Designing Tangible Magnetic Appcessories

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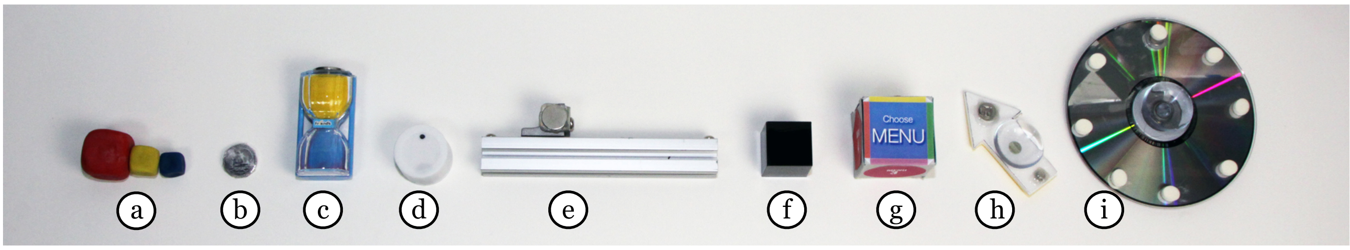

Figure 1: The *magnetic appcessories* supporting interactions of: (a) identification, (b, c) flipping/orientation, (d) continuous spinning, (e) linear movement, (f) position, (g) command selection, (h) discrete spinning, and (i) device orientation.

ABSTRACT
Tangible interaction allows the control of digital information through physical artifacts - virtual data is tied to real-world objects. Sensing and display technologies that enable this kind of functionality are typically complex. This represents a barrier to entry for researchers and also restricts where these interaction techniques can be deployed. Addressing these limitations, recent work has explored how the touch screens on mobile devices can be used as sensing and display platforms for tangible interfaces. This paper extends this work by exploring how magnets can be employed to achieve similar ends. To achieve this, it describes the design and construction of eight *magnetic appcessories*. These are cheap, robust physical interfaces that leverage magnets (and the magnetic sensing built into mobile devices) to support reliable and expressive tangible interactions with digital content.

Author Keywords
Tangible interaction; prototyping; magnetic field sensing.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces – input devices and strategies, prototyping.

General Terms
Design.

INTRODUCTION
Tangible interfaces connect bits with atoms and the resultant systems promise advantages such as physical affordance, natural support for collaboration and increased user engagement [7]. They have attracted much attention in the research community as an input mechanism for tabletop computers in domains as diverse as learning and education, problem solving and entertainment [7]. Most commonly, tabletops track manipulable tangible tokens placed on their horizontal display surface by means of visual markers sensed by a camera. Indeed, this design has proven a popular, generalizable and enduring platform for the development of tangible systems.

However, tabletop computers are a specialized technology with a high cost (or development overhead) and specific "computing by the yard" [11] use scenario. Consequently, authors have recently remarked on the need for techniques that lower barriers to entry, facilitate early stage prototyping [12] and enable tangible systems on alternative platforms and form factors. Addressing these issues, research has begun to explore how ubiquitous multi-touch capacitive sensing screens on tablets and smart-phones can be appropriated to create tangible interfaces [3, 12]. Rather than the optical tracking techniques used in tabletops, this work relies of designing tokens that can be tracked by the pattern of capacitive touches they register on touch screens. The simplest implementations rely on no more than conductive paint (or pencil marks) on physical blocks [12]. While promising, there are a number of limitations to this approach. Firstly, tokens need to occupy (often relatively large) portions of the screen. Moreover, the tokens cannot be passively sensed, requiring either human contact or active electrical components to simulate finger touch [10].

Motivated by these limitations, this paper seeks to explore an alternative sensing mechanism that can enable rapid prototyping of tangible objects on and around mobile devices. It achieves this by exploring how permanent magnets can be embedded in physical prototypes to create a range of interactive objects that can be sensed by the magnetometers built into many current mobile devices. Its focus is on exploring objects that can be meaningfully manipulated (e.g. moved, flipped, turned) and placed either on or alongside the mobile device screen. It terms these

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tangible objects *magnetic appcessories*. The ultimate goal of this work is to introduce a reliable, expressive sensing technique that will enable and inspire authors to rapidly and cheaply prototype mobile tangible applications. The remainder of this paper reviews the work related to this topic, briefly introduces magnetic sensing and describes and discusses the design and development of a range of eight magnetic appcessories (see Figure 1).

