MagPen: Magnetically Driven Pen Interaction On and Around Conventional Smartphones

Sungjae Hwang
Graduate School of Culture Technology
KAIST
best@kaist.ac.kr

Andrea Bianchi
College of Information and Communication Engineering
Sungkyunkwan University
abianchi@skku.edu

Myungwook Ahn
Graduate School of Culture Technology
KAIST
chapi@kaist.ac.kr

Kwang-yun Wohn
Graduate School of Culture Technology
KAIST
wohn@kaist.ac.kr

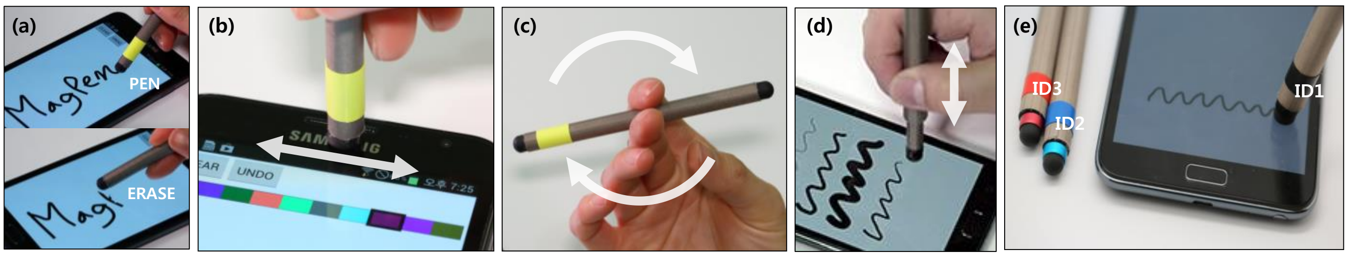

Figure 1: Five magnetically driven input techniques for pen interaction: a) detecting pen orientation, b) making a dragging motion along the device frame, c) determining pen-spinning gestures, d) estimating the pressure applied to the pen, and e) identifying

ABSTRACT
This paper introduces *MagPen*, a magnetically driven pen interface that works both on and around mobile devices. The proposed device is accompanied by a new vocabulary of gestures and techniques that increase the expressiveness of the standard capacitive stylus. These techniques are: 1) detecting the orientation that the stylus is pointing to, 2) selecting colors using locations beyond screen boundaries, 3) recognizing different spinning gestures associated with different actions, 4) inferring the pressure being applied to the pen, and 5) identifying various pens associated with different operational modes. These techniques are achieved using commonly available smartphones that sense and analyze the magnetic field produced by a permanent magnet embedded in a standard capacitive stylus. This paper explores how magnets can be used to expand the design space of current pen interaction, and proposes a new technology to achieve such results.

Author Keywords
Magnets; pen interaction; magnetometer; mobile device;

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interface, Input Device.

INTRODUCTION

Touch screens provide intuitive and effective input and commonly support interaction with both human fingers and capacitive pens [4]. Researchers have long attempted to increase this input space to complement the lack of expressiveness seen in plain, touch-based interaction. These methods include magnetically augmented tokens [2], pressure-sensitive inputs [4, 10], and gesture recognition systems [6, 7, 12]. In particular, magnetic-based interfaces [2, 5, 9] have proven to be very effective in expanding the expressiveness and scope of the input space. In fact, magnets are very cheap, small, and robust. They do not require power, and their positions and orientations can be easily detected wirelessly using magnetometers embedded in modern phones [2]. For these reasons, researchers have recently begun exploring how to include magnetic sensing capabilities in traditional interactive pens for mobile devices [e.g., 7, 9]. This paper builds on previous work and tries to extend the possible input interaction schemes of magnetically-based pen interfaces. We propose *MagPen* and suggest ways to use this device to augment the existing design space and enable user input with a richer set of actions and larger interaction area, ultimately increasing the input expressiveness.

RELATED WORK
The aim of our work is to expand the input vocabulary for pen interaction by merging the advantages of pen-input techniques with those of magnets. Here in the next two sections, we present previous work that has been done in each of these two related fields.

