Novel Input and Output opportunities using an Implanted Magnet

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ABSTRACT

In this case study, we discuss how an implanted magnet can support novel forms of input and output. By measuring the relative position between the magnet and an on-body device, local position of the device can be used for *input*. Electromagnetic fields can actuate the magnet to provide *output* by means of in-vivo haptic feedback. Traditional tracking options would struggle tracking the input methods we suggest, and the in-vivo sensations of vibration provided as output differ from the experience of vibrations applied externally – our data suggests that in-vivo vibrations are mediated by different receptors than external vibration. As the magnet can be easily tracked as well as actuated it provides opportunities for encoding information as material experiences.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**.

KEYWORDS

implant, magnet, haptics, perception, implanted magnet

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Figure 1: X-ray of the first author's hand, palm facing the reader. The magnet is visible in white, located in the fatty tissue above the bone.

1 INTRODUCTION

A magnetic implant can be used to enable input to and output in ways which otherwise would be difficult or impossible to achieve. After briefly surveying related work, we discuss new input and output opportunities afforded by a magnetic implant[1].

Implanted devices are not a new idea. Novels such as Gibson's Neuromancer popularized the concept in the early 1980's. Here, implants augment perception and abilities as well as providing users with access to information. These fictional implants of the past were interactive augmentations of our bodies, superseding bodily abilities and at the forefront of our attention. This vision did not become reality. Though implants permeate bodies in the form of stents, pacemakers, or medical delivery systems, they are at the background of our attention. Today's implants are rarely interactive. Instead, the world around us has become more interactive, devices smart and responsive, and the use cases for interactive implants increasingly less obvious. The gritty future of hacked bodies is replaced by a present which provides interactivity without penetrating the skin.

However, there are trends in HCI which suggest that we should – once again – consider the body more, exemplified by series of workshops which explore merging bodies with technology [4, 13, 20] and discussion on Human-Computer Integration [21]. Concurrently, DIY [2] and body-modification communities [29] have continued exploring these ideas with functioning prototypes and basic implanted devices such as magnets [27] or RFID chips [8]. It seems prudent, then, to revisit the subject matter of implants.

We do so by (1) proposing implanted magnets used as local anchors for on-body positioning, providing new opportunities for body-centric interactions with wearable devices, and (2) highlighting that vibrotactile feedback provided by an implanted magnet is experienced differently from vibrotactile feedback applied externally, extending the potential bandwidth of haptic information transfer.

2 RELATED WORK

There is a small body of work which has explored implanted interfaces, however, devices which were actually implanted, typically do not take advantage of their unique placement with regards to

[1]This paper is not meant as an endorsement for implanting magnets. The first author had the magnet implanted in 2012, no in-vivo procedures were conducted for this paper.

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interaction. Instead, designers have opted for communicating with implanted devices through mobile phones or other proxy devices [2]. Implanted devices could, however, be directly interacted with. Holz et al. [12] demonstrated that, theoretically, implanted devices could provide a broad variety of input options, however their work does not consider biocompatability.

Implanted devices have also been used for measuring neural activity, for example, by inserting sensing-meshes between the skull and the brain, to collect high-definition real time information of neural activities. Typically, such systems however are deployed to collect data which is later analyzed post-hoc, not affording any real time interaction [6]. An interesting twist to the 'implanted' genre are devices which are swallowed, as demonstrated by Stelarc [26] and more recently by Li et al. [18]. However, the device by Stelarc was intended to be viewed with medical imagery devices, while the device by Li et al. is interacted with through a smartphone app. Again, neither device takes advantage of its in-vivo position in terms of novel interactions.

While a range of in-vivo devices exist, the question of how one might use such devices for novel interaction is still largely unanswered. A simple implant, which can easily support novel interactions is a magnet (see also Heffernan et al. [11]). Such an implanted magnet has no active parts which require power or control, and can provide input to magnetic tracking systems, and can be provide the user with in-vivo haptic stimuli.

The potential for novel interactions using an implanted magnet should be obvious, when looking at the plethora of HCI prototypes which currently improve their input abilities using a magnet [1, 9, 19] and the common use of solenoid style actuators for providing haptic feedback [16, 24, 28].

