Augmenting the Input Space of Portable Displays Using Add-On Hall-Sensor Grid

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ABSTRACT
Since handheld and wearable displays are highly mobile, various applications are enabled to enrich our daily life. In addition to displaying high-fidelity information, these devices also support natural and effective user interactions by exploiting the capability of various embedded sensors. Nonetheless, the set of built-in sensors has limitations. Add-on sensor technologies, therefore, are needed. This work chooses to exploit magnetism as an additional channel of user input. The author first explains the reasons of developing the add-on magnetic field sensing technology based on neodymium magnets and the analog Hall-sensor grid. Then, the augmented input space is showcased through two instances. 1) For handheld displays, the sensor extends the object tracking capability to the near-surface 3D space by simply attaching it to the back of devices. 2) For wearable displays, the sensor enables private and rich-haptic 2D input by wearing it on user's fingernails. Limitations and possible research directions of this approach are highlighted in the end of paper.

Author Keywords
Add-On Sensing; Hall-Sensor Grid; Magnetism; Portable Displays; Tangible Interaction; Subtle Interaction

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

INTRODUCTION
Handheld and wearable displays enable various mobile applications, which are gradually changing our daily life. To allow users naturally and efficiently to interact with the high fidelity visual information, manufacturers embedded various sensors into the devices to provide multiple input modalities. For examples, capacitive multi-touch panel captures users' 2D gestures, motion sensors capture the embodied gestures that users performed on the device, cameras capture rich visual information, and microphones capture rich auditory information, etc. On the flip side, since each sensor has its limitations, there are still some cases that are unable to be resolved by the built-in sensor sets (e.g. 3D tangible interactions), even through combining several sensors together in use. For interaction designers who want to push the boundary of user interactions toward new dimensions on existed devices, add-on sensing technologies are required.

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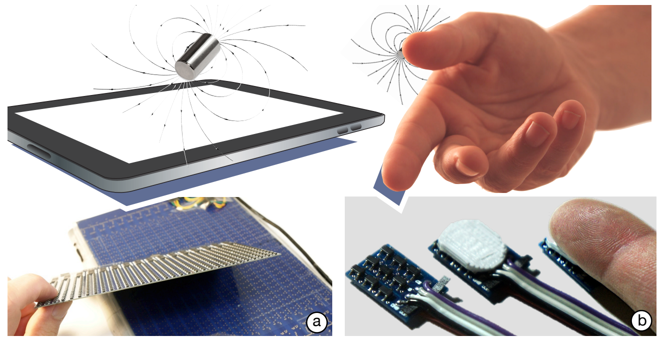

Figure 1. Two examples of using add-on Hall-sensor grid to augment the input space of portable displays: (a) Extending the object tracking capability of handheld displays by attaching the sensor grid to the back, or (b) enabling private and rich-haptic 2D inputs for wearable displays by wearing the sensor on users' fingernails.

Researchers have started to explore new input techniques by exploiting magnetism, especially those of the magnetostatic fields. Magnetostatic fields can be obtained by permanent magnets without additional power supplies. Moreover, they are 1) constant, uniform, and directional; 2) invisible and non-obtrusive; 3) remotely detectable and occlusion-free. These explicit features are able to compensate other input modalities. However, in the common set of sensors in portable displays, magnetic fields can only be detected by magnetometer (a.k.a. compass). Despite of its high accuracy [6], the limited detection capability (i.e., resolving the magnetic field intensities along three axes) leaves the input space rarely-exploited.

We, therefore, developed the new magnetic field sensor, GaussSense [10], which is a thin-form (2mm-thick in prototype) analog Hall-sensor grid for reconstructing the nearby magnetic fields as a bitmap image of magnetic field intensity. Since the magnetic field image can be utilized to resolve multiple magnetic objects' position and orientation simultaneously [9], it considerably expands the input space of the magnetism. This lightweight sensor can be attached to a portable display to extend its input space, or worn on user's body to enable the input capability on the corresponding skin portions [3], as shown in Figure 1.

