Haptic Mouse

Enabling Near Surface Haptics in Pointing Interfaces

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***Abstract*— In this study, we are introducing an innovative pointing interface for computers, which provides mouse functionalities with near surface haptic. It could also be configured as a haptic display, where users can feel the basic geometrical shapes in the GUI by moving the finger on top of the device surface. These functionalities are attained by tracking 3D position of a neodymium magnet, using Hall Effect sensors grid and generating like polarity haptic feedback using an electromagnet array. Where previously haptic sensations are felt only on top of the buttons of the haptic mouse implementations, this interface brings the haptic sensations to the 3D space.**

Keywords- pointing interface; near surface haptic feedback; tactile display; tangible user interface.

I. INTRODUCTION

Ordinarily, Pointing devices are used to control and provide data to the graphical user interfaces (GUI) using physical gestures [1]. Movements and commands sent by pointing devices are echoed on the screen through movements of the mouse pointer (or cursor) and other visual changes. Mouse is the most common and popular pointing device in use nowadays. Pointing interfaces have been in the use along with computers for almost four decades [9]. They were continuously improved by adding new features like dragging, scrolling, multi-touch and recently, attempts were made to include haptic feedback sensations. It was argued that the addition of haptic sensations will create excitement, realism, and an added natural feel for the users [10].

Haptic Mouse (Fig. 1) is introduced as a new type of pointing interface which will provide mouse interactions, haptic feedback and additional enhanced features. The key advantage of this system over other haptic pointing interfaces is that users are able to control the mouse cursor and feel haptic sensations from 4cm above the device surface. This will enable the haptic sensations in 3D space which will be a novel experience. Varied haptic sensations provided by this system can be felt like attraction, repulsion, and various patterns of vibrations. Those sensations can be easily configurable as feedbacks for different mouse commands using the driver software that we have developed.

The system provides attraction and repulsion sensations by changing the polarity of the electromagnets. Polarity of an electromagnet can be changed by swapping the positive and negative voltage supply to electromagnet using a controller circuit. When the neodymium magnet worn on the finger tips and the electromagnet array underneath the device positioned in the opposite polarity, (N – S or S - N) users feel an attraction towards the device surface. When those magnets are in like polarity (S - S or N-N) positions users feel the repulsion sensation.

Vibration sensations are initiated by setting up neodymium magnet and magnetic array in a like polarity position and then rapidly switching on and off the electromagnets in the array in certain frequencies. This rapid switching on and off dynamically changes the magnetic field it produces and affects the static magnetic flux developed by the neodymium magnet worn on the finger tips. While electromagnet is switched off, neodymium magnet drop towards the device surface, but when the electromagnet is switched on, the neodymium magnet rises due to the repulsion force felt as a vibration.

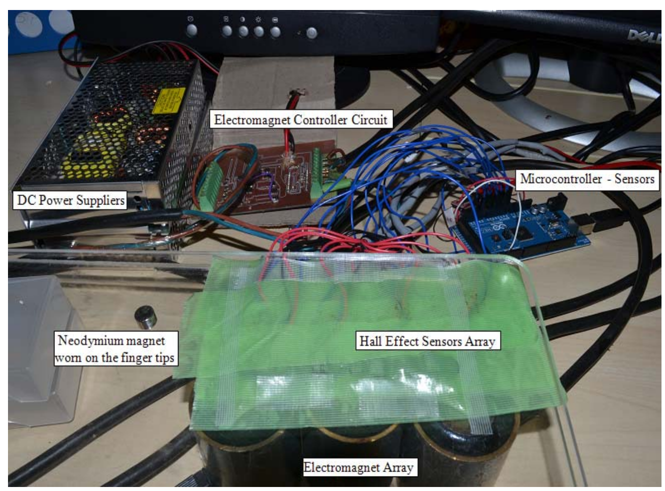
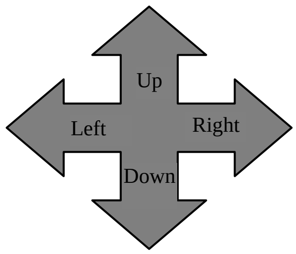
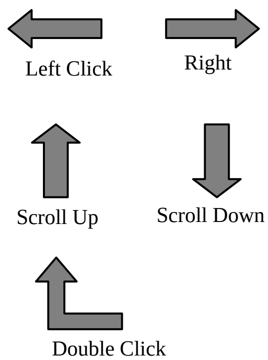


Figure 1. Haptic mouse system : User can move the neodymium magnet worn on the finger tip above the device surface and interact with the computer & sense haptic feedback for their inputs.

