A Novel Human-Machine Interface using Subdermal Magnetic Implants

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Abstract— **This paper explores a novel tactile human-machine interface based on the controlled stimulation of mechanoreceptors by a subdermal magnetic implant manipulated through an external electromagnet. The selection of a suitable implant magnet and implant site is discussed and an external interface for manipulating the implant is described. The paper also reports on the basic properties of such an interface, including magnetic field strength sensitivity and frequency sensitivity obtained through experimentation on two participants. Finally, the paper presents two practical application scenarios for the interface.**

Keywords-magnet, implant, finger, man-machine, interface

I. INTRODUCTION

Man-machine interfaces today are primarily visual or auditory based and as a result can overload the human senses of sight and hearing. This has given rise to need for the use of alternative information channels [1], [2].

This paper explores the use of subdermal magnetic implants towards an alternative useful man-machine interface. The inspiration for this work came originally from reports in 2004 of self-experimenters being able to sense magnetic fields after implanting magnets into themselves [3]. To this time most work in the area has involved non-scientific self-experimentation. One role of this paper therefore is to provide an initial academic/scientific study as to the effects and possibilities of such implants.

Any movement of a magnet implanted into the hypodermis of the skin will trigger mechanoreceptors, and in some cases nociceptors, signaling to the central nervous system indications of movement or pain. The four primary mechanoreceptors are made up of two classes: quickly adapting (QA) and slowly adapting (SA) [4]. Of these, the QA receptors are the Pacinian corpuscle (PC) and the Meissner corpuscle (MC).

The PC receptors respond to vibrations in the frequencies of 200-300Hz [5] whereas the MC receptors are typically used to detect textures and pick up vibrations at frequencies of around 50Hz [5]. Being deeper within the skin, the PC receptor is able to obtain input from a wider range whereas the MC receptors are closer to the surface of the skin and so has a much smaller area of input available to them [4].

The basic idea in this research is to implant magnetic implants into fingertips and to stimulate the magnets into moving by means of electrical coils in the vicinity of (easiest is wrapped around) the fingertips involved. Different external effects due to attached sensors (e.g. ultrasonic) can then be used as initiating forces. Hence an external signal from an ultrasonic sensor (which is proportional to distance) can be used to excite a coil which in effect is an electromagnet and this in turn moves an implanted magnet within a fingertip which the participant can experience through their mechanoreceptors.

Both the PC and MC receptors are important in this research as varying the vibration frequency of the magnets realizes a method to input various signals to the body of high and low stimuli.

The SA receptors are the Ruffini Organ (RO) – also known as - SA2 (slowly adapting type 2 MR) and Merkel's Disc (MD) – also known as - SA1 (slowly adapting type 1 MR) [5]. The RO/SA2 receptor is used to detect stretching and tension on the skin and is not vital in this research [5]. However the MD/SA1 receptor responds to static change, i.e. touch and pressure, and is therefore pertinent here.

When the magnet is attracted to another magnet or caused to vibrate by an electromagnet the MC, PC and MD receptors can be used to detect the movement of the implanted magnet in relation to an external stimulant and hence these are fundamental to the research described here. Research questions clearly arise as to the fundamental links between the external initiating signal and the participant's experience and the sensitivity encountered.

In the following section a look is taken as to the selection of the implants employed and subsequent to this a description is given of the actual implant procedure involved. A description is then given of the interfacing involved and some experimental results are described and discussed. Finally some potential application areas of this technique are speculated on.

II. SELECTION OF MAGNETIC IMPLANT

Several factors need to be considered when selecting an implant magnet type.

A. Magnet type

Implantation is an invasive procedure and hence implant durability is an important requirement. Only permanent magnets retain their magnetic strength over a very long period of time and are robust to various conditions. This restricts the type of magnet that can be considered for implantation to permanent magnets. Hard ferrite, Neodymium and Alnico are easily available, low cost permanent magnets suitable for this purpose.

B. Magnetic strength

The magnetic strength of the implant magnet contributes to the amount of agitation the implant magnet undergoes in response to an external magnetic field and also determines the strength of the field that is present around the implant location.