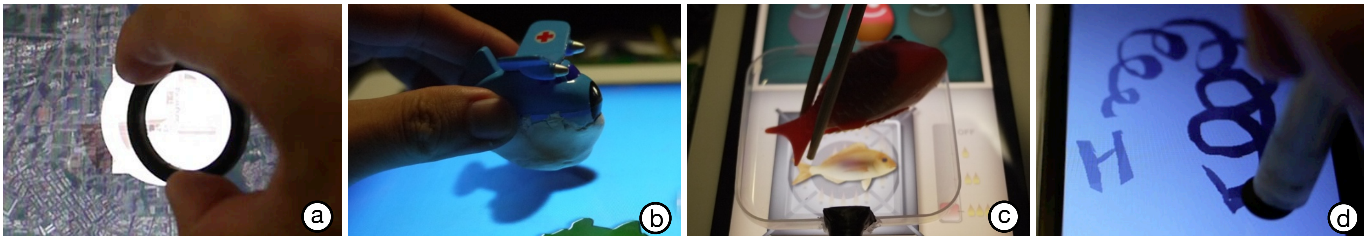

Figure 2. Examples of enhancing object tracking on handheld displays. (a) In tangible map navigation, a user navigates around the map by tilting the ring-shape magnetic tool glass. (b) In flying simulation, a user controls a well-shaped toy aircraft by pinching it above the display. The on-screen virtual shadow provides information on tracking. (c) In cooking simulation, a user flips the fish on the plastic pan using the wooden chopsticks. (d) In drawing application, a user draws a darker stroke by exerting harder pressure on the magnetic stylus' tip, which is made of soft conductive rubber.

The potential of magnetostatic fields and the GaussSense technology have not been explored yet. In this paper, the author explains the background of the technology first, then explores the design space by revisiting the prior work, and finally highlights what developers can do with this add-on sensing technology in the future.

BACKGROUND

Using Magnetostatic Field as Signal Source

Magnetostatic field can be obtained from the permanent magnets. Compare to alternative electromagnetic wave, the unpowered static field have consistent strength and better penetrability. Additionally, they cause no interferences on capacitive, visual, aural sensing, as well as wireless communications. Above all, it is suitable to be utilized as additional signal of sensing.

The author suggests to use neodymium magnet[1], the strongest type of commercially available permanent magnet, to provide magnetostatic field as signal source. Since neodymium magnet is well magnetized, the strong magnetic field provided can be easily discriminated from the earth's magnetic field within a range, and the uniform magnetic field are usable to extract additional information. Additionally, neodymium magnets are harder to be demagnetized than conventional ferromagnets because of the much higher coercivity. The features ensure the effectiveness and endurance of signal quality.

Tracking Magnetic Fields Using Analog Hall Sensor Grid

Among all types of magnetic field sensors [8], analog Hall sensor (a.k.a. Hall-effect sensor) is a type of miniature, low power-consuming magnetic field sensor which is suitable for portable use. The sensitivity and accuracy of the sensor are customizable. By deploying the analog Hall sensors as a 2D grid, it can serve as a camera to see the invisible magnetic fields nearby the sensor. The signals of the 2D sensor grid forms a bitmap of magnetic field intensities, which allows for extracting rich information of the magnetics through the simple image processing methods in real time.

In the following sections, the author showcases two examples to demonstrate how to apply the add-on Hall-sensor grid sensing on two major types of portable displays: handheld displays and wearable displays.

[1] http://www.ndfeb-info.com/

HANDHELD DISPLAYS: ENHANCE OBJECT TRACKING

Handheld displays such as smartphones or tablets have been tightly interwoven with our everyday life. In addition to the multitouch and embodied gestural interactions, developers have started to bring tangible interactions on the platform to leverage the user experiences for wider applications. Capacitive touchscreen are used to sense physical objects on the display surface based on the capacitance tag techniques [14]. However, the interactions are confined to the 2D space because of the technology limitations [4, 22]. Although using external cameras [2, 7] can extend the object tracking to 3D space, they are sensitive to hand occlusions, which limit the possible physical expressions of the tangible design and degrade the user experiences.

The goal is to enrich the tangible interaction design on and above the handheld displays by using the highly compatible extension. With our add-on Hall-sensor grid, developers can easily enable an extra channel of magnetic sensing by simply attaching it to the back of the display as shown in Figure 1(a). No modification on the display hardware is required. This method enhances the object tracking capability of handheld displays in several ways, which are explained as following.

