Force Attraction Pen: A Haptic Pen with Variable Attraction Force

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Abstract
We present the Force Attraction Pen, a haptic stylus that encourages the users to move in a particular direction by providing variable attraction force feedback based on their actions. The tip of the stylus is augmented with an electromagnet that can repel or attract the stylus to a metallic surface. By altering the polarity and voltage, we change the amount and direction of the force produced. The tactile expressions of the stylus may enable a higher grain of control during tasks such as tracing an image, performing selection, and other high precision tasks. In this paper we present the design and implementation of such a system, along with a formative study as a preliminary investigation into the haptic feedback generated by our system.

Author Keywords
Haptic Pen, Force feedback, electromagnet.

ACM Classification Keywords
H5.2 [Information interfaces and presentation]: User Interfaces.

Introduction
Styluses have long been used as input devices, with a focus on creative or artistic applications (e.g. drawing, handwriting, or calligraphy). The simplicity of the stylus form is well suited to these uses, but offers little

feedback to the user. Moving a stylus across a surface has no restrictions, with no inherent indication as to whether the stylus can be moved within a certain area or not. Current solutions to this problem involve cumbersome devices such as actuated arms (e.g. PHANToM devices).

Recently, a team of researchers have proposed dePenD [7], a system made of a magnet moving in 2D underneath a surface to control the tip of a regular ballpoint pen. Our solution, the Force Attraction Pen (Figure 1), is slightly similar to this, except that (1) the actuation mechanism is directly embedded in the pen via an electromagnet, thus allowing (2) our system to control the **strength of attraction or repulsion** through software based on the position of the pen. Figure 2 and 3 illustrate how our system can be used.

Figure 1: The Force Attraction Pen being used on a surface (in this case, a grid of magnets).

Figure 2: In this example, a "Delete All" button is surrounded by a repulsion boundary to ensure that a user must actively intend to click it. (1) The user moves freely in areas away from the "Delete All" button. (2) As the user moves the stylus closer to the "Delete All" button, the electromagnet in the stylus is polarised such that it is repelled from the grid of magnets. (3) This results in a repulsive force which offers enough resistance to prevent accidental clicking, but not so much that the user is unable to click the button if they mean to.

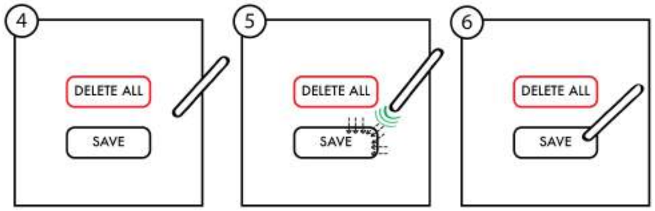

Figure 3: In this same example, the "Save" button is surrounded by an attraction boundary to encourage the user to save their work (4) The user moves freely in areas away from the "Save" button. (5) As the user moves the stylus towards the button, the electromagnet in the stylus is polarised such that it is attracted to the grid of magnets. (6) This results in an attractive force which is strong enough to guide the user's stylus towards the "Save" button, but not so strong that the movement is unintentional.

Related work

Our related work focuses on previous investigations into magnetic table tops and haptic pens. Providing haptic feedback via magnets has been explored in previous projects such as FingerFlux [6]. FingerFlux alters the polarisation of the surface rather than the device. The input resolution of their solution is dependent on the number of electromagnets in the surface, whereas the resolution of the Force Attraction Pen is dependent only on a single electromagnet.

Efforts have been made in the past to integrate tactile feedback into styluses, e.g. with Haptic Pen, which uses vibration and only provides one-dimensional feedback [1]. The authors of Haptic Pen only focused on feedback from active events such as clicking. wUbi-Pen [4] attempts to further broaden the types of feedback offered by styluses through vibration, impact, texture, and sound. As mentioned previously, dePenD [7] is a system made of a magnet moving in two dimensions underneath a surface to control the tip of a regular ballpoint pen. The magnet is mounted on a 2D plotter. This system only allows discrete feedback (attract or not attract), unlike the Force Attraction Pen. This work could also be seen as an extension of previous work into electromagnetic friction-based mice [3, 5]

Implementation

Final design
We used a 25N electromagnet and an infrared LED housed in a pen-like casing. The final input surface is a grid of twenty 32N neodymium magnets, arranged 14mm apart from each other in both directions. The infrared LED in the casing is used for location tracking, utilising a pre-existing solution involving a Wiimote [2], see Figure 4. Given the quantity and strength of the neodymium magnets we had, we found that a 14mm gap was appropriate. This was tested through a number of permutations in magnet count, size, and density. However, to create a more uniform magnetic field, an ideal system would use a higher density grid of weaker magnets.

