Exploring Around-Device Tangible Interactions for Mobile Devices with a Magnetic Ring

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Abstract

We present our initial work on using a magnetic ring as a tangible input control to support around-device interactions for mobile devices, aiming to address touchscreen issues such as occlusion and imprecision, at the same time provides tangibility to interaction. This input mechanism allows users to use the surface on which the mobile device is placed as an extended input space, with a rotatory motion as the main form of interaction. Our technique requires no calibration, no modifications to the mobile device, and no external power for the ring, which also functions as an accessory item (a finger ring) when not in use. We discuss our design criteria, prototype implementation and illustrative applications, and directions for future work.

Author Keywords

Around-device interaction; mobile device; magnetism; magnetic ring; wearable; jewelry; tangible interaction.

ACM Classification Keywords

• Human-centered computing~Human computer interaction (HCI) • Human-centered computing~Interaction devices • Human-centered computing~Gestural input • Human-centered computing~Mobile devices

Introduction

Touch interactions with mobile devices suffer from issues such as occlusion and imprecision [13]. Around-Device Interactions (ADIs) address these by extending the interaction regions beyond the device itself [4,10], while enabling novel interaction techniques that are not possible on a display surface where contact must be maintained (e.g., mid-air 3D [11]). The extra regions also allow additional hardware to provide tactile feedback that is missing from a typically featureless touchscreen (e.g., physical widgets [10]).

However, in many cases, ADIs either require the mobile device to be augmented with special sensing hardware, for example, SideSight [4] uses an array of proximity sensors to determine finger positions; or require a custom input control, often because the control must have specific physical affordances to represent its functionality, for example, MagGetz [10] uses various physical widgets which are an embodied representation of their associated control in the mobile interface. Such requirements lead to reliance on dedicated custom components that are not easily available to average consumers and, hence, reduce practicality.

We overcome this limitation by using sensing hardware that is commonly available in modern mobile devices, and an affordable (~USD$5) and easily obtainable input control. We use magnetism through combining the built-in magnetometer of a mobile device, and a magnetic ring, which is commonly used as an inconspicuous prop in close-up magic performances[1].

[1] Also known as "PK (Psycho-Kinetic) ring", with which magicians appear to be able to manipulate objects with their minds.

Related Work

There has been active research in ADIs for mobile devices using various techniques, including proximity sensing [4,12], visual tracking [6], and acoustics [8]. We focus on those that uses magnetism as the main input detection mechanism, and group them into two categories of either using magnets only, or with other items, to compare their advantages and drawbacks.

ADI with Magnets Only

Han et al. [7] and Harrison & Hudson [9] used a finger-worn magnet, and tracked its movements using a magnetic sensor worn on the user's wrist. Both work used dedicated magnetic sensors to detect fluctuations in magnetic field to determine the magnet's position, for recognizing handwriting [7] and selecting items [9].

MagiTact [11] explores three different magnet shapes (rod, pen, and ring) for 3D gesture inputs. Nenya [2] focuses on the ring form factor to provide subtle and eyes-free input, where the user wears the ring and selects menu items with one- and two-hand gestures.

The advantage of this approach is that the magnets being used are easily obtainable and can be very small (fraction of the size of one's fingertip). However, the drawback is that the input vocabulary with magnets alone is limited to those actions that affect the magnetic field, namely, translations and rotations.

ADI with Magnets Attached to Other Items

TMotion [14] attaches a magnet and an inertial measurement unit (IMU) to a stylus to detect 3D inputs. Abe et al. [1] used a similar setup, but removed the need of an IMU by limiting the movements to the surface on which the mobile device is placed.

MagGetz [10] attaches magnets to a number of customizable controllers that mimic GUI interface components, and detects their associated actions (e.g., pressing a button, moving a slider, turning a wheel). Bianchi & Oakley [3] attached magnets of different strengths to various objects to enable identification of tokens, as well as their movements and positions.

The advantage of this approach is that the magnet-augmented items provide greater tangibility and affordance of use, for example, a stylus for drawing, a button for pressing. However, the drawback is that each item is often interface-specific and has to be swapped out for different interactions, requiring the user to carry all of them along and taking up space.