Haptic Mouse allows users to both control and interacts with the graphical user interfaces as similar to other pointing interfaces. Figure 2, shows the related gestures of 2D cursor movements and Commands of the system. Users can easily move the neodymium magnet attached to the finger tip on top of the device surface and control the GUIs. This can be visualized as a movement of an invisible mouse on the mouse pad.



2a. Haptic Mouse cursor movement gestures while North Pole is positioned downwards



2b. Haptic Mouse commands while South Pole is positioned downwards

Figure 2. movement and Command gestures of the Haptic Mouse

Furthermore, this interface can be configured as a low resolution haptic display. It is possible for a user to move his/her finger on top of the surface and sense the basic shapes of the objects on the screen. This is achieved by providing one vibration pattern once the user moves the cursor on top of the interested object and then change to a different vibration patterns when the cursor crosses the border of that object. Simple geometrical shapes which are bigger than 200 pixels * 200 pixels can be sensed and identified. As further developments, if there is an application which is restricting the user to a particular window, this device can use the haptic feedback and let the user know about the virtual boundary. The sensing of simple gestures will be helpful for users to increase their interaction with computers.

This paper will discuss the prior research and publications as related work, where the limitations and research gaps will be highlighted. The implementation details of the Haptic Mouse will be discussed extensively in the system description section while the results section will be presenting two technical experiments. The Conclusion & Future Work section presents the end users perspectives and the potential directions for further research.

II. Related Works

This section will discuss prior research with which the authors are arguing for the novelty value of the Haptic Mouse.

Liquid Interface [2] is a previous work of the authors which has provided the base technologies for the current pointing interface. It is an organic user interface that utilizes ferrofluid as an output display and input buttons embodied with musical notes. Using a matrix of Hall Effect sensors, magnetic fields generated by neodymium magnets worn on the fingertips are measured and then converted into signals that provide input capability. This input actuates an array of electromagnets and generates ferrofluid bubbles. By matching like polarities between the electromagnets and the neodymium magnet, haptic force feedback can be achieved. This system is limited to detect switch on and switch off type of interactions and used to develop a ferrofluid based piano.

FingerFlux [4] is an output technique which generates near-surface haptic feedback on interactive tabletops. It combines electromagnetic actuation with a permanent magnet attached to the user’s hand. FingerFlux provides enhanced features like, feel the interface before touching, attraction and repulsion, development of applications such as reducing drifting, adding physical constraints to virtual controls, and guiding the user without visual output. They have achieved the vibration sensations up to 35mm above the table. As limitations, Fingerflux could only works with table top computers. It uses camera tracking based sensing and the maximum vibration feeling height is comparatively lower than our system.

Tactile Explorer [5] is a device which provides access to computer information for the visually disabled based on a tactile mouse. The tactile mouse resembles a regular computer mouse, but differs in having two tactile pads on top that have pins that move up and down. These translate the data on the screen to tactile sensation. Tactile Explorer provides possibilities to find and select desirable on-screen information and study it with different options.

Microsoft tactile mouse [6] is a commercially available mouse implementation which combines haptic sensation and will be developed to support rich features of their latest operating system. This mouse has a touch sensitive strip which contains two buttons, one on each end. Haptic-feedback, in the form of vibration through the touch-sensitive strip, indicates which one of the three scrolling speeds has been selected. Both Tactile Explorer and Microsoft tactile mouse are mouse implementations combined with Haptic. It supports enhanced haptic interactions. However, operations and sensations are limited to the device surface. Furthermore, the haptic actuation is limited to a small area of the device surface.

III. System Description

Haptic Mouse contains three modules. They are Neodymium Magnet attached to the finger and Hall Effect sensors Grid, Software Interface Driver and Electromagnetic Array with Controller Circuit. These three parts are described in the following sections.

A. Neodymium Magnet and Hall Effect sensors Grid

The neodymium magnet attached to the finger tip allows users to actuate the Hall Effect sensors grid which is placed bellow the acrylic surface. Polarity of the neodymium magnet and various gestures made by the user are identified with the help of Hall Effect sensors grid. Neodymium magnet could generate higher density of magnetic flux compared to other permanent magnets. Therefore, the size and weight of the permanent magnet is important for this system to become smaller in order to fit it on the fingertip of the user.