Pen Interaction
Pen-like interfaces provide users with higher precision and less occlusion, as well as tactile clues already familiar to

most users [3]. Because of these advantages, many researchers have explored a number of methods for enabling pen interaction. Liao et al. [8] introduced a pen interface that can be used to manipulate digital documents directly, using printouts as proxies. UnMousePad [10] is a multi-touch force-sensing input pad that can be used to track multiple fingertip touches and a pen. Similarly, N-Tring [3] is a transparent digitizer on an LCD that supports both multi-touch and pen interactions. Although these methods have successfully enriched users' experiences with tangible interfaces (styli), enabling pen interaction for these approaches requires either special sensory surfaces that come in contact with the pen (e. g., dot patterns [8], a force sensor grid [10], or an electrostatic grid [3]) or pen customization with mechanical parts such as an IR camera [8] or capacitive probes [3]. The design space of pen interaction can also be expanded by including features that transcend common usage (e.g., drawing or pointing). These techniques include operations such as rolling [1], tilting [11], gripping [4], and contacting various areas of the display [12]. Bi et al. [1] introduced a pen rolling technique to change operational modes. Similarly, Tilt Menu [11] is a technique that generates secondary inputs by having the user tilt the pen to select a menu. Song et al. [4] introduced a multi-touch pen called MTPen with a capacitive multi-touch sensor wrapped around an off-the-shelf stylus. They augmented their digital pen with grip and touch gestures. Finally, Vogel [12] introduced Conte, a cuboid stylus that switches interaction modes by changing the contact points on the display (e.g., corner, edge, end, or side). These approaches have successfully augmented the standard pen using supplementary interaction schemes. However, these approaches are somewhat limited, since they cannot easily be adapted to mobile environments. In fact, the need to introduce cumbersome or expensive new sensing hardware (e.g., Vicon markers and cameras [1], a tilt sensor [11], multi-touch sensors [4], or IR LEDs with a camera [12]) limits the practical value of these techniques and the scope of their usage.

Magnetic Input Techniques

A number of input techniques using magnetism have been introduced in various forms, in an attempt to augment interactive surfaces beyond the bounds of a small device. Previous studies include a magnetic input technique that allows accurate selections for small screens [5], a magnet-based hand writing system [7], and a magnetic interface for musical performance [6]. While magnets definitely improve usability by expanding interactivity beyond the device screen [2], the main limitation of these approaches is that the interaction happens without requiring contact between the magnetic token and the device [5], leaving users without tactile feedback (i.e., drawing in the "air" as opposed to drawing on a "surface"). To solve this problem, Liang et al. [8] introduced GaussSense, a system that enables inputs with stylus on an arbitrary surface. They used a 2 mm-thick board with 192 Hall-effect magnetic sensors that could be directly attached behind a device to enable stylus input. The authors successfully demonstrated that pen-augmented interaction (e.g., tilting, hovering, and varying pressures) worked on arbitrary materials (wood, aluminum, and plastics). However, the system does not properly work for ferromagnetic materials such as iron and it is very bulky because of the additional hardware (a magnetic sensor grid) and the need for a USB connection to the device. Our work builds on these ideas by presenting a more complete set of interaction techniques that can increase input expressiveness without requiring additional hardware beyond that already installed on current mobile devices.

MAGPEN PROTOTYPE

Hardware

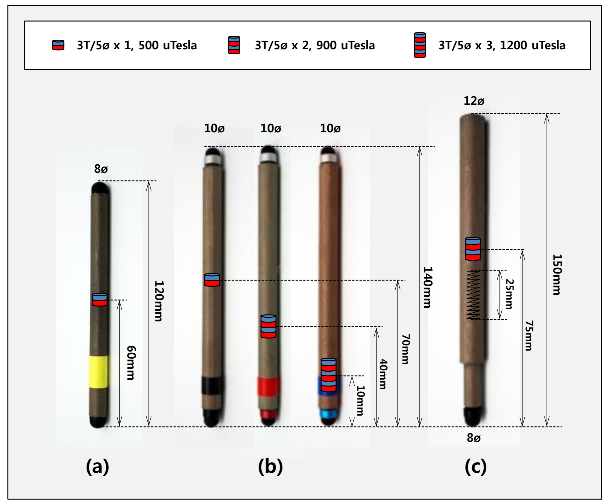

Figure 2. Three types of *MagPen* prototypes: (a) a simple pen, (b) three identifiable pens, and (c) a pressure-sensitive pen