We employ the magnet-only approach, so as to keep the input control as compact and portable as possible. Additionally, we chose to use a finger ring form factor, which naturally suggests rotatory actions via its circular shape. However, instead of wearing the ring during use (as in Nenya [2]), we explored scenarios where the ring is taken off and placed parallel to the mobile device (similar to on-surface interactions by Colley et al. [5]).

Design Criteria

To lower the barriers in adopting ADIs, for example, costly and custom hardware, effort to learn and perform interaction gestures, we established the following four design criteria:

DC1: No modification to the mobile device.
The technique should be usable by most if not all modern mobile devices. This means no additional hardware attached to the device, and preferably no modification to the operating system (e.g., rooting).

DC2: Requires minimal setup/calibration.
The technique should be available for anyone. This means no elaborate and time-consuming setup (e.g., extraneous computing items that require calibration).

DC3: Input control is self-contained and -sufficient.
The technique should be available at any time. This means the input control does not rely on any external support that renders itself unusable if missing (e.g., battery). If power is needed, it has to be self-powered.

DC4: Ergonomic to use.
The technique should allow repeated activation without causing much fatigue. This means no large movements (e.g., constant mid-air gestures). Smaller movements also have the advantage of drawing less attention.

Prototype

We designed our technique to use only the built-in magnetometer of a mobile device (available in most Android devices[2], and all iOS devices except 1st-gen iPhone, iPhone 3G, and iPod Touch[3]) for sensing the magnetic field. This sensor is accessible without any modifications (DC1). The input control, a magnetic ring, is a permanent magnet shaped as a finger ring (DC3).

Input gestures are mainly performed on the same plane as the mobile device's display. Mid-air gestures are possible, but to minimize fatigue we focus on scenarios where both the device and ring are on a surface (DC4).

[2] Android's sensor overview webpage: https://developer.android.com/guide/topics/sensors/sensors_overview.html

[3] Apple's iOS device compatibility reference webpage: https://developer.apple.com/library/content/documentation/DeviceInformation/Reference/iOSDeviceCompatibility/DeviceCompatibilityMatrix/DeviceCompatibilityMatrix.html

Figure 1. Setup of the prototype. Top: Mobile device (Nexus 5), Bottom: Magnetic ring (diametrically magnetized). The ring can be placed anywhere around the device as long as its movements are within the detection range of the device's magnetometer.

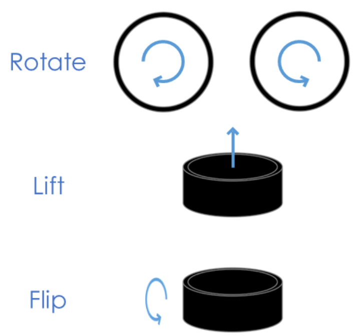

Figure 2. Three input gestures with the magnetic ring. Top: Rotate (clockwise/counter-clockwise), Middle: Lift (up), Bottom: Flip. All actions are assumed to be starting from a surface at the same plane as the devices display.

The input gestures are actions that cause discernable fluctuations in the magnetic field as detected by the mobile device. These changes are deterministic and hence can be measured without calibration (DC2).

Figure 1 shows the physical setup of the prototype demonstrating the technique. The magnetic ring can be anywhere around the mobile device as an input control.

Implementation

We tested on an LG Nexus 5 (running Android 6.0.1) as the mobile device, and a magnetic ring (diameter: 20mm, height: 7.5mm, thickness: 1mm, diametrically magnetized with strength: ~50 mT at each pole) as the input control. We implemented the sensing software using Android API 23, which measures calibrated magnetic field strength in the x-, y-, and z-axes aligned to the device's orientation.

Input Gestures

Through experimenting with our prototype, we identified three promising input gestures (Figure 2) using the following three actions. We describe their working principles and performance considerations.