The force between two magnets can be represented as follows:

$$F = \frac{\mu q_{m1} q_{m2}}{4\pi r^2} \qquad (1)$$

where F is the force between two poles, q_m1and q_m2 are the magnitudes of those poles, μ is the permeability of the separating space and r is the distance between them. Importantly equation (1) indicates that the force on the two magnets is proportional to the strength of the magnets. Consequently, the force applied on the mechanoreceptors surrounding the implant will also depend on the strength of the implanted magnet, as specified by Newton's Third Law.

In our case one of the two magnets in (1) is the electromagnet whereas the other is the implanted permanent magnet. Thus, increasing the strength of the implanted magnet allows the external electromagnet to achieve the same level of agitation using lower driving powers.

Neodymium is the strongest type of permanent magnet and hence is the type settled on for this research.

C. Size and shape

The size and shape of the magnet can have significant implications on the daily experiences of the implantee. Larger magnets require more intrusion in the body thus making it more likely to interfere with physical activities such as gripping objects. Smaller magnets can be less intrusive but may sacrifice the strength of the magnet. Shapes with sharp corners such as cubes and spheres concentrate force on a tiny area and can, as a result of the pressure, agitate and quickly destroy the surrounding tissue. Disc magnets reduce pressure by spreading it over a larger area but can be more prone to breakage.

D. Coating

The human body is a very hostile environment for implants due to the presence of oxidizing agents and due to the threat of rejection by the natural defense system. Similarly, an implant can present challenges to the body and may harm the body toxins. Hence, all implants need to be prepared for surviving within the body without causing it any harm. This usually involves enveloping the magnet with a biocompatible coating to make the implant inert. Silicon, PTFE and Parylene C are popular biocompatible coatings that are used in implantable RFIDs, pacemakers etc.

Although the team has previously been successful with silicon based implants of a different type [6], there have been numerous reports [7] of silicon coated magnetic implants causing problems due to failed and ruptured coating and hence were not considered despite its ease of availability. Parylene has had reports of problem-free experiences [8]. PTFE and Parylene were therefore preferred for this experimentation. Further, magnets coated in PTFE and Parylene are readily available.

III. IMPLANTATION

The glabrous skin on the human hand contains a large number of low threshold mechanoreceptors [5] that allow us to experience in great detail the shape, size and texture of objects in the physical world through touch. The highest density of mechanoreceptors is found in the fingertips, especially of the index and middle fingers (Fig 1).

Figure 1. Receptive centers of mechanoreceptors [5]

The mechanoreceptors in the hand are located in the dermis and subcutis layers (Fig 2). The Meissner corpuscles are located on the upper dermis and are primarily used in sensing soft touch. They are responsive to low frequencies and is most sensitive to 50Hz [9]. The Pacinian corpuscles are located deeper within the subcutis and are primarily used for sensing deep pressure and rapid changes. They are fewer in number than Meissner corpuscles but have a large receptive area. They are responsive to high frequencies and are most sensitive to 200Hz-300Hz [9].

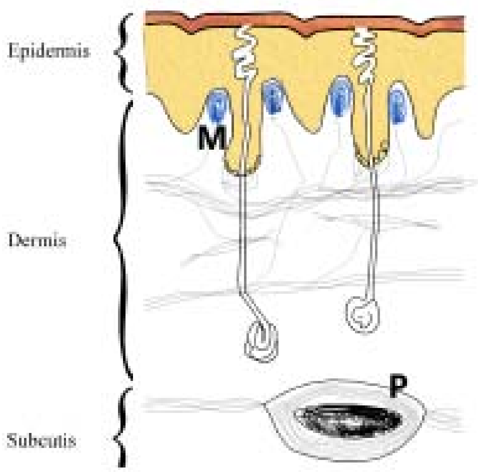

Figure 2. Vertical section through the skin [10]

The pads of the middle and ring fingers were the preferred sites for magnet implantation as the finger pads have a relatively large number of mechanoreceptors present [11] and the middle and ring finger are less important for gripping than the index finger and thumb. The handedness of a person can be used to decide which hand gets the implants as the less dexterous hand is likely to have a lower impact on daily life if something was to go wrong with the implants.