We have used an Arduino [3] based microcontroller for processing the Hall Effect sensor readings. Analogue voltage readings of the sensors then converted to digital values using the built-in analog to digital converters and fed in to interface driver software to identify the gestures and commands. Hall Effect sensor grid used in this device is a 4*3 array (4 sensors along the X axis and 3 sensors along the Y axis). The space between two Hall Effect sensors were allocated 100 pixels. In physically, distance bettween two sensors is 2cm for X axis and 1.36cm for Y axis. All the sensor values recorded are represented as X,Y coordinates (0-300 in X axis and 0 to 132 in Y axis).

B. Software Interface Driver

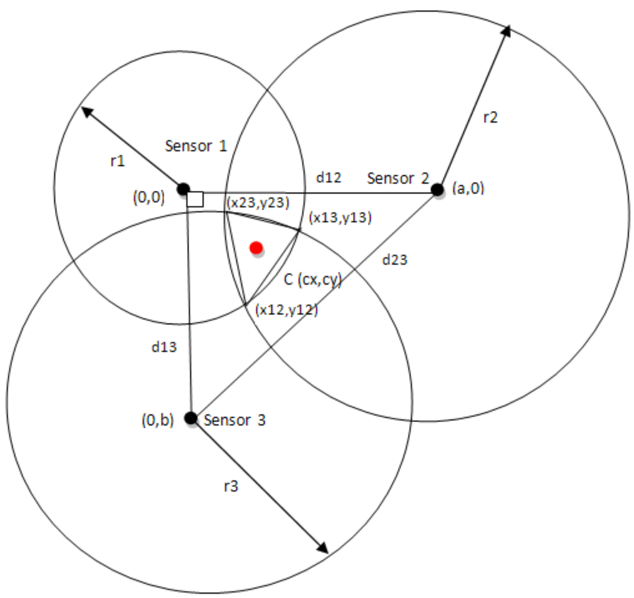


Figure 3. Based on the distance to the neodymium magnet from each sensor the position of the neodymium magnet is determined.

For the precise operation of the pointing device, there has to be a device driver which can integrate with the operating system. Therefore, using the Windows API we have developed a software driver for this device. This driver accepts the digital sensor readings from the microcontroller of the Hall Effects sensors grid as the input. When the North Pole of the neodymium magnet is positioned downward, sensor values are fluctuating in between 512 -1024 range and when the South Pole is downward, sensor values are changing between 0 and 512 of range. These sensor values are sorted in the descending order and if the magnet is North Pole downwards, software searches for the sensors in the grid where it received the maximum readings. Sensors which are nearest to the neodymium magnet, output the maximum values in this case. Based on those intensity values, relative distance to the neodymium magnet from the nearest three sensors is calculated.

The localization algorithm of the neodymium magnet is derived from the 2D trilateration technique. Trilateration is the process of determination absolute or relative locations of points by measurement of distances using the geometry of circles, spheres or triangles [13]. It is widely used for localization algorithms which can be found in GPS, RF based indoor positioning, navigation, and survey systems. As illustrated in Figure 3, the distances to the neodymium magnet is calculated from the expressions found in the table 1. These distances can form circles and based on their intersection position of the sensor can be located. To increase the probability for intersections we have multiplied the distances by a constant factor (which is greater than one) and made the three circles intersect most of the times. This forms a circular triangle [(x_{12}, y_{12}), (x_{13}, y_{13}), (x_{23}, y_{23})] and by finding the center the position of the neodymium magnet can be obtained. The mathematical method we derived is explained bellow.

Let us assume that all there circles formed by the readings are intersect with the each other. Therefore, the conditions for the circles to intersect are as follows.

$$r_1 - r_2 < d_{12} < r_1 + r_2 \quad (1)$$

$$r_2 - r_3 < d_{23} < r_2 + r_3 \quad (2)$$

$$r_1 - r_3 < d_{13} < r_1 + r_3 \quad (3)$$

By following Fewell's [12] method to calculate area of circular triangles, we can calculate the coordinates of the intersection points, (x_{12}, y_{12}), (x_{13}, y_{13}) and (x_{23}, y_{23}) as follows. By defining the origin of the coordinate system is placed at circle 1 and X axis is passed through the center of the circle 2,

$$x_{12} = \frac{r_1^2 - r_2^2 + d_{12}^2}{2d_{12}} \quad (4)$$

$$y_{12} = \frac{1}{2d_{12}}\sqrt{2d_{12}^2(r_1^2 + r_2^2) - (r_1^2 - r_2^2)^2 - d_{12}^4} \quad (5)$$