ROTATE (AROUND THE Z-AXIS)

Like a dial, the circular shape of the ring naturally affords a rotate (turn) action. As shown in Figure 3, rotating the ring at a fixed position relative to the mobile device causes discernable changes along the x- and y-axes, and reverts back to the original values when a full rotation is completed. Utilizing this property, we calculate the angle created by the x- and y-values using the following formula:

$$\theta = \tan^{-1}\frac{y}{x},\ \theta \epsilon [-180°, 180°] \qquad \text{Eq. 1}$$

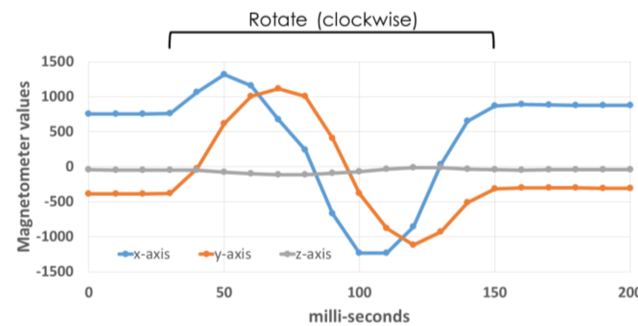

Figure 3. Magnetometer values in x-, y-, and z-axes as the ring rotates clockwise for 360 degrees at approximately 5cm away.

This value is consistent as long as the relative position of the ring remains the same. Hence, it can be mapped to any continuous input parameter within a range.

LIFT (ALONG THE Z-AXIS)

Examination of the ring's magnetic field reveals that it behaves like a typical bar magnet, with North and South poles on its opposite arcs. This means that tracking techniques employed in prior work (e.g., [1,9]) can be applied to determine the position of the magnetic ring. However, this is in conflict with the detection of the rotate gesture, as both use the same x- and y-values from the sensor. Since we want to prioritize the rotate gesture in this work as afforded by the ring's circular shape, our technique does not associate translation actions with input gestures.

Nevertheless, a lifting action causes a discernable change along the z-axis, which is not present in the rotate action, and hence can be associated with a different input gesture. In actuality, such action is equivalent to moving the ring away from the device, thus causes changes not just in z-axis but all the axes

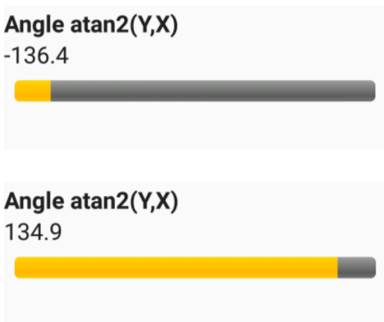

Figure 6. Example control using the angle calculated between the x- and y-values. The -180-180 range is mapped to a linear level control.

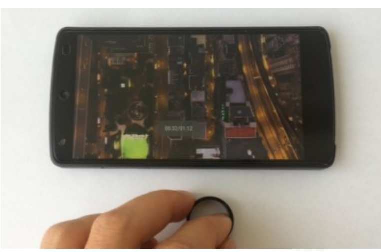

Figure 7. Example using change in angle to scrub through a video clip. Rotating clockwise advances the playback, rotating counter-clockwise rewinds the playback.

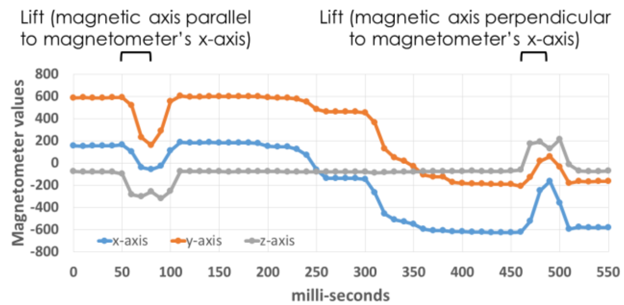

Figure 4. Magnetometer values in x-, y-, and z-axes as the ring lifts approximately 5cm upwards. Note how the orientation of the ring affects the way these values change.

(see Figure 4). One caveat, is that the orientation of the ring (magnetic axis) has an effect on how these values change, and warrants further investigation to properly recognize such gesture.

Flip

An interesting action, only possible when the ring is not worn, is flipping (turning the ring upside down). As shown in Figure 5, this action causes a drastic change in polarity in one/both of the x- and y-values, which can be mapped to a discrete input.