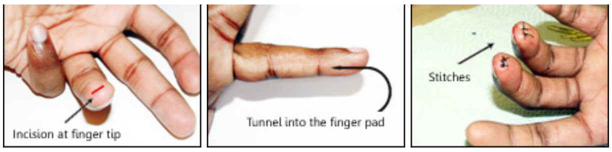

Figure 3. Incision-Pocket procedure

A. Implantation Technique

Implanting the magnet inside the body requires minor invasive surgery. The method that has been used in all known/reported cases of subdermal magnetic implants by self-experimenters [12] has involved the following procedure:

1) An incision is made near the target location of the implant. (Fig 3, left)

2) A tunnel is made towards the target location by cutting and separating the tissue. (Fig 3, center)

3) The implant magnet is inserted into the tunnel and pushed into its final position.

4) The incision wound is covered with band-aid or closed with stitches. (Fig 3, right).

Two 3.4mm diameter, 0.73mm thick disc magnets with 0.05mm coating of Parylene C were implanted into the ring and middle fingers on the left hand of author JH (Jawish) on 22 December 2008. The magnets were positioned so that the disc lay flat on the finger (Fig 4), thus reducing pressure that maybe applied during normal gripping and other activities. The wounds healed within 3-4 days and fingers were back to normal within 10 days of the surgery.

A further two magnets were implanted into the same fingers (middle and ring) of author IH (Ian)'s left hand on 21 July 2009 with similar recovery statistics.

Figure 4. X-Ray of magnet within the finger pad

IV. ELECTROMAGNET INTERFACE

A simple interface containing a coil mounted on a wire-frame was designed for generating the magnetic fields to manipulate the implanted magnet (Fig 5).

Figure 5. Interface coil

V. EXPERIMENTS

A number of double blind experiments were designed and carried out to test various properties of the interface. All experiments carried out also employed a magnet stuck to the skin using a dab of glue, on the corresponding fingers of the hand without the implant, as a control for comparing against the subdermal implant.

A. Field strength

Firstly, in order to assess the magnetic field strength generated around the implanted permanent magnet, tests were made on both the pad side and nail side of the finger with measurements taken using a gauss meter. The magnetic field strength on the surface of an identical magnet (external to the finger) was also measured for comparison.

Middle finger: 0.408mT (nail side), 12.96mT (pad side)

Ring finger: 0.561mT (nail side), 20.20mT (pad side)

Surface of the magnet – external to finger: 200.6 mT

It is worth pointing out here that the implantation had been carried out on the pad side of the finger, hence it was only to be expected that measurements taken on this side would realize a much higher magnetic flux value. As there was little difference between the two implantees – results are given here merely for the first recipient – JH.

B. Field strength sensitivity

Aim: To test the range of magnetic field strengths that the implant is sensitive to.

Method: A computer was used to administer samples at various magnetic field strengths, chosen at random between the range 0 Tesla and 1mT, by altering the current to the electromagnet. The upper limit was based on known sensory awareness to electromagnetic sources present in everyday environments. The subject responded to each sample with a "Yes" or "No" depending on whether a sensation was induced or not, respectively.

The results, shown in Figure 6 for JH only, were pretty similar between the two recipients. They indicate that magnetic fields were easily and correctly detectible in an accurate fashion from a very low field strength – in other words, the sensitivity of the finger pad area appears to be eminently suitable for such implantation.

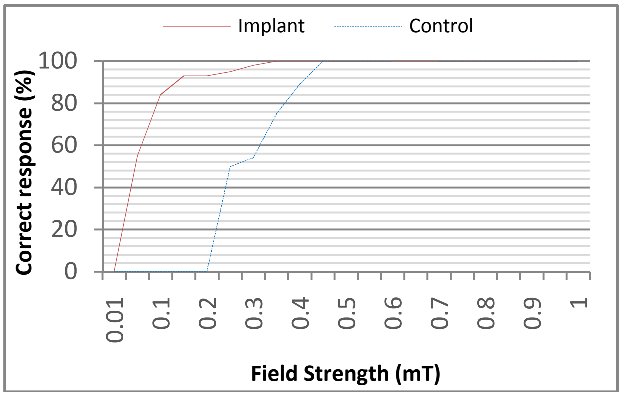

Figure 6. Sensitivity to field strength

C. Frequency sensitivity

Aim: To test the range of frequencies that the implant (and hence implantee) is sensitive to.