By assuming origin of the (x',y') system is located at the center of the circle 1 and x' axis passes through center of circle 3,

$$x'_{13} = \frac{r_1^2 - r_3^2 + d_{13}^2}{2d_{13}} \quad (6)$$

$$y'_{13} = \frac{-1}{2d_{13}}\sqrt{2d_{13}^2(r_1^2 + r_3^2) - (r_1^2 - r_3^2)^2 - d_{13}^4} \quad (7)$$

By transform back to the (x,y) coordinates system and obtaining (x_{13}, y_{13}),

$$x_{13} = x'_{13} cos\theta' - y'_{13} sin\theta' \quad (8)$$

$$y_{13} = x'_{13} sin\theta' + y'_{13} cos\theta' \quad (9)$$

$$sin\theta' = \sqrt{1 - cos^2\theta'} \quad (10)$$

$$cos\theta' = \frac{d_{12}^2 + d_{13}^2 - d_{233}^2}{2d_{12}d_{23}} \quad (11)$$

By assuming origin of the (x'',y'') system is located at the center of the circle 2 and x'' axis passes through center of circle 3,

$$x''_{23} = \frac{r_2^2 - r_3^2 + d_{23}^2}{2d_{23}} \quad (12)$$

$$y''_{23} = \frac{1}{2d_{23}}\sqrt{2d_{23}^2(r_2^2 + r_3^2) - (r_2^2 - r_3^2)^2 - d_{23}^4} \quad (13)$$

By transform back to the (x,y) coordinates system and obtaining (x_{23}, y_{23}),

$$x_{23} = x''_{23}cos\theta'' - y''_{23}sin\theta'' + d_{12} \quad (14)$$

$$y_{23} = x''_{23}sin\theta'' + y''_{23}cos\theta'' \quad (15)$$

$$sin\theta'' = \sqrt{1 - cos^2\theta''} \quad (16)$$

$$cos\theta'' = - \frac{d_{12}^2 + d_{23}^2 - d_{13}^2}{2d_{12}d_{23}} \quad 17)$$

$\theta'$and $\theta''$are the angles between the x axis and respective abscissas of the two additional coordinate systems. After calculating the intersections of the circular traingle we can obtain the center of the traingle where the position of the neodymium magnet exsists is as follows.

$$C_x = \frac{(x_{12} + x_{13} + x_{23})}{3} \quad (18)$$

$$C_y = \frac{(y_{12} + y_{13} + y_{23})}{3} \quad (19)$$

By finding the position of the neodymium magnet and comparing it with the next position, relative X,Y displacement can be calculated. Then these relative displacements are mapped to the last coordinates of the mouse curser position and moves the cursor to a new X,Y location.

In the case of identifying mouse commands, firstly, driver identifies the neodymium magnet which is placed South Pole downwards by reading the digitally converted values. If the magnet is South Pole downwards, software driver searches for the three minimum sensor reading values and determines the coordinates of those sensors. Then, the distance to the neodymium magnet from each sensor is calculated and its position is determined. The movement path of the neodymium magnet is tracked and if the path follows the gestures defined for the mouse commands, the driver activates the appropriate commands. As the final step, it updates Electromagnet controller circuit about the necessary vibration pattern which would eventually provide the user with the vibration feeling.

In the case of sensing the shapes, the driver software keeps a selected vibration pattern until the user move the mouse cursor on top of the interested object in the screen. Once the cursor is moved away from the object boundary, driver sends commands to the microcontroller of the electromagnet controller circuit to change the output frequency.

The sensors were capable to detect the the position accuratly more than 90% of points. Mouse curser position is only when there are two ajecent accurate neodymium magnet position readings exsists and then added the difference of the X,Y displacement to the previous cursor position. Therefore, the accuracy of the movement of the mouse cursor was improved. When the neodymium magnet is placed from 2 cm above the device surface, sensors were only capable to track position about 60% of the movements. In 4cm of hight above the device surface, the sensor array only able to track the position of the neodymium magnet less than 40% of the movements. In this hight, the curser movement became fairly difficult. Because interface driver have to cancell out inaccurate localization data and use only the accurate data to move the mouse pointer

C. Electromagnetic Array and Controller Circuit

This part of the system is made with six electromagnets, Magnet controller circuit and Arduino based microcontroller. As the current required by the six electromagnets is 13A [7], it becomes necessary to control the power supplied to the electromagnets via a relay circuit. This is because the voltage and current from the microcontroller pins amounts is only 5V, and 40mA respectively [3], which is insufficient to drive the electromagnet. To address this, the relay circuit acts as a mechanism that is able to switch on a much larger power to drive the electromagnets. For this power up electromagnets, six N-Type MOSFET [8] were used, one for each electromagnet. The connections to the MOSFET are configured such that the MOSFET will enter linear region and produce a drain current ID, of approximately 1.9A when the Arduino outputs a 5V signal to turn on the electromagnet. When the Arduino outputs 0V signal and the MOSFET turns off, the drain current drops to 0A which turns off the electromagnet as illustrated in the figure 4.