3 SYSTEM COMPONENTS

The interactions presented use a wearable device, augmented with Magnetips, and an implanted magnet:

Magnetips: The hardware used was previously published as Magnetips – a system which could track and actuate a magnet remotely [19]. Magnetips was in part inspired by prototypes built to vibrate the magnetic implant of the first author. The interest in tracking the location of the magnet originated in part from the wish to do local on-body position tracking of devices relative to the implant's location. Here we extend upon our previous work by discussing how magnetips interacts with an implanted devices.

Implanted Magnet: The first author of this paper has a magnet implanted in the palm of their left hand (see Figure 1). The magnet is a neodymium magnet approximately 2mm in diameter and 4mm length. The magnet is coated with Parylene C. The position was chosen as it is relatively well protected by fatty tissue, and not likely to significantly interfere with equipment which is sensitive to magnetism. The palm is also an area of the hand with relatively strong sensory innervation. While the fingertip would offer even stronger innervation [14], positioning the magnet there has the potential to interfere with activities such as climbing, or calibrating equipment sensitive to magnetism.

The interactions presented use a smartwatch as a familiar example. The Magnetips system, however, might instead be embedded in garments [5] or jewelry [22], or might be used as guidance and interaction system for epidermal robots roaming the body [3].

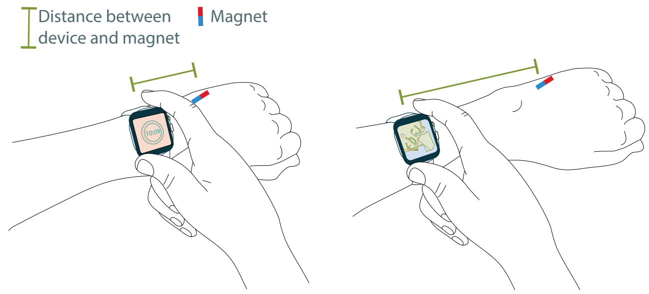

Figure 2: The position of the smartwatch can be inferred by its distance to the implanted magnet. Here, positions are mapped to applications. Close to the wrist, the smartwatch displays the time, when moved away from the wrist the display switches to a map. This can also be used for continuous input. For example, the user might hold the watch-face steady while rotating their hand to scroll through a list.

4 INPUT

Magnetips enables tracking of a magnet attached to the user's fingernail. Instead of using the system to interact with a magnet attached to a fingernail [19], Magnetips can also be used to interact with an implanted magnet. Depending on how the Magnetips system is attached to the body, different types of interaction become possible:

4.1 (a) Device Manipulations

If the wearable device is loosely fit around the body, the magnet can be used as an anchor-point for detecting local on-body position of the wearable device. This can enable a user to change the device's position or orientation as an input-method. For example sliding the device up or down the wrist (see Figure 2), or rotating it around the wrist.

Rotation based interactions might be captured using an Inertial Measurement Units (IMU), however, an IMU cannot distinguish between a rotation of the users arm together with the device, and rotating the device while the arm remains stationary. Additionally, translation (for example moving a bracelet towards or away from the wrist) would be hard to capture with an IMU at all. In Figure 2, a user selects applications based on the devices position on the arm. Position is inferred by the distance to the magnet.

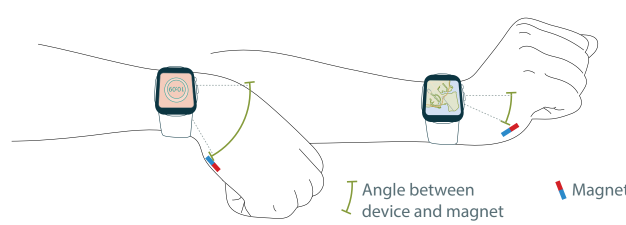

Figure 3: If the smartwatch is in a fixed position, any change in direction of the magnet can be attributed to hand movement. This enables robust gestural interaction. Here the user has applications mapped to hand-poses. A user switching from a time-telling to map application, based on wrist-angle. Continuous movement might also be used for continuous control, such as volume adjustment.