Near-Surface Interactions

Magnetic fields distribute surround a well-magnetized magnets uniformly. Hence, they are suitably used for sensing the magnets remotely. An axial-magnetized cylindrical magnet is used as example herein. The 3D position of the magnet can be obtained by the shape and intensity of its magnetic field [9], even when hovering above the display. If the magnet's direction of magnetization is perpendicular to the sensor plate, the tilt information, such as angle or direction, can be observed by the gradient of magnetic field. If the direction of magnetization is parallel to the sensor plate, the roll information can be represented by the bi-polar magnetic fields. The flip operations can be detected if the magnetic unit consists of unequal parts of bi-polar magnetic fields. The hover, tilt, roll, and flip operations extend the input space of tangible interaction on portable display from 2D to the near-surface 3D space, as the map navigation example shown in Figure 2(a).

Occlusion-Free Interactions

Magnetic fields penetrate through non-ferrous materials, such as the users' hand. Therefore, the magnetic unit can be stuffed into an appropriately shaped non-ferrous object, without leaving the feature of detection outside. Users can freely grasp the magnetic objects in hands without affecting the detection. Interaction designers can freely design the objects in meaningful expressions and to help users better perceive the available set of operations [5], as the flight simulation example shown in Figure 2(b). Moreover, designers can provide some non-ferrous tools for users to simulate tasks in more realistic and intuitive ways, as the cooking example shown in Figure 2(c). The occlusion-free detection method unlocks the expressiveness of tangible interaction design, which is essential for enabling metaphor-free natural user interactions [11] on and above the handheld displays.

Incorporating with Capacitive Sensing

Magnetic fields do not affect capacitive sensing. Therefore, designers can leverage the capacitive sensing using the magnetic field tracking methods by either makes the magnetic objects conductive or non-conductive.

Coating the magnetic unit using non-conductive materials allow the magnetics to be sensed only by the Hall-sensor grid. Therefore, object events are easily discriminable from the finger touch events. Therefore, designers can freely add tangible+touch interactions [20] into the applications.

On another hand, coating the magnetic tangible with non-ferrous conductive materials and deploying conductive contacting points on its bottom can connect user's hand to the touchscreen. Therefore, user's touch on the tangible can be detected. If the contacting points are made of soft conductive materials, such as conductive rubber, the pressure that users hand exerted on the object can be resolved [10], as the drawing application shown in Figure 2(d). Deploying more complex contacting point patterns at the bottom of the magnetic objects can extend either the ID space or the interactivity of magnetic tangibles [9].

WEARABLE DISPLAYS: ENABLING RICH, SUBTLE INPUT

Wearable visual displays provide rich and private visual outputs to enable various applications without needs of hands holding the device (e.g. Google Glass[2]). However, their input methods may not offer the same privacy. For examples, voice input raises privacy issues with its use in public spaces [16], and gesture input suffers from similar privacy concerns because input actions are easily observable. To permit private input, recent research considered subtle input methods such as unobservable muscle movements [15], foot gestures [17], and subtle gestures on the ring [1, 13]. These input methods are implicit, instantly available and socially acceptable [21], but their input space are generally limited.

The goal, therefore, is to provide rich input methods for users easier to interact with the wearable display without conflicting privacy concerns. Owing to the dexterity and stability of the hands, we considered fingertips, the historical unused space for user input. A tiny, thin 3x3 analog Hall-sensor grid is mounted on the index fingernail, and a plate holding a small magnet and fixes its orientation on the thumb fingernail, as shown in Figure 1(b). Based on the magnetic field bitmap captured by the Hall-sensor grid, the device transforms the approximated magnet position into the calibrated coordinates, then sends these coordinates to the applications Figure 3. To detect when user's thumb landing on the fingertip, as well as the finger flick-up committing, an accelerometer is added to the sensor plate to detect the impact of the finger contacts.

[2]http://www.google.com/glass

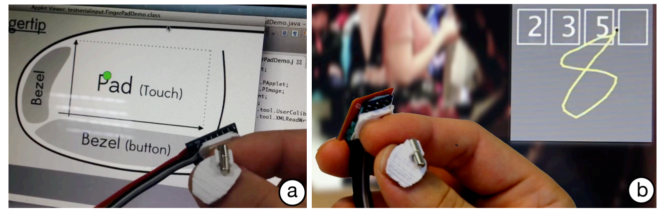

Figure 3. (a) Wearing the 3x3 Hall-sensor grid and the magnet on the fingernails allows for 2D input. (b) With a wearable display such as glass displays, the user can draw numbers using the thumb tip on the index fingertip to enter passwords.