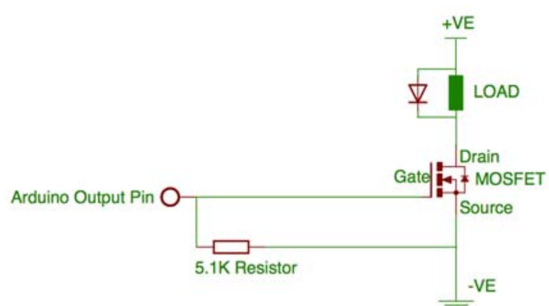


Figure 4. MOSFET based magnet driver circuit

By programming the Arduino to switch continuously from high to low and vice versa in rapid succession, a PWM output wave is produced which in turn causes the MOSFET to continuously turn on and off the main power supply like a relay, generating another PWM output signal with enough current to drive the electromagnet. A diode connected in parallel to the electromagnet to prevent the damage to MOSFET by the backflow of current. A resistor is connected in parallel to the Arduino Pin and acts as a safety turn off mechanism. This design was replicated 6 times to drive the 6 electromagnets.

The electromagnets require PWM to run. The purpose of PWM is to simulate an analog voltage by rapidly toggling a digital pin between on and off. Software Interface Driver sends a 20 character length data frame for every 10ms via the serial connection to the microcontroller to activate the required electromagnets. These data frames are interpreted as commands to turn on the electromagnets that correspond to the haptic feedback sensations felt by the user. Due to the limitations of the electromagnet, the maximum frequency that can be achieved is 100 Hz. Therefore, different frequencies between 5 Hz to 100Hz were used to provide different Haptic sensations to the users.

IV. RESULTS

Two technical experiments were carried out to measure the capabilities and limitations of the system.

A. Hall Effect sensor reading versus horizontal and perpendicular distances to the neodymium magnet

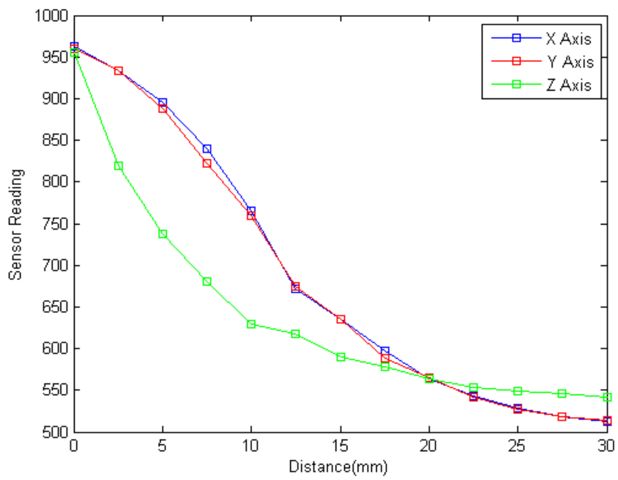


Figure 5. Plot of Sensor Output vs. perpendicular distance to the neodymium magnet

TABLE I. EXPRISSIONS TO DETERMINE THE DISTANCE BETWEEN THE HALL EFFECT SENSOR AND NEODYMIUM MAGNET BASED ON THE HALL EFFECT READINGS

Distance (mm)	**Deriving distance calculation expressions**		
	M	***C***	***Expression***
0 - 2.5	-12	963	Y = -12X + 963
2.5 – 5	-15.2	973	Y = -15X + 971
5 – 7.5	-22	1005	Y = -22X + 1005
7.5 – 10	-30	1065	Y = -30 + 1065
10 – 12.5	-37.2	1137	Y = -37.2X + 1137
12.5 – 15	-14.8	857	Y = -14X + 857
15 – 17.5	-15.2	863	Y = -15.2X + 863
17.5 – 20	-13.6	835	Y = -13.6 + 835
10 – 22.5	-8	723	Y = -8X + 723
22.5 – 25	-6	678	Y = -6X + 678
25 – 27.5	-3.6	618	Y = -3.6X + 618
27.5 30	-2.4	585	Y = -2.4X + 585