MagPen is a capacitive pen augmented with a magnet that allows interaction on and around mobile devices (Figure 2). It is made from a plastic cylinder (8-12ø, 12-15cm) covered with conductive tape and physically connected to two conductive rubber tips (8 mm) at the pen's extremes. Using this setup we can easily determine whenever one of these tips is in contact with the capacitive screen, as the capacitance of the user's hand holding the pen is conducted to these tips. *MagPen* comes in three different forms: basic, identifiable, and pressure sensitive type. For the basic pen, a single coin-shaped permanent magnet (3T/5ø, about 500 uT) is embedded in the center of the pen, with the magnet facing parallel to the screen. With this setup, our system can easily determine which of the two tips is being used by looking at the sign of the magnetic field's intensity (which flips when the magnetic field's polarity is inverted), as shown in Figure 2a. For the identifiable pen, we attached magnets with different magnetic properties (intensity and position), as shown in Figure 2b. These two types have colored rubber bands next to one tip, so that users can recognize which pen they are selecting by color and tell which side of the pen they are using by the position of the

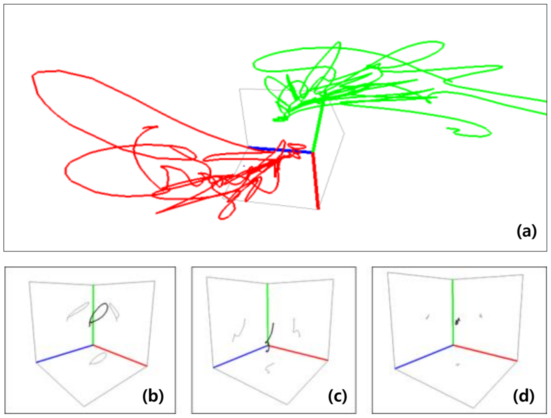

Figure 3. (a) Traces of the pen with different directions. Different pen-spinning gestures were sensed using a three-axis magnetometer: (b) Charge, (c) Twisted Sonic, (d) Zigzag.

bands. Finally, we designed the pressure-sensitive pen to adapt its length depending on the pressure being applied to the tip (Figure 2c). We modified the tip by inserting a second cylinder inside the pen and attached this cylinder to a spring. When pressure is applied to the tip, the inner spring is squeezed, reducing the pen's length and bringing the magnet inside the body of the pen and closer to the device (a change of about 250 mm).

Software

We developed a toolkit to allow Android 4.0.4. (SHV-E160S, Samsung Galaxy Note) to sense the magnetic field generated by the stylus and to recognize user actions. We also built a 3D visualizer using OpenGL to examine changes in the magnetic field (Figure 3). We then made a simple drawing application based on this toolkit. The inertial three-axis magnetometer sensed the magnetic field at a sampling frequency of 100 Hz. We used a buffer to reduce sampling noise; the movement vector from the last reading to its predecessor was computed and normalized. This final value reflected the magnetic field variations. By tracking these, we were able to determine the actions of the magnetically driven pen, as shown in Figure 1.

MAGPEN INTERACTION

In this section, we explore the design space of a magnetically augmented stylus for a drawing application. We briefly show five different techniques, how we achieved them, and their benefits. To verify some of these techniques, five participants (2 women) who had right-dominant hands and were aged between 28 and 34 (average 31.4, SD 2.4) were involved.

Determining Pen Orientation

It is possible to detect the direction of a pen through the bipolar property of magnets (Figure 3a). To verify this idea, the participants we recruited were asked to train our machine learning software by free drawing with both sides of the simple pen for 10 seconds. We then conducted a 10% cross validation, and the results show that our application correctly determined which of the two tips was being used with accuracy up to 99% (99.8%, K=0.99 using J48 Decision Tree). As an example, we built an option within the drawing application to either draw or erase depending on which tip of the pen was being used (Figure 1a).