Since this device is functionally equivalent to a touchpad, we call it FingerPad [3]. FingerPad allows for 2D inputs, as well as basic circling, swiping, and clicking gestures. The highly mobile sensing mechanism works even in the walking condition. Additionally, since FingerPad is attached on the fingernails, the natural haptic feedbacks are preserved. Therefore, it allows for eyes-free use, and does not affect the native functions of the fingertips. Compare to other finger-worn control devices such as a fingerstall-like touchpad, or a ring device [12] with a tiny optical mouse, FingerPad places no constraints on the fingertip, finger, and hand, and more suitably deployable in daily life.

DISCUSSION

Summarization of the enabled features

In the two examples, exploiting magnetism for input enables several features. The remotely detectable magnetic fields, which are usually in the similar shape with magnet, allow for the 3D position (x,y,z) and part of the 3D orientation (pitch, yaw, roll) of magnet to be resolved. Magnetic fields penetrate through non-ferrous materials, allows for the magnetics to be designed in richer physical expressions, and permits the tracking mechanism to be attached to the back of surface. This preserves both surface texture information, such as tactile feedback, and the privacy of input. Finally, since there are no interferences between magnetic fields and other signal sources, the Hall-sensor grid sensing can incorporate with other sensors for advance sensing.

Limitations

The magnetic-field tracking method has some known limitations. On the dimensions of tracking, the sensing distance is limited to the near-surface 3D space, because the magnetic strength rapidly attenuates with the sensing distance. Although using stronger magnets or more sensitive sensors can be slightly increased by the sensing distance, the sensing still cannot be extended to full 3D sensing effectively. On tangible design, the magnetic objects cannot effectively support full 6-DOF control. On the detection of multiple magnetics, the interferences of magnetic fields and magnetic forces should be carefully deal with, as discussed in [9].

If designers want to apply external magnetic fields to temporally change the neodymium magnets' magnetic strength, such as using solenoids, the working temperature should be carefully controlled. When the neodymium magnet is heated over 80°C, some percentage of the magnetization would be irreversibly lost. However, in the room temperature or even in the extremely low temperature condition (∼-100°C), the magnetic field strength of is almost consistent.

Possible Research Directions

Future research can consider to explore new aspects of magnetism or form factors as new dimensions of user inputs:

1) *Changing magnetic strength*. Applying external magnetic fields using electromagnets or actuators can temporarily change the constant magnetic field. Hence, possible applications in frequency domain, such as the frequency ID [22], can be considered.
2) *Combining magnetic fields*. Since the magnetic fields of several magnets combine with each other in laws of addition, the resulting fields can be used to resolve the geometry of a combination of magnetics, such as building blocks.
3) *Building organic magnetics*. Hall-sensor grid can see the shape of stretchable magnetics, such as magnetic clay, because the 2.5D shape of the magnetic fields can be resolved. Hence, crafting organic interfaces [19] using magnetics can be considered.
4) *Defying gravity*. Magnets can be fixed on the thin ferrite surface by either covering a Hall-sensor grid to the front or attaching a Hall-sensor grid to the back. The latter permits some percent of magnetization to penetrate through the surface and get sensed. The surface attractions between the magnets and the fixed surface counteract with gravity and other magnetic fields, thus enabled more possible applications on the portable platform, such as playing chessboard games with multiple tokens.
5) *Customizing for different portable displays*. It is feasible to apply this add-on sensing method on other portable displays, such as wrist-mounted displays, flexible displays, nail-mounted displays [18], or digital jewelries. The suitable parameters of devices or human factors can be further explored.

CONCLUSION

The author has presented how to enrich the input space on portable displays by exploiting magnetism as an additional input channel, through the use of an add-on Hall-sensor grid. The design space, limitations, and possible directions of this sensing method are illustrated and discussed.

We envision that, in the near future, this sensor hardware can be fabricated in more compact form factors by better manufacturing process to allow for the integration with the built-in sensor set of the portable displays as commodity hardware. We also hope broader HCI community applying this technique on more novel and interesting ways of design.

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