2. **Push button** (Figure 5B): Repelling magnets keep the button lifted off the floor. These magnets offer resistance when pushed, simulating the act of compressing a spring.

3. **Analog stick** (Figure 5C): A perimeter of repelling magnets pushes against the stick when it is off-center, while a pair of attracting magnets creates a center rest-point. The tactile texture generated resembles the stick controls found in Sony’s PlayStation® Portable or Nintendo’s 3DS.
4. **Stepped slider** (Figure 5D): An array of magnets is embedded along the track, corresponding to a pair placed in the slider. The slider ‘clicks’ as if there were detents when it is pushed along the track.

5. **2D slider** (Figure 5E): A variation of the stepped slider, the **2D slider** uses a two dimensional grid of regularly spaced magnets instead.

6. **Side toggle** (Figure 5F): A series of repelling magnets offer push back when the button is pushed along the shaft. This creates three rest positions for the button.

**Physical Actuation**

Our initial exploration on input widgets revealed that magnets can be easily configured in a physical part as a substitute for different physical mechanisms. This motivated our exploration for output widgets; and we focused on using magnets to translate simple physical movements into more complex actuation.

1. **Latch** (Figure 6A): This widget consists of two moving parts: a rotating arm, and an opposing pin constrained to move along its shaft. Depending on the polarity of the magnets arrayed around the arm, its rotation translates to linearly pushing or pulling the pin along its shaft.

2. **Multi-solenoid** (Figure 6B/C): A set of four pins is animated via a circular magnet array. Pins rise or fall depending on the polarity of the opposing magnet on the wheel as it rotates, and different animations can be created by rearranging the polarity of magnets around the wheel.

**Characterizing tactile mechanisms**

We observed that the tactile mechanisms of each widget can be characterized by two parameters: namely, the angle between its movement path and the orientation of its magnets (tangent or normal), as well as the polarity of opposing magnets (attraction or repulsion) (Figure 7).

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**Figure 6:** Output widgets— A) **Latch**, pushing or pulling a pin based on the opposing magnet’s polarity. B/C) **Multi-solenoid**, the animation of the four pins is determined by the different arrangements of the magnet polarities around the wheel.
Figure 7: Matrix of fundamental tactile mechanisms.

A combination of tangent alignment and attraction creates a “hard stop”. This tactile mechanism is expressed in the toggle switch widget, and feels similar to the click of a light switch. Combining tangent alignment with repulsion resembles a “spring”, as observed in the push button and analog stick widgets. A combination of normal alignment and attraction creates a “detent”. This tactile mechanism is demonstrated by the stepped slider and 2D slider widgets, and feels similar to dials that turn with discrete increments. Finally, combining normal alignment with repulsion creates a “soft barrier”. This is expressed by the side toggle widget; repelling magnets form a barrier which is overcome with enough force.

This initial classification is an attempt at characterizing the tactile mechanisms afforded by Mechamagnets. Thus far, we have focused our exploration on modeling tactile mechanisms found in existing interfaces. While these four categories may not comprehensively encompass all possibilities, we believe that it serves as a useful vocabulary to guide the development of new tactile mechanisms for tangible input.

Figure 8: Using copper tape to trace circuits directly on the widgets’ surface.

Instrumenting Mechamagnet Interfaces

Beside tactile mechanisms, we further investigated methods of creating functional Mechamagnet interfaces. We used the widgets developed from the design exploration as a platform to explore different instrumentation methods.

The “untoolkit” approach [5] to physical computing proposed by Mellis et al. was particular inspiring to us, and resonated with our material-centric perspective. They harnessed craft practices and materials to create functional tangible interfaces. In our exploration, we used copper tape to trace circuits directly on the widgets’ surface. We were able to create simple contact switches to sense binary input with this method; such as to detect the state of the toggle switch and the push button widgets (Figure 8).

Magnetometers have been used to detect the identity, location and states of tangible tokens and widgets [1,2,10]. Similarly, we explored using 3-axis magnetometers to estimate the position of magnets in a Mechamagnet widget, thus providing an operationalization for user interaction. A rig and visualization was developed to test each widget (Figure 9A). Compared to the former method of instrumenting the widgets with copper tape circuits, the magnetometer setup was able to detect not just binary state changes, but also analog variations between a widget’s states. For example, we were able to sense the depth of a push button (Figure 9B), as well as the position of an analog stick (Figure 9C).

Benefits & Limitations

Magnets provide many opportunities for the design of functional and expressive tangible user interfaces. Our
work extends this body of research by demonstrating a means to embed tactile mechanisms with magnets for tangible interfaces. At this stage, we believe that Mechamagnets benefits the design of tangible interfaces in the following ways:

1. **Mechamagnets offers a relatively efficient technique for prototyping tactile mechanisms.** As a comparative example, creating a conventional stepped slider requires the integration of springs, ball bearings and detents; while the Mechamagnet stepped slider (Figure 5D) employs an array of identical magnets. Furthermore, these magnets are embedded via a simple hole feature, thus providing designers with more flexibility when considering other aspects of a tangible interface.

2. **Mechamagnets is an economical technique.** All widgets demonstrated were fabricated with a low-end 3D printer, while magnets were inserted either manually or with regular hand tools. Identical magnets were also used in all widgets, simplifying the bill of materials.

3. **Mechamagnets addresses both instrumentation and tactile feedback in the design and fabrication of tangible interactive systems.** We build on the work of others (such as [2]) by demonstrating how embedded magnets afford digital sensing as well as tactile mechanisms.

There are certainly limitations to Mechamagnets; primarily due to the properties of magnets themselves. The widgets demonstrated in this paper were designed as tangible interfaces for hands and fingers, and the chosen magnetic unit was able to provide sufficient force to afford different tactile textures. For applications involving greater forces (such as foot or full body interfaces), other methods might be more effective (such as springs with a larger spring constant). Magnets are also affected by magnetic materials. While this is not a concern with the 3D printed plastic parts demonstrated, this property constrains the material space of Mechamagnet interfaces.

**Future Work**

We have explored replicating the tactility of common interfaces and proposed an initial vocabulary to describe the range of fundamental tactile mechanisms afforded by Mechamagnets. In addition, we explored embedded magnets for physical actuation.

Moving forward, we plan to engage with other tangible interaction designers to imagine new tactile textures and mechanisms with embedded magnets. We will also work on developing more robust characterizations of magnets to understand its affordance for the Mechamagnets technique. Ultimately, we aim to formalize a practical approach for supporting designers as they develop tactile textures and mechanisms for tangible user interfaces with embedded magnets.

Furthermore, 3D modeling—and 3D printing by extension—remains a challenge for design novices. While we envision Mechamagnets as a prototyping technique, we also see an opportunity for CAD tools to facilitate the design and fabrication of interfaces with embedded tactile mechanisms. This can increase the accessibility of Mechamagnets to a wider range of designers. In its simplest form, such a tool could offer parametric Mechamagnet primitives where designers can customize different parameters associated with the form, mechanism and tactile texture of the part.
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References