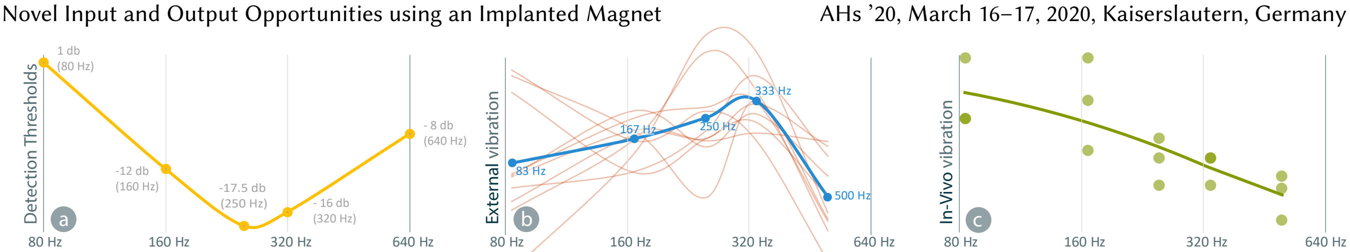

Figure 4: (a) Vibration detection thresholds by Verillo [32], yellow line shows the intensity of vibration required for it to be perceived. (b) Magnitude estimation study by McIntosh et al. [19], red lines show estimates of perceived strength of vibration, blue line represents the mean. (c) Replication of the experiment conducted by McIntosh et al. but with single participant and an implanted magnet. Green dots show estimated magnitudes, green line shows polynomial function fit to the data.

4.2 (b) Body Movements

If Magnetips is in a known position (for example by being firmly connected to a body-part) all measured movement of the magnet can be attributed to movements of the body. For example, if Magnetips is firmly attached to the wrist, and the magnet is implanted in the users hand, all motion of the magnet must be caused by motion of the users hand. This can be used to support gestural input. In Figure 3 the user selects applications based on wrist angle. Wrist angle is inferred based on the direction of the magnet.

4.3 (c) Mixed Body-Centric Interactions

Magnetips also has an IMU, so it can detect its own movements. In sum – given the position of the first authors implant – Magnetips can distinguish between three scenarios. If the smartwatch moves, but the magnet remains in a fixed relative position, we can infer *movement of the arm*. If the smartwatch moves and the magnet performs the opposite relative motion, we can infer *movement of the device*. Finally, if the smartwatch is stationary, but the magnet moves, we can infer *movement of the hand*. This allows combining arm movements, wrist movements and device manipulation, providing a rich space for body-relative interactions, which otherwise would be difficult to achieve.

5 OUTPUT

Magnetips can also actuate a magnet remotely – be it an external or implanted magnet. Previous work has already suggested that users are more sensitive to in-vivo vibrations, and has speculated that the mediation methods between the two types of stimulation might differ [10]. We extend upon this work by exploring the experience of in-vivo vibration over a wider frequency range.

Sections 5.1 and 5.2 present two experiments which were conducted by the second author with the first author as participant. The first author had no information regarding order of conditions, and was not aware of the parameters of the stimuli he felt. It should be pointed out that within psycho-physics, such single-participant experiments are not uncommon for establishing relations between physical stimulus and experienced sensation [7]. Single participant case-studies are also common within HCI (see also Lazar et al., Chapter 7 [17]). For better comparison of results, we use the same hardware and software which was used in the evaluation of Magnetips [19]. The experiments were conducted two years ago out of pure curiosity, at the time we did not expect these results and had no intention of writing this paper, so there was no particular desired outcome which might have biased the results.

5.1 Surprising Observations

In this section we compare results from three experiments: (a) measures of human sensitivity to vibration by Verillo [32] (Figure 4a), (b) our prior magnitude estimation study using Magnetips [19] (Figure 4b – overall average in blue, 10 individual participants in red), and (c) replication of the experiment conducted by McIntosh et al. but with an implanted magnet (Figure 4c). A summary of these studies can be found in Table 1.

Verillo found that the frequency which required the minimum amplitude to be perceived was at ∼250 Hz. For higher or lower frequencies, participants required a higher amplitude to perceive the vibrations (Figure 4a) [32]. In the Magnetips study we asked participants to report the perceived magnitude of a stimulus at varying frequency (Figure 4b). We expected to find a result negatively correlated to the data provided by Verillo, which we did. The reported magnitudes in the Magnetips study largely corresponds to the detection thresholds observed by Verillo. There appears to be a discrepancy in the peak of the two signals (250 Hz and 33 Hz respectively). This could be due to measurement error or idiosyncrasies of the Magnetips system. It should be noted that a result which correlates perfectly with the data by Verillo [32] would not be significantly different from our data at $p < 0.05$ (see [19]).

