# Abracadabra: Wireless, High-Precision, and Unpowered Finger Input for Very Small Mobile Devices

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**ABSTRACT**
We present Abracadabra, a magnetically driven input technique that offers users wireless, unpowered, high fidelity finger input for mobile devices with very small screens. By extending the input area to many times the size of the device's screen, our approach is able to offer a high C-D gain, enabling fine motor control. Additionally, screen occlusion can be reduced by moving interaction off of the display and into unused space around the device. We discuss several example applications as a proof of concept. Finally, results from our user study indicate radial targets as small as 16º can achieve greater than 92% selection accuracy, outperforming comparable radial, touch-based finger input.

**ACM Classification:** H.5.2 [Information interfaces and presentation]: User Interfaces - Input Devices, GUIs.

**General terms:** Human Factors

**Keywords:** Mobile devices, small screens, pointing, finger input, magnetic, interaction techniques, gesture, cursor.

## INTRODUCTION

Advances in small and low power electronics have created new opportunities for mobile computing, leading to an explosion of new devices for the general public. Overall, these advances have allowed extremely powerful computing capabilities to be packaged in smaller and smaller form factors. These devices offer tremendous new potential due to e.g., their extreme mobility. However, with this potential come new challenges for interaction design [1,6].

In particular, while electronic devices have simultaneously increased in computational power and decreased in size, human factors have not changed dramatically, e.g., our fingers are the same size and our average visual acuity has not changed. As a result, for some devices, we are now bounded not by the size of the electronics or perhaps even battery size, but instead by the surface area needed to support user I/O. In these cases, conventional input mechanisms such as buttons and touch screens cannot be scaled smaller because of the way they interact with e.g., fingers. This recently led Olsen to pose as a grand challenge question: "If I can fit my entire PC in a cubic inch, how will I interact with it?" [6]. The technique described in this note attempts to address at least part of that question.


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We introduce Abracadabra, a magnetically driven input approach that makes use of the (larger) space around a (very small) device. Our technique provides robust, inexpensive, and wireless input from fingers, without requiring powered external components.

Other potential approaches have employed cameras [10], microphones [5], proximity sensors [2], magnetic tags [7], and accelerometers [3]. Each of these can potentially operate in small spaces, but suffer from at least some drawbacks, e.g.: how to integrate the camera on a cubic-inch device without occlusion from fingers/hands; the sequential nature of speech and the need to be robust in noisy environments; the difficulty of making complex interfaces from generally low-resolution proximity sensing; the footprint and energy required to power resonant magnetically-coupled tags; and the need to use accelerometers as relative rather than absolute pointing devices, or limit them to gestural input, with limited expressiveness.

## SENSING

Magnetometers are used in a variety of applications, including the detection of artifacts in archaeology, earthquake forecasting in geology, navigation in aerospace, and imaging for medical purposes. As a result, a multitude of advanced magnetic sensors are commercially available in robust, small and inexpensive forms. We primarily focus on the use of multi-axis magnetometers, which are often employed to determine orientation relative to the Earth's magnetic field (i.e., digital compasses). To appropriate these sensors for use as input devices, we simply override the Earth's magnetic field with a local magnet, which can be unobtrusively worn on the finger (e.g., as a ring). This technique has several interesting properties that make it conducive for input.

Foremost, the magnetic field produced by the magnet extends with sufficient strength for detection for several tens of centimeters. This allows the finger to operate like a wireless input device, taking advantage of an input area many times the size of a typical mobile device screen. This provides a C-D (control-device) gain of 4:1 or greater, enabling fine interface-related motion control without corresponding fine human motion, as typically seen in touch screen interactions. Not only does this open the possibility of more complex interfaces, but may also allow some users with diminished fine motor control to successfully use small interfaces. Additionally, screen occlusion is greatly reduced, as the fingers do not need to operate on the display surface, as touch screen interactions require. Upper quadrants, however, can still be occluded by the pointing hand, and require consideration when designing user interfaces.

Secondly, magnets, although active, require no batteries. Not only does this mean they never need to be recharged, but also enables them to be small and robust against impact and liquid damage. Their ability to be wireless and unpowered gives Abracadabra a unique edge over other a number of other spatial input methods, including IR pens, active magnetic sensing, and ultrasonic locators [11]. (Electric field sensing [8] may offer similar advantages, but has yet to be implemented in devices of this size.) It should be noted, however, that despite these advantages, a magnet worn on the finger shares similar downsides to that of stylus - most notably that uses have to manage and interact with an additional object.