Method: The computer was employed to administer samples in 10Hz steps, between the range 0Hz and 1KHz. The upper frequency here is based on a quick test of sensory awareness to frequencies in multiples of 100 Hz. The (blindfolded) test subject was required to respond to each sample with a "Yes" or "No" depending on whether a sensation was induced or not, respectively. Breaks were taken periodically to avoid saturating the mechanoreceptors. The two participants were compared.

Figure 7. Sensitivity to frequency - a comparison of the two participants

Results of the frequency sensitivity tests are indicated in Figure. 7. The horizontal axis indicates frequency of stimulation whereas the vertical axis indicates the field strength necessary for stimulus recognition – working on a given maximum – this is therefore a subjective figure once away from the maximum value.

It is interesting to compare the two subjects in this case. Whereas field strength results had been remarkably similar – and hence only one set have been reported on - distinct differences can be witnessed in terms of the frequency sensitivity profile.

In terms of the magnitude difference it may be that because Ian's implant occurred much more recently so his sensitivity is much higher – twice as much at maximum. Conversely it may be that the results are merely due to the magnets being positioned differently or even simply to the fact that Ian is more sensitive in this region of the body. Further trials with other recipients are expected to be added here.

VI. APPLICATIONS

A. Ultrasonic ranging assisted navigation

This application scenario connects the magnetic interface to an ultrasonic ranger for navigation assistance for the visually impaired. Distance information from the ranger was encoded via the ultrasonic sensor as variations in frequency of current pulses, which in turn were passed on to the electromagnetic interface.

It was found that this mechanism allowed a practical means of providing reasonably accurate information about the individual's surrounding towards navigational assistance. The distances were intuitively understood within a few minutes of use and were enhanced by distance "calibration" through touch and sight.

B. Morse reading

This application scenario applies the magnetic interface towards communicating text messages to humans using an encoding mechanism suitable for the interface. Morse code was chosen for encoding to its relative simplicity and ease of implementation.

The application makes use of a computer with software to take text input, encode as Morse Code and send the dots and dashes via the audio line-out to interface. The dots and dashes could be represented as either frequency or magnetic field strength variations.

It was found that "reading" text messages using this approach was practical and, very intuitive. The achieved words-per-minute was limited due to unfamiliarity with Morse code and frequent need to look up reference tables. The best performance was achieved through frequency variation for representation – low frequency for dot and high frequency for dash. This research follows on that previously carried out with regard to communicating directly to/from the human nervous system [13].

VII. FUTURE WORK

The use of subdermal magnets opens up exciting possibilities for implementing 'virtual surfaces'. This would involve the finger being drawn across a flat featureless surface whilst textures and/or shapes are artificially generated by stimulation of the implant related to its position. Touch screen type technology could enable this, while research on capturing frequency components of surfaces has been investigated for use on haptic end effector devices [14]. This is now the subject of ongoing further investigation.

VIII. CONCLUSIONS

Subdermal magnetic implants are an interesting approach to man-machine interfacing. The work reported in this paper has gathered the data on the basic properties of such an interface and tested its practicality. The initial experimentation reported on here has demonstrated that subdermal magnetic implant interfaces can be a low power, cost effective and useful man-machine interface for establishing a new channel of information into the human brain.

Further work is required to investigate the effects of different types of magnets, different implant sites and different types of stimulating signals. In terms of communication with the device, the team also wish to investigate communication in parallel by means of two input signals being applied respectively to the two fingers at the same time.

Both recipients (mentioned here – JH and IH) of the magnet implants have retained them as functional units for ongoing experimentation. Neither has experienced any problems of any kind due to infection or rejection. Indeed an earlier recipient (Todd Huffman) has reported that his own implant, of the same kind, has now been successfully in place for well over 6 years, with no reported problems [15].

ACKNOWLEDGEMENTS

The authors wish to extend their gratitude to the University of Reading Research and Ethics Committee for giving their approval for this research project to proceed.

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