However, similar to the lifting action, the degree of polarity change varies with the flipping action relative to the magnetic axis of the ring: the change is the strongest if it is perpendicular to the ring's magnetic axis, and decreases as it gets closer to being parallel to the axis, which can be unnoticeable (Figure 5, left).

Illustrative Applications

We provide two examples utilizing the input gestures mentioned above to illustrate how our technique can facilitate around device tangible interaction.

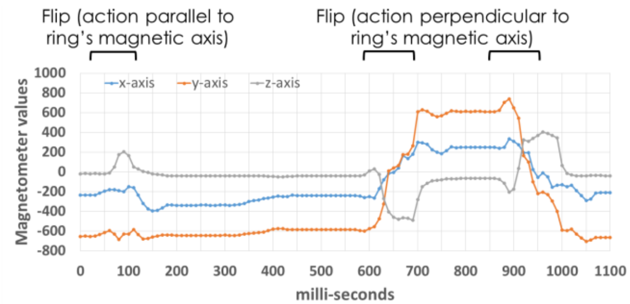

Figure 5. Magnetometer values in x-, y-, and z-axes as the ring flips. Note how the action's relative to the ring's orientation affects the degree of changes in the values.

Level Control

As mentioned above, the angle of the rotate action can be mapped into an absolute value within a range. Figure 6 shows an example of such control. To prevent wrapping around of angles (happens when the angle goes beyond -180° or 180° using Eq. 1), the device can alert the user that they are reaching the extremes, and ignore these values close to them. Other actions (lift or flip) can be incorporated as a confirmation gesture.

Media Scrubbing

Using a sliding window approach, one can determine the change in angle between two time frames. This change indicates both the direction as well as the speed of the rotation. Figure 7 shows an example of using this value as a media scrubbing parameter (clockwise advances, counter-clockwise rewinds, rotation speed proportional to frames skipped).

Discussion

We discuss the implications based on our initial observations on the current prototype.

Range Limit

Since all the actions are triggered by discernable disruptions to the measurements of the mobile device's magnetometer, there is a physical limit to the distance at which the actions can be reliably detected (approximately 8cm around the device, in all directions). This limit is dependent on the magnetic ring's strength, the magnetometer's sensitivity, as well as the magnetic field fluctuation of the surroundings.

Nevertheless, our initial tests show that once in range, the measurements are fairly stable, regardless of where the interaction takes place, as the strength of the static magnetic ring dominates all other field strengths to the magnetometer. We developed our media scrubbing prototype with this insight by using a change threshold, beyond which starts the input, and basing the play head's movement on the change in the measurements. This approach also allows the device to be tilted (for a better viewing angle), though both the ring and the device had to be in the same respective positions, and we did not investigate how large the angle could be.

Location Limit

Similar to Abe's [1] technique, our design is limited to surfaces with non-magnetic substance, as the presence of such will affect the magnetic properties of the ring. Moreover, since the ring itself is a magnet, it will adhere to a magnetic surface, making rotation difficult.

Orientation of the Magnetic Ring

We observed that all the actions except rotate are impacted by the orientation (magnetic axis) of the ring. During lifting, different orientations result in either increase or decrease in measurement along all the x-, y- and z-axes; whereas during flipping, different orientations result in either discernable (when perpendicular) or unnoticeable (when parallel) changes along the x- and y-axes. One way to mitigate this issue is to have markings on the ring to indicate orientation, though how this variation can be incorporated into the gesture recognition process requires further work.

Conclusion & Future Work

In this paper we explored the use of magnetism to enable around device interaction. Through combining the built-in magnetometer of a mobile device, and a magnetic ring, we proposed three input gestures that require no calibration, no modifications, and no external power. The shape of the ring also provides tangibility to the interaction, and is a compact item that can be worn as an accessory item when not in use.

As future work we aim to further investigate the recognition of input gestures given that some are affected by the ring's orientation, and evaluate their performance in different environments (in/outdoors). We also plan to explore other possible gestures [5], mappings between these tangible gestures and digital interactions, and evaluate their utility by replacing touch-based inputs in typical applications such as games and media players.

Acknowledgements

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