It is also possible to mount the sensor behind the display (i.e., inside the device), which has several benefits. Foremost, it does not consume any real estate on the outside of the device, which is the limited resource (especially the "top" of the device, which in many cases, is best dedicated entirely to the display). This stands in strong contrast to most existing input methods, including infrared [2], camera [10], ultrasonic, and capacitive based techniques, as well as conventional buttons (but not accelerometers). Second, the center point for gestures and other motions (e.g., rotations) can actually be in the center of the device without occluding/breaking the screen. This provides a symmetrical (i.e., optimal) input field, both in terms of range and accuracy. Additionally, being located inside the enclosure ensures the sensor is well protected from wear and other damage.

Finally, the ability to operate through obstructing materials opens the possibility for interaction through, e.g., grasped hands and uneven surfaces (e.g., wrinkled tablecloth), as well as enclosed places such as pockets, bags, and draws. Most previous sensing techniques have required either direct manipulation (e.g., buttons, touch screens), or at least line of sight (e.g., ultrasonic range finding, infrared proximity [2], vision systems [10]).

## PROTOTYPE HARDWARE

To assess the feasibility of our input approach and to experiment with various interaction techniques, we constructed a prototype platform (Figure 1). We chose a wristwatch form factor, as this is a quintessential small device with limited input ability, and has been the focus of previous input research (e.g., [1]). However, the technique also applies to devices, e.g., sitting on a desk, resting on one's leg, gripped in the hand, or laying in the palm.

Our setup consisted of a NHJ VTV-101 TV wristwatch modified to receive a signal from a conventional desktop computer (where sensor processing and interface rendering takes place for our proof-of-concept system). The 1.5" TFT LCD (30x23mm) provides a resolution of 280x220. Although still somewhat bulky as a wristwatch, we believe this screen size reflects what future "miniature" devices are likely heading towards, and more importantly, represents a size where touch screen interaction becomes troublesome.

Figure 1. Prototype Abracadabra-augmented wristwatch.

For magnetic sensing, we employ a Honeywell HMC1052L Dual Axis Magnetic Sensor. This solid state IC, costing less than five dollars in bulk, provides angular accuracy of around ±2°. The sensor measures 3x3x0.9mm, enabling its integration into even the smallest of mobile devices. Furthermore, power draw is negligible: 0.15mA at 90 samples/sec – considerably less than comparable active sensing methods (e.g., [2,11]).

The final component of our system is a magnet placed on the finger. A small strip of Velcro is used to attach a three-gram, N52 grade, disk-shaped, neodymium magnet measuring approximately 12x3mm in diameter and height respectively. This sized magnet provides an effective range of about 10cm, yielding a circular area of input of roughly $300cm^2$ (50 times larger than the $7cm^2$ display we employ).

## INPUT

We support two distinct input modalities. The first is one-dimensional polar input circumscribing the device, where information from the sensor's two axes is used to calculate a bearing to the user's finger. Unsurprisingly - as this is what the sensor was primarily designed for - accuracy is exceptional (approx. ±2° including sensor noise).

It is also possible to approximate the two-dimensional spatial location of a user's finger by taking into account the field strength. This enables the finger to act like a cursor. The software must compensate for the exponential drop off in field strength and, consequently, lower resolution at greater distances. Our work on this feature is preliminary, but shows considerable promise. It is also possible to calculate location using vector data from two sensors [4].

Although it is possible to build interfaces entirely from rotational and positional actions alone (e.g., using crossing-based interactions), a binary "click" is more familiar and intuitive. To support this action, we take advantage of magnets' unique dipolar property. As seen in Figure 2 (left), a finger above the device projects the magnet's south (negative) field over the sensor. However, when the user "clicks" their finger downwards, below the sensor, the field

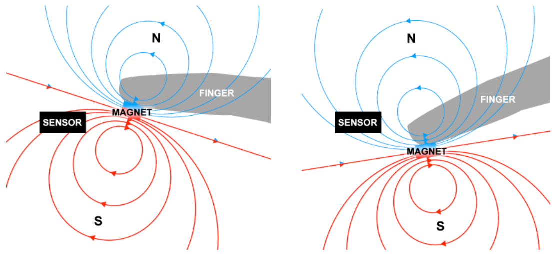


Figure 2. When a finger descends below the sensor plane during a "clicking" action, the magnetic field inverses.

reverses (Figure 2, right). This is seen by the sensor as a near instantaneous jump of 180° from the previous orientation, which is interpreted by our software as a click. The original bearing resumes when the finger is returned to the standard "floating" position. Although not implemented in our present software, it is possible to capture both on-press and on-release actions, enabling advanced interactions like dragging icons and moving sliders. While the finger is "depressed", interaction would have to take place under the device (e.g., under the arm in a wristwatch scenario).