As the user moves the Pen, polarity and strength values are sent to an Arduino, determined by the user's proximity to a boundary in our software. The Arduino controls the current provided to the electromagnet based on these values, using an H bridge (see Figure 4) to alter both the magnitude (generated magnetic field strength) and direction of the current (alternating the polarity of the magnetic field), consequently controlling the level of attraction or repulsion from the surface.

We ran the Force Attraction Pen at 25V and 0.25A for a total power consumption of approximately 6.25W. Using a more efficient electromagnet could reduce this, but in its current form, the power consumption is not necessarily too high to prevent commercialisation.

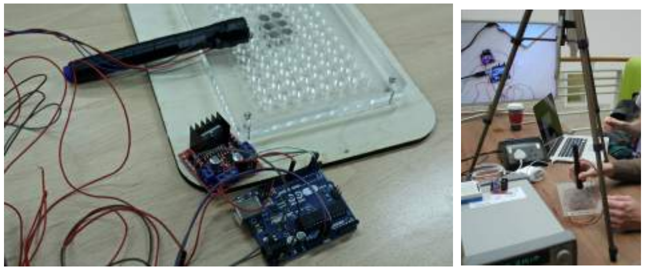

Figure 4. Hardware implementation and experimental setup

Alternative designs
We initially considered using a grid of electromagnets, with a permanent magnet in the stylus itself, as this would allow us to interface with the magnets individually, similar to controlling pixels in a display.

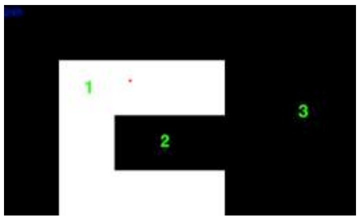

Figure 5. A sample maze attempted by the participants.

However, we deemed the power required for this number of electromagnets to be excessive. We also experimented with a large magnet as opposed to the grid. However, this proved infeasible, as large magnets are made of a ferrite core, which requires a much higher volume for the same strength magnetic field.

Formative study

We performed a preliminary study to gather initial user feedback.

Task

In order to test whether the feedback generated by the Pen was noticeable, and that the user could distinguish between the three modes of feedback (namely attraction, repulsion, and no force), a basic "maze" was generated to demonstrate each class (see Figure 5). The point of using a maze was to convey to the users obvious "good" and "bad" areas along with an associated goal, which acted as suitable demonstrations of the attractive and repulsive forces. However, the regularity of the magnetic field at this time is not sufficient for a fully-fledged maze and so a simplified model was used instead (Figure 5).

The maze was designed (1) to attract the Pen on the path, (2) to provide free-motion in non-path areas within the maze, (3) and to repel the Pen outside of the maze area. This design served to highlight the difference between our pen and other solutions, e.g. the Haptic Pen's vibration motor, in that our pen provides both magnitude and direction of feedback.