Verillo [33] later showed that his measures correspond closely to direct cell readings of Pacinian Corpuscles obtained by Sato [25]. It can be assumed that the vibrations created using Magnetips are also mediated by Pacinian Corpuscles, though an explanation for the discrepancy in peak sensitivity requires further investigation.

We repeated the magnitude estimation task presented in Magnetips [19], with the first author, who has an implanted magnet, as sole participant (Figure 4c). We found similar effects of duration as before, but the effects of frequency were markedly different. We plot raw response scores as green circles and – as we would expect to find a polynomial function – we superimposed the best fitting polynomial function of second degree on our results (Figure 4c). In the high frequency areas – above ∼300 Hz– the results are as expected, corresponding both to the experiment by McIntosh (Figure 4b [19]) and with what we would expect based on detection

	Method	Vibration	Participant #
(a) Verillo [32]	Detection Threshold	External	3
(b) McIntosh [19]	Magnitude Estimation	External	10
(c) Present Studies	Magnitude Estimation	In Vivo	Single

Table 1: Overview of studies (studies b and c used the same experimental hardware and software).

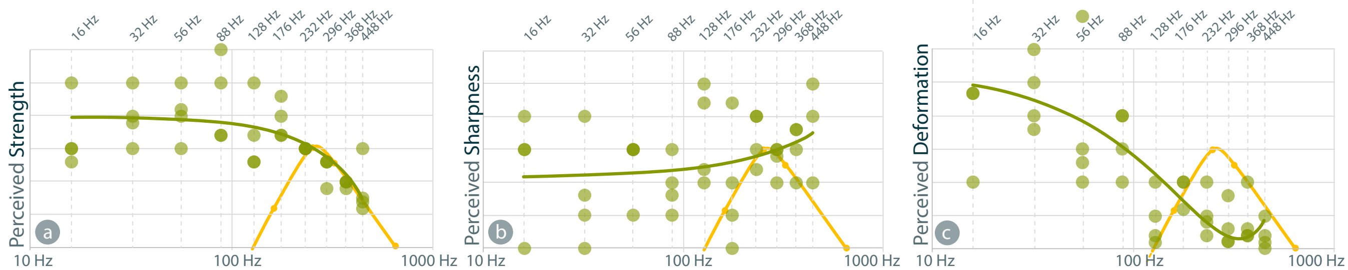

Figure 5: Magnitude estimation of in-vivo vibration: (a) estimates of perceived strength, (b) estimates of perceived sharpness and (c) estimates of perceived deformation. Each point represents one estimate, solid lines are the polynomial function which best fits the recorded data. Expected sensitivity to vibration added yellow for reference (the inverse of detection thresholds reported by Verillo [32]).

thresholds (Figure 4a [32]). However, for low frequencies – below 250 Hz– the perceived intensity increased, which is surprising.

5.2 Experiencing In-Vivo Vibration

As the relatively high strength of low frequency vibration was unexpected, we conducted further, informal tests with a wider parameter range and different pulse durations. We found that varying the frequency created qualitatively distinct experiences. While describing these beyond that they are *distinct* is difficult, some of these experiences felt sharp, while others felt less like vibration and more as if something were pulling or pushing. To see if the unexpected effect of frequency was consistent, and to gain insight on the qualitative experience, we repeated the experiment. This time we tested a wider range of frequencies (16 Hz, 32 Hz, 56 Hz, 88 Hz, 128 Hz, 176 Hz, 232 Hz, 296 Hz, 368 Hz, 448 Hz) but only a single level of pulse duration (1200 ms). We chose the frequency levels so that the differences between the stimuli were a geometric series, and so they covered the range we were most interested in. Stimulus order was randomized and each frequency was presented four times. The entire procedure was repeated three times, once for perceived strength, once for perceived sharpness and once for perceived deformation (experience of pulling or pushing).