RELATED WORK

The combination of magnets and magnetic sensing represents a practically appealing input channel. This is for a number of reasons. Perhaps most significantly, magnets make ideal elements to embed in tangible tokens. They are cheap, robust, come in a wide range of form factors and are entirely passive – they require no power. They also do not degrade over time and their fields are relatively insensitive to interference from obstructions. Equally, due to their importance in navigation applications, cheap, high accuracy, low latency magnetometers are a current feature of modern mobile devices [4]. Finally, magnetic sensing itself fits into the emerging space of Around-Device Interaction (ADI) [2], where input in the area around a small computer is sensed to minimize occlusion of the screen. Taken together, these properties highlight the rich potential of magnetic sensing for interaction.

The research community has recognized these advantages and proposed a wide variety of magnetic interaction techniques in a range of application areas. For instance, Nenya [1] is a magnetic ring that can be rotated around the finger it is worn on to make uni-dimensional input on a wrist-mounted computer. Harrison and Hudson [4] describe the use of a magnet worn on the finger and moved in the space around a very small device to control cursor position. They suggest such a system could also be used to recognize gestures and indeed, other authors have explored this possibility. For instance, Ketabdar et al. [6] explore this input space to support the performance of musical gestures (such as strumming a guitar). Similarly, Shirazi et al. [9] investigate the viability and security of magnetically captured gestures for password entry.

Other authors have explored the use of magnetic sensing in more constrained ways, for instance by controlling more limited interaction spaces such as single variables or application modes. For instance, Mobile ActDresses [5] uses specific spatial arrangements of magnets in slip-on mobile device covers that customize the appearance of the device software and user interface; changing the cover changes the interface. Similarly, Paradiso [8] used orientation and proximity of magnetically-coupled tags for interacting with a musical controller. These examples highlight the potential of input via magnetic sensing. This paper seeks to build on this work and present a more systematic exploration of the potential of magnetic sensing to support tangible, physical interaction on mobile devices.

MAGNETIC SENSING

Magnetic fields have two properties: strength and direction. Strength is the intensity of a magnetic field and it varies from magnet to magnet and with distance. Direction

Table 1. The magnets used for the magnetic appcessories. *Strength measured using a gauss-meter in gap configuration

Size	Thickness	Diameter	Strength*
Small	2 mm	0.5 cm	400 Gauss
Medium	2 mm	1 cm	1000 Gauss
Large	2 mm	2 cm	1500 Gauss

Figure 2: Identification tokens. Set of three tokens integrating magnets of differing strength. Tokens in use (center and right).

reflects the fact that magnets have a north and south pole. Flipping a magnet inverts the poles, causing substantial changes to the magnetic field. Both strength and direction can be measured with a gauss-meter (see Table 1 for details of the magnets used in this work) or via magneto-meters and compass sensors. Modern magnetometers, such as those integrated into mobile devices, are highly accurate, capable of detecting the presence of a magnetic field at distances of 10 or more centimeters. Harrison and Hudson [4] present additional information on the practicalities and viability of magnetic sensing.

MAGNETIC APPCESSORIES

Eight interaction techniques were created based on inferring the size, orientation, position and movement of a magnet positioned on or around the screen from readings of the strength and direction of its magnetic field. These were: identification; flipping/orientation; position; discrete spinning; linear movement; continuous spinning; command selection and; device orientation.

Identification

Magnets of different intensities can be discriminated simply by measuring field strength. By embedding such magnets into physical tokens (like the cubes in Figure 2, left), objects placed on a mobile device can be identified by their magnetic properties. This technique can substitute for tagging systems such as RFID and a possible usage scenario consists of triggering a specific action (e.g., opening an email account) when a specific token is placed on or around a mobile device. A limitation of this approach is that only few tokens can be simultaneously discriminated, as magnetometers rely on a single cumulative value for magnetic strength. Moreover, as field strength decays with distance, tokens cannot be identified if positioned outside a predefined area. To solve this problem, the current prototype uses a simple GUI to indicate where to place the tokens (Figure 2, center and right).

Flipping/Orientation

The direction of a magnetic field can be used to detect object orientation. For instance, with a coin-shaped magnet it is trivial to identify heads or tails (Figure 3, center). This presents the possibility of assigning actions to the different sides of token. In one exploration of this concept, we

Figure 3: Flipping / orientation tokens. A coin and a hourglass afford detectable flipping actions (center and right).

mounted a hourglass with a magnet (Figure 3, right) and used it to track time for a cooking application. This served to augment the physical properties and affordance of the token with digital content. This flipping technique can be used in combination with the object identification method, as strength and direction are non-conflicting properties.