Dragging Gesture on the Device Frame

It is possible to estimate the position of the pen outside of the screen frame using the magnetic data from a single magnetometer. The advantage of this technique is that it alleviates occlusion on the touchscreen, resulting in a larger interaction area. For example, we designed a drawing application (Figure 1b) that infers the position of the pen being dragged on the device frame in order to choose a color. This is achieved using a vector calculation that compares the incoming magnetic value to the values stored when calibrating.

Spin Gesture Recognition

Spinning the pen between the fingers is a common activity among many users who are concentrating. We tried to explore how this common activity could be encoded in a rich vocabulary of recognizable gestures (Figure 1c). We considered three fundamental pen-spinning gestures [13]: Charge, Twisted Sonic, and Zigzag. We assigned different software behavior for each gesture, such as choosing a pen type (Charge or Twisted Sonic) or undoing the most recent stroke (Zigzag). To avoid the influence of magnetic noise around the device, the system calculates the derivative signal over time by subtracting consecutive values and using a high-pass filter. The beginning and end of a spinning gesture were identified based on the magnitude of the signal and movement speed over the threshold. Three different spinning gestures were classified using a machine-learning approach (J48 decision tree) with a set of features that included the average movement speed, speed variance, size of the gesture, shape, and trajectory. To verify our prototype, we conducted a pilot study and sampled 10 trials for each gesture from among five participants (5 participants × 10 trials × 3 gestures). We then conducted a 10% cross-validation and found that the gestures were classified correctly with 99.3% accuracy (K= 0.99).

Identifying Different Pens

To identify pens with different magnetic properties (Figure 2b), we made an algorithm that used the magnetic intensity and the distance between the pen and the sensor. Figure 4a shows three average curves for three different pens. The magnetic intensities for the three pens, and the gaps among them, decrease as the distance increases. We used these curves as standards to identity each pen. For instance, a touch event at a distance of 70 mm with magnetic intensity of 250 uT is considered to indicate Pen 3. In this way, we can use the magnetic intensity as a proxy for a unique property (e.g., color or brush type). To demonstrate the feasibility of this technique, we conducted a pilot study as noted above, collecting data on 10 trial strokes for each pen

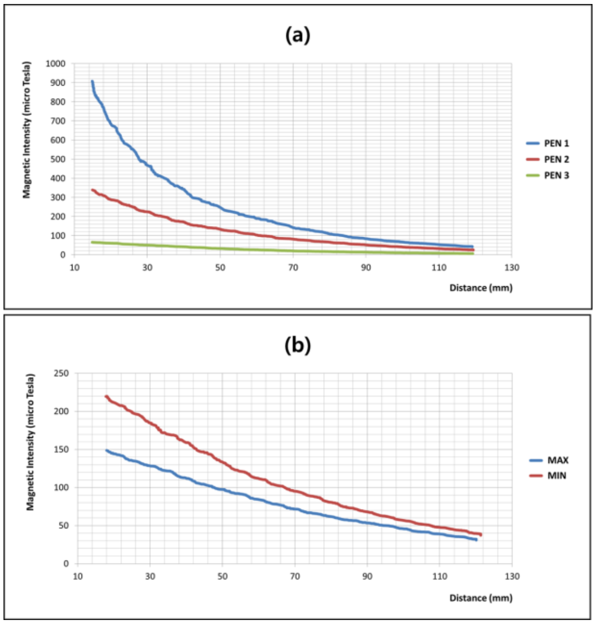

Figure 4. (a) Graph of magnetic intensities according to the distance for different pens. (b) Graph for two different pressures applied to the pen.

from all five participants (5 participants × 10 trials × 3 pens). To observe the distance effect, the participants were asked to make 10 horizontal strokes, starting from the top (closest to the sensor) and going to the bottom part of the touchscreen that was farthest from the sensor. Our results showed that the pens were classified correctly with 92.6% accuracy and that all errors occurred at distances of more than 83.5 mm. The average distance that led to pens being misclassified was 95.55 mm (SD 5.35).