Although only receiving preliminary attention, it is also possible to support interactions involving the curling and rotation (twisting) of fingers. Both actions invert the magnetic field, like a click, but without vertical motion. Figure 3 illustrates this effect. These could simply serve as alternative clicking actions. However, slight differences in how the magnetic field changes over time might allow for such motions to be uniquely identified. For example, in addition to flick driven clicking, a curl could serve as a conceptual "grabbing" action for dragging items.

## EXAMPLE APPLICATIONS

As part of our investigations, we evaluated a variety of input styles. We discuss the most promising avenues below.

### Rotation and Clicking

One-dimensional polar movement and selection (via clicking) is well suited to navigating hierarchical interfaces. The success of Apple's iPod, which features a circular scroll wheel and central select button, demonstrates the usability and acceptability of such interfaces. In response, we built a functional, proof-of-concept audio player application (seen in Figure 1) with a similar interaction style. This features four distinct modes: volume control for the active song, a list of artists, a list of songs (based on the previously selected artist), and a "now playing" screen, which displays song and progress information. Navigating between screens relies on scrolling - by clockwise and counterclockwise movement - and by clicking on desired items. In the case of

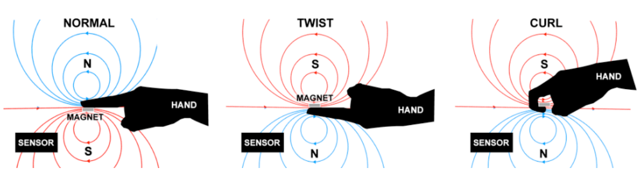


Figure 3. Twisting the hand and curling the finger also cause the magnetic field to invert.

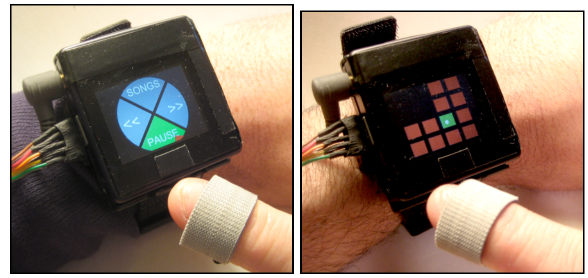


Figure 4. Left: wedge shaped buttons for absolute 1D polar input. Right: clicking a series of abstract buttons with pointer control (white dot). The upper-left quadrant is not utilized, as the hand occludes the screen.

the artist and songs lists, it is possible to navigate backwards by selecting the "back" item. In the "now playing" mode, a click forwards the user to the volume control, which serves as the home screen. Volume can be adjusted by rotating clockwise and counterclockwise.

We also developed a simple photo browsing application. Users can scroll through a list of photo albums - clicking enters the selected album. Users can then scroll through pictures contained within. A second click exits the album.

Finally, the high angular accuracy of our system also enables interfaces based on absolute angular position. For example, Figure 4 (left) shows an interface we built that uses four, equally sized, wedge shaped buttons. Users can simply move to the corresponding "slice" in space radiating outwards from the device; clicking activates that item.

### Gestures

It is also possible to support gestures using 1D polar or 2D positional movements. Figure 5 illustrates three 1D polar gestures supported by a simple gesture recognizer we developed. Gestures could be used to, e.g., switch applications, answer an incoming phone call, or mute alerts.

### Cursor Control

As described earlier, it is possible to approximate conventional cursor position by taking in account the field strength of the magnet. Our proof of concept implementation of this feature is encouraging (a functional button clicking demo application is shown in Figure 4, right). We strongly believe more advanced sensors and processing could yield excellent cursor control. This ability could be used to support conventional widget-based interfaces, including buttons, sliders, and hyperlinks. Furthermore, natural support for fine-grained cursor control (via high C-D gain) without significant screen occlusion allows Abracadabra to sidestep targeting issues described in, e.g., [9].