Position

Leveraging the fact that magnetic fields decay with distance, the position of a magnetic token can be reliably detected both on or around the screen surface. To illustrate this, we developed a prototype that senses four different positions of a cube token (Figure 4). The positions were highlighted on the screen, and placing the token over each resulted in different graphical feedback. To enable this functionality, each of the predefined locations corresponded to a stored set of triaxial magnetic field readings. When a token was on the screen, template matching was used to select the position that best fits the sensed data. While effective, limitations of this approach are that the tokens and locations need be predefined and that multiple tokens cannot be used simultaneously. However, this technique is compatible with both object flipping and identification.

Discrete Spinning

Magnets attached to a token that can be physically rotated can be used to determine its absolute orientation. This technique is robust and can be combined with position sensing to create a rich possible input space. To illustrate this effect, we created an arrow token with two differently sized magnets, one in its head and one in its tail. The magnets were flipped so they would have opposite polarities. This device was mounted on a suction cup that could be fixed to a mobile device screen (to stabilize position) and which allowed independent rotation of the arrow via a pivot (see Figure 5). An application was developed that used the template matching approach to discriminate between two different fixed locations (marked direction and time in the prototype) and the four cardinal directions from these points (e.g. north, south, east and west as well as 3, 6, 9 and 12 o'clock). As with prior techniques, only a single token can be used at any given time.

Linear movement and continuous spinning

Tri-axial variations in sensed magnetic field strength can also be used to dynamically track the relative motion and rotation of magnets. For example, embedding a magnet in a simple slider creates a linear one-dimensional control suitable for applications such as volume control (as in Figure 6), a fader or a scroll bar. Similarly, a pair of magnets embedded on opposite sides of a cylinder can be used to infer relative rotation (Figure 7), a technique suitable for continuous analogue input in a wide range of applications (e.g., controlling the size of a brush in a painting application). Once again, limitations of these two approaches are the need to position the tokens in a predefined location and that calibration before usage will be required. For instance, in Figures 6 and 7, the slider is positioned below the mobile device and a graphical icon marks the on-screen location where the dial must be placed.

Command selection

A six-item physical command menu can be constructed by placing a magnet inside a cube token. A combination of the strength and direction of the magnetic field can be used to accurately identify the upwards-facing surface (Figure 8). Consequently, each face of the cube can be associated with a different application behavior. With appropriate calibration procedures, this technique could also be combined with the position technique, so that different

Figure 4: Position token. Placing the token on differing zones of the screen results in different feedback (center and right).

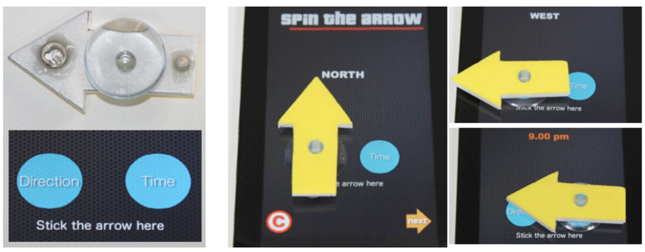

Figure 5: Discrete Spinning. Simultaneous detection of the location and orientation of a arrow token (center and right).

Figure 6: Linear movement. A magnet on a slider creates a linear one-dimensional volume control (center and right).

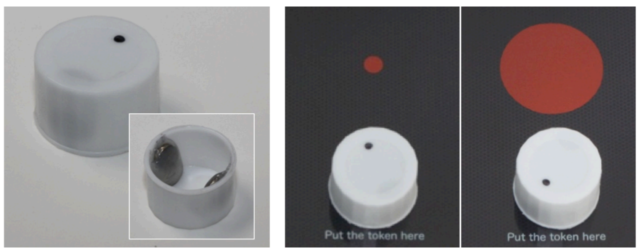

Figure 7: Continuous spinning. A pair of magnets in a cylinder allow continuous detecting of rotation.

Figure 8: Command selection. Changing the orientation of a cube containing a magnet can be used to issue commands.

Figure 9: Device orientation. A magnetic turntable (left) allows the detection of device orientation (center and right).

positions of the cube (highlighted via on-screen graphical feedback) could be associated with different command sets.