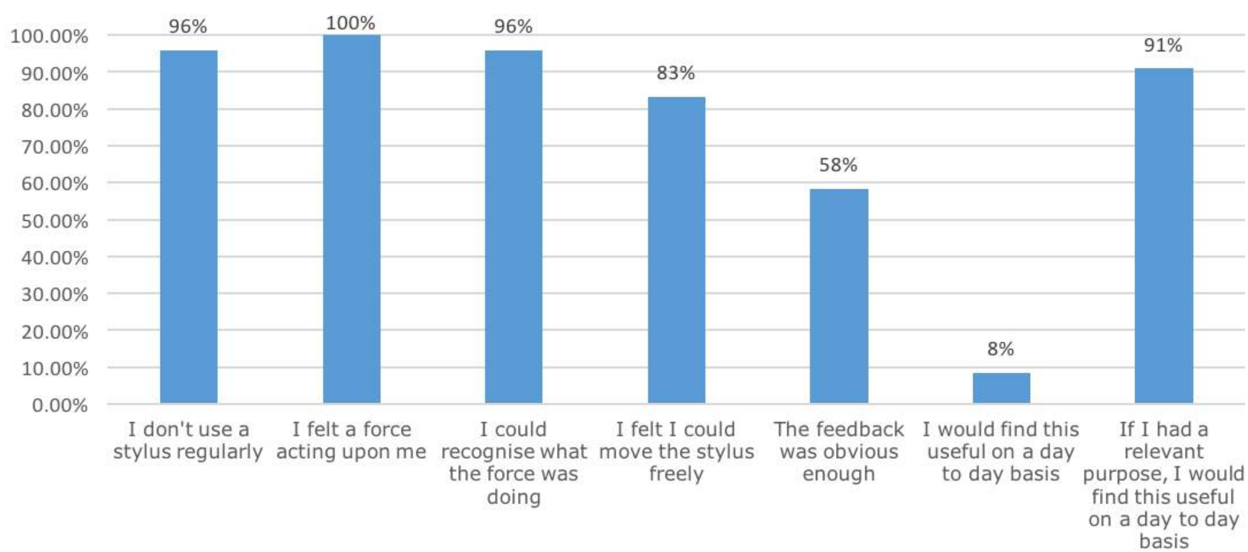

Figure 6. The range of responses to the interview questions following the task.

Interview
After completing the task, participants were asked a series of questions by an interviewer. This interview included questions about their familiarity with tablets and styluses. We asked participants to rate on a four point Likert scale whether they felt and understood the tactile feedback the Pen provided, and a number of questions addressing the strength and intuition of the feedback. The question "could you recognise what the pen was doing?" was asked, and if answered in the affirmative, we asked them to specify what their impression was. We finally asked them if they thought it would be useful on a day-to-day basis.

Participants
23 participants (16 to 25 years old), made of students, staff, and visitors to our Computer Science department, took part in this experiment.

Results
Figure 6 illustrates the responses to a number of questions. All of the participants felt a force acting upon them, with only one participant unable to distinguish between a repulsive and attractive force. 83% of participants found the force to be enough to indicate a response, but not so strong that they could not move the stylus as they wished.

The most divisive aspect was the desired strength of the feedback generated. Nearly 60% believed the feedback produced was sufficient, but the remainder believed that the force could be stronger.

Only 8% of participants believed it would be useful on a day-to-day basis; however, over 90% of those who disagreed with the statement believed it would be useful if their job involved a suitable task. Notably, all but one of our participants were unfamiliar with using a stylus, often commenting that their brief experiences with them in the past had been unimpressive. The fact that all but two of our participants would regularly use the Pen for a suitable task, coupled with the highly positive comments, indicates that the Force Attraction Pen could make styluses a more attractive method of input for certain tasks.

Discussion and future work
The Force Attraction Pen prototype has several limitations which we aim to address in future implementations. The mazes created for the experiment were relatively simplistic in nature. A higher resolution maze, and additionally a higher granularity of feedback, can be achieved with weaker magnets in closer proximity than the 14mm gap in the current implementation. If the ferrite core of the 25N electromagnet were removed, a steel sheet could be used with extremely high resolution, at the expense of requiring a larger current to achieve the same force.

In the current prototype, the Force Attraction Pen is run from a bench power supply. For a mobile version a battery would be required. This battery could be inductively recharged using the electromagnet; with a suitable isolation circuit between the DC current drive and AC power rectification circuit.

Whilst our study provided positive initial feedback, more in-depth studies could be carried out, looking at areas such as the spatiality of the interaction. Additionally, studies directly comparing the effectiveness of the Force Attraction Pen with related solutions, especially dePenD, could be carried out.

Conclusion

The results obtained from the initial Force Attraction Pen study are promising. The pen is attracted to and repelled from the touch surface and the magnitude of the force felt by the user can be programmatically controlled and tailored for different tasks.

The force feedback provided by the Pen received positive responses in our preliminary study. Whilst the user study suggests the Pen is not suited to everyday use, there is the potential for it to be of great use in a number of specialised tasks. These are tasks that could require a certain amount of guidance, such as learning to write, or tasks that could require frequent use of boundaries, such as selection in user interfaces or graphic design.

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