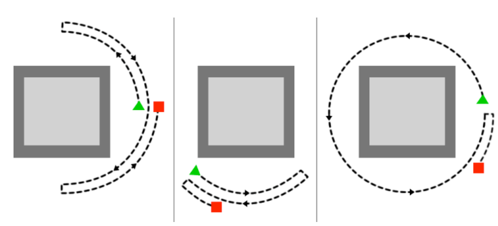

Figure 5. Three example 1D polar gestures.

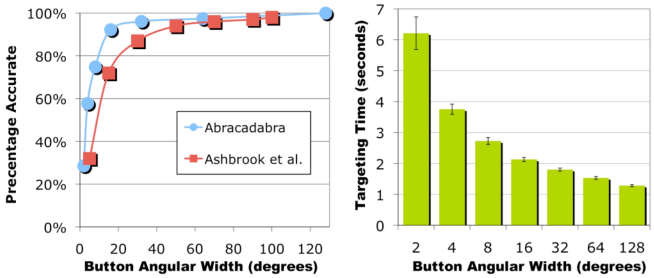


Figure 6. Left: targeting accuracy of different-sized radial targets. Results from Abracadabra and [1]. Right: time to acquire targets of different angular widths (data from successful trials only).

## EVALUATION

We recruited 15 participants (9 female) with mean age of 28.5 (min=21, max=54). Participants were paid five dollars for their involvement in the study, which took approximately 15 minutes. Our prototype hardware was placed on participants' wrists (a side of their choosing) and secured with Velcro. A small Velcro band with integrated magnet was worn on the index finger of the other arm.

Due to the length of the evaluation, participants were seated at a table so that they rest their elbows on the surface (suspending ones arms in front of the body for several minutes is both tiring and unrealistic). In piloting the study, we found that there is no significant performance difference between the seated and standing position. This is mostly because rotational finger motions in these postures involved anchoring the elbow (to the desk or body) and using it as a pivot point.

Participants were asked to navigate a 1D polar cursor over a series of wedge shaped buttons (similar to those shown in Figure 4, which have angular widths of 90°). Once the desired target was reached (as best possible), the user would press a conventional button located under their non-pointing hand. This captured the current angular position (for later accuracy analysis) and also initiated the next trial. Angular widths of 2, 4, 8, 16, 32, 64, and 128 degrees were evaluated. Each button width was repeated 20 times, for a total of 140 trials per participant (2100 trials collected in total). Order and position was randomized.

## RESULTS

As shown in Figure 6 (left), users were able to archive accuracies in excess of 92% for targets with angular widths of 16º or greater. Below 16º, accuracy drops off precipitously.

The test we performed has the character of a typical Fitts law experiment: a variety of target sizes and distances between targets. However, because targets are open-ended wedges in space surrounding the device, their effective size from a Fitts law perspective is very dependent on motion direction, which in turn varies considerably based on the angular distance between targets. Further, the actual "aim point" for user motions can vary substantially in this open-ended situation. Thus, it was not surprising that we found a poor regression fit ($R^2 = 0.389$) with the Fitts equation. Nonetheless, we can see the expected characteristic relationship between target size and selection time when we average across all distances (Figure 6, right).

Ashbrook et al. [1] evaluated several input styles for circular interaction on a watch-sized device. Their "through" method, where one moves in a straight line to the next radial target (potentially over the face of the display), is most similar to what we observed with participants using our prototype. The Ashbrook prototype used a modified mobile phone with a circular bezel placed on top. Interaction required touch, with users physically pressing their fingers to the device.

This work provides an excellent baseline from which to compare Abracadabra's wireless input to direct finger manipulation. The fixed radial width (varied angular width) condition is most comparable (see Figure 7b in [1]). Comparative results are shown in Figure 6 (left). While both methods achieve high accuracy for button widths of 40° and greater, Abracadabra's reduced screen occlusion and high C-D gain appears to provide a significant performance edge on smaller targets (e.g., 28% vs. 7.8% error rate with 15° and 16° targets respectively). On average, this benefit cuts the error rate by more than half.

## CONCLUSION

We have presented Abracadabra, a magnetically driven input technique for very small mobile devices. Use of a magnet sensed at a distance enables wireless and unpowered input. This makes use of the much larger space surrounding the device, rather than limiting the range of motion to the size of the device itself.

## ACKNOWLEDGMENTS

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