Device orientation

Rotations of the mobile device can also be sensed. This can be achieved by placing a magnet on a fixed structure with a pivot. By attaching the mobile device to the pivot, it can be freely spun and the variations this causes in the magnetic field easily detected. To demonstrate this functionality, we built a simple turn-table using a CD (Figure 9). This featured an off-center magnet and eight rubber cushion tips that anchored it firmly to a flat surface. A bearing was placed in the center of the CD to serve as a pivot and a suction cup mounted on this supported attachment to the mobile device. This setup enabled reliable detection of device orientation via sensing and classifying the data from the magnetometers (Figure 9, center and right). However, orientation sensing, typically derived from accelerometer input, is already a common feature of mobile devices that is used for automatic view adjustment. The appcessory approach realizes a number of novel features. Basically, it functions horizontally (or at any other device angle) and in relation to a portable, movable and directly observable physical object - the turn-table appcessory.

DISCUSSION AND CONCLUSIONS

This paper introduced a series of interaction techniques and tangible interfaces based on the magnetic sensing built into commonly available mobile devices. By exploring the design space of embedding magnets in tangible tokens, we demonstrate that this approach is expressive and capable of supporting a diverse range of user input.

However, there are several practical limitations. The first relates to calibration - the current system was implemented on a single mobile device model and differences in sensing hardware between devices (and in precise placement *within* devices) will likely impact performance. The second relates to the tolerance of the system to extraneous magnetic fields. Immediate future work will explore procedures for both automatic or manual calibration and mechanisms to limit or detect the influence of magnetic interference from the environment (e.g. via the use of shields or alerting users). Finally, as magnetometers read only cumulative magnetic field strength there are limitations to the number of magnetic appcessories that can be simultaneously deployed. We will explore solutions to this issue based on discriminating orthogonal properties of pairs of magnets (e.g. strength and/or direction) and via "snappable" tokens in which multiple magnets are combined to make new uniquely identifiable tokens with stronger fields.

Beyond these practical issues, future work will explore the potential of active magnetic tokens (e.g., electromagnets pulsing at different frequencies) to create larger token sets and combine magnetic sensing with capacitive sensing. These extensions promise to significantly increase the richness of the magnetic appcessory interaction space.

REFERENCES

1. Ashbrook, D., Baudisch, P., White, S., Nenya: subtle and eyes-free mobile input with a magnetically-tracked finger ring, in Proc of CHI '11.
2. Butler, A., Izadi, S., Hodges, S., SideSight: multi-"touch" interaction around small devices. In Proc of UIST '08, 201-204.
3. Chan, L., Müller, S., Roudaut, A., Baudisch, P., CapStones and ZebraWidgets. In CHI '12, 2189-2192.
4. Harrison, C., Hudson, S.E., Abracadabra: wireless, high-precision, and unpowered finger input for very small mobile devices. In Proc. of UIST'09, 121–124.
5. Jacobsson, M., Fernaeus, Y., Nylander, S., Mobile ActDresses: programming mobile devices by accessorizing. In CHI EA '12, 1071-1074.
6. Ketabdar, H., Jahanbekam, A., Yuksel, K.A., Hirsch, T., Abolhassani, A.H., MagiMusic. In Proc. of TEI '11,
7. Klemmer, S.R., Hartmann, B., Takayama. L., How bodies matter: five themes for interaction design. In Proc of DIS '06, 140-149.
8. Paradiso, J.A., Hsiao, K., Benbasat, A., Tangible music interfaces using passive magnetic tags. NIME 2001, 1-4.
9. Shirazi, A.S., Moghadam, P., Ketabdar, H., Schmidt, A., Assessing the vulnerability of magnetic gestural authentication to video-based shoulder surfing attacks. In Proc of the CHI '12, 2045-2048.
10. Yu, N., Chan, L., Lau, S.Y., Tsai, S., Hsiao, I., Tsai, D., Hsiao, F., Cheng, L., Chen, M., Huang, P., Hung, Y., TUIC: enabling tangible interaction on capacitive multi-touch displays. In Proc. of CHI '11, 2995-3004.
11. Weiser, M., The Computer for the 21st century. Scientific American 265(3):94–104, 1991.
12. Wiethoff, A., Schneider, H., Rohs, M., Butz, A., Greenberg, S., Sketch-a-TUI. In Proc of TEI '12.