The results are plotted in Figure 5a. Raw estimates are indicated as green circles and the best fitting polynomial function of second degree as a solid green curves. The expected response curve for perceived strength, based on the inverse of detection thresholds established by Verillo [32], is indicated in yellow.

We found that, again, the *perceived strength* is strongest for low frequencies, below 250 Hz (Figure 5a). This is surprising, as we expected the experienced strength to drop off similarly below 250 Hz as it does above 250 Hz (indicated in yellow). One might argue that there is an observed peak at 88 Hz and then a slight decline below that, but further experimentation is required for stating this with any certainty. This result is at odds with the Magnetips study (see also Figure 4b) [19] and to what one would expect based on detection threshold alone (Figure 4a) [32], but consistent with our initial experiment using the implant (Figure 4c).

The experience of *sharpness* (Figure 5b) had a very slight positive correlation with frequency, similar to previous studies which related frequency to sharpness [30]. The experience of *deformation* (Figure 5c) was strongest at low frequencies (~100 Hz and lower) and decreased at higher frequencies. We assume that this experience might be the reason that the overall magnitude estimation results for the implanted magnet differ so strongly from what we expected to find. There is a strong difference in quality of experience below ~100 Hz (high deformation, low sharpness) compared to above 100 Hz (low deformation, high sharpness).

5.3 Discussion of Haptics Explorations

The difference between the results found in the in-vivo study and the previous study by McIntosh et al. [19] might be attributed to the location of the stimulation. The study by McIntosh stimulated the fingernail, while here the stimulation occurred in the palm of the hand. The study by Verillo [32], however, also stimulated the palm of the hand, which makes this explanation unlikely. One might also argue that the deformation experience might be explained by the magnet literally being pushed and pulled. While this explanation is possible, we also find it unlikely as the stimulation mechanism was the same as used by McIntosh et al. [19]. Also the experience of deformation was not of a rapid pushing and pulling, but rather a slow, continuous sensation.

While the data is too preliminary to draw any strong conclusions beyond the observation that the results are unexpected, a reasonable argument can be made for the in-vivo magnet stimulating receptors differently to externally applied vibration: The sensitivity of *Pacinian cells*, which are usually associated with the perception of textures and vibration, peaks between ~250 Hz and ~300 Hz and decreases linearly above and below that [14]. This aligns with the measures by Verillo [32, 33] and the results of the study by McIntosh et al. [19]. *Meissner Corpuscles* are responsive to lower frequency vibration from ~5 Hz to ~50 Hz (sometimes also referred to as flutter-vibration [31]). They are similar in structure to Pacinian Corpuscles and typically associated with the perception of fine surface features, edges and contours [14]. The observed results would make sense if in-vivo vibrations were more strongly mediated by Meissner corpuscles than externally applied vibrations.

6 TOWARDS FUTURE APPLICATIONS

The implanted magnet provides opportunities beyond body-relative input and corresponding vibrotactile feedback. Co-located sensing and actuation is promising for conveying a variety of material experiences: recent explorations of haptic experiences such as textures [24], compliance [15], abstract mid-air sensations [28], or concrete mediated forces, such as penetrating a drop of water with a needle [23], not only rely on precise haptic actuation, but in same parts require precise tracking of human actions. If we wish to extend the humans perceptive horizon by providing information we usually do not experience directly, such as the presence of a WiFi signal or the passing of time, we could use similar schemes for encoding this information. Such encoding would require both measurement of movements, and precise actuation which can be achieved using the implanted magnet.

In anecdotal reports of sensations conveyed through implanted magnets, it is often highlighted that it takes weeks or even months before users can correctly interpret the sensations created when the magnet is stimulated by arbitrary electromagnetic fields in ones environment [11, 27]. This highlights that the permanent placement of the magnet might support the user in creating a mental model for interpreting the sensation.

7 CONCLUSION

We have demonstrated that an implanted magnet can provide input opportunities for HCI which are difficult or impossible to achieve using more traditional means such as an IMU. In terms of output provided through the implanted magnet, the clear qualitative differences between external and in-vivo vibration might potentially be leveraged to provide a wider bandwidth of haptic information to a user. The experienced strength of of low-frequency in-vivo vibration invites further investigation.

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