Determining Applied Pressure

As explained in the hardware session, we built a pressure-sensitive pen (Figure 2c). To determine the pressure being applied to the pen, we revised the algorithm that we were using for identification. Figure 4b shows the average curves for two different pressures. As in the identification of pens, the gap between the maximum and minimum pressure decreases as distance increases. We used a relative position between the two curves as a coarse proxy of pressure (The farther the distance is, the denser the pressure levels). In this way, we were able to infer the pressure being applied to the pen regardless of the touch point. Finally, we implemented a drawer application that varies the size of a brush according to the pressure applied to the pen.

DISCUSSION AND CONCLUSION

We have presented *MagPen*, a magnetically driven pen prototype, and shown initial work on a rich set of interaction techniques based on recognizing different magnetic field properties. Through a discussion of the technical challenges in realizing our prototypes, we have shown how *MagPen* provides users with high input expressiveness, a wide input area, and rich tactile clues without requiring power or wireless connections. We believe that *MagPen* will open a large area for novel pen interaction designs. Future work will explore how to further extend the expressiveness of this interface (e.g., using multiple pens simultaneously) or additional degrees of freedom (e.g., pen hovering or tilting). We plan to run several user studies to gauge the feasibility of this interface and determine how it compares with previous, more complex hardware solutions.

REFERENCES

1. Bi, X., T. Moscovich, G. Ramos, R. Balakrishnan, K. Hinckley., An Exploration of Pen Rolling for Pen-based Interaction. *In Proc. of UIST*, (2008), 191-200.
2. Bianchi, A., Oakley, I., Designing Tangible Magnetic Appcessories. *In Proc. of TEI*, (2013), 255-258.
3. Engelhard, L., Native Dual Mode Digitizers: Supporting Pen, Touch and Multi-Touch Inputs in One Device on any LCD. *Society for Information Display*, (2008), 1306-1309.
4. H. Song, H. Benko, F. Guimbretiere, S. Izadi, X. Cao, K. Hinckley. Grips and gestures on a multi-touch pen. *In Proc. of CHI*, (2011), 1323-1332.
5. Harrison, C., Hudson, S. E., Abracadabra: wireless, high-precision, and unpowered finger input for very small mobile devices. *In Proc. of UIST*, (2009), 121-124.
6. Ketabdar, H., Haji-Abolhassani, A., Yüksel, K. A., Kehribar, I., Ercil, A., Digital Music Performance for Mobile Devices Based on Magnetic Interaction. *In IEEE Transactions on Instrumentation and Measurement*, (2011), vol.60, no.11, 3524-3533.
7. Ketabdar, H., Roshandel, M., and Yüksel, K.A., MagiWrite: towards touchless digit entry using 3D space around mobile devices. *In Proc. of MobileHCI*, (2010), 443-446.
8. Liao, C., Guimbretiere, F., Hinckley, K., Papiercraft: a command system for interactive paper. *In Proc. of UIST*, (2005), 241-244.
9. Liang, R.H., Cheng, K.Y., Su, C.H., Weng, C.T., Chen, B.Y., Yang, D.N., GaussSense: Attachable stylus sensing using magnetic sensor grid. In Proc. *In Proc. of UIST*, (2012), 319-326.
10. Rosenberg, I., Perlin, K., The UnMousePad: an interpolating multi-touch force-sensing input pad, *In ACM Trans. Graph*, (2009), 28, 3, Article 65.
11. Tian, F., L. Xu, H. Wang, X. Zhang, Y. Liu, V. Setlur, G. Dai. Tilt menu: Using the 3D Orientation Information of Pen Devices to Extend the Selection Capability of Pen-based User Interfaces. *In Proc. of CHI*, (2008), 1371-1380.
12. Vogel, D., Casiez, G. Conté: Multimodal Input Inspired by an Artist's Crayon. *In Proc. of UIST*, (2011), 357-366.
13. Website: http://en.wikipedia.org/wiki/Pen_spinning.