The objective of this experiment is to investigate the variation in the magnetic field strength vs. the distance of all thee axis and determine the strength of the magnetic field needed to be produced by the neodymium magnet to achieve the desired tracking ability. The experiment was conducted by positioning the neodymium magnet on top of the Hall Effect sensor and measure output readings at various distances in all three axis and results are shown in the figure 5. According to the results shown in figure 5, it is clear that sensor reading values are following nonlinear curves but along the X and Y axis the readings are approximately the same. Therefore based on the X and Y axis sensor readings we have derived set of equations to calculate the distance between the sensor and the neodymium magnet which is presented in the Table1. As a result these expressions provide the distance values needed by 2D trilateration based localization algorithm to obtain the position of the neodymium magnet.

B. Height of Haptic sensation is felt vs. Pulse Width Modulation for different voltage levels

The purpose of the experiment is to evaluate the relationship between the PWM and the maximum height that haptic sensations can be sensed above the device surface by running ellectromagnets in three different voltage levels. With the results, the PWM values and voltage levels that correspond to achieve haptic sensations in certain heights can be determined. In addition, the optimal PWM values that need to be set during actuation can be verified.

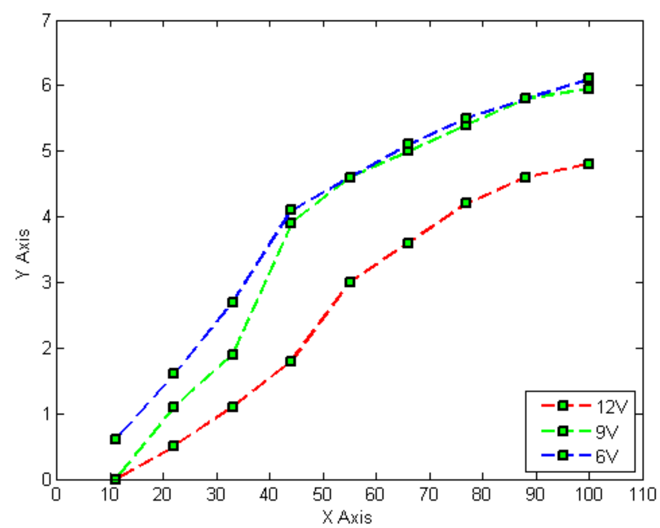


Figure 6. Plot of the maximum haptic sensation height achieved vs. PWM values.

As shown in Figure 6, the relationship between the PWM and the maximum height that haptic sensation can be sensed follows an increasing linear trend in all three different voltage levels, suggesting that the system is linearly controllable. However, it is noted that the haptic sensations were started to feel from PWM running on 11% for 6v and 9v mode but when electromagnets operate on 12v haptic sensations can be felt in 0.6 cm. Further, when the PWM values are between 90% and 100%, it is hard to notice the maximum difference of the actuation for 9v and 12 v. With these results we were able to provide haptic sensations up to 6.1cm above the device surface. However, by changing the type of the electromagnets, it may be posible to increase the height that heptic sensations can be felt.

V. Conclusion & Future Work

To conclude, in this paper we have presented a new type of computer interface which provides basic pointing interface functionalities with near surface haptic feedback up to 6 cm of height. The advantages and limitations of the system were also discussed with the related works. Using two technical studies we were able to show that system can perform in an adequate manner and has strong potentials to be improved. Haptic Mouse provides the base tools to combine magnetic field based devices with computers.

The haptic feedback resolution of the interface can be improved by using smaller electromagnets in larger numbers. When the device is used as a haptic display, an increased resolution would offer a better accuracy and representation of the virtual objects in the computer screen. Moreover, implementing variable friction for haptic interface using this technology will be an interesting research topic in future since variable friction has not been implented for touch sensitive haptic feedback systems.TeslaTouch [11] is the closests execusion of such haptic display .

This device has great potentials to be improved as an interface for visually handicapped who rely mostly on touch sensation. In orderto improve to this level of proficiency, this system is required to minimize the size of the electromagnets and increase the density of electromagnets packed in the electromagnets array which will provide a better resolution. This device could also be improved as an easy learning tool for children, which can be used to draw some basic shapes or characters that will enhance the interactive enjoyment.

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References

[1] Maria Virvou and Katerina Kabassi. 2002. Reasoning about users'actions in a graphical user interface. Hum.-Comput. Interact. 17, 4 (December 2002), 369-398.

[2] Kasun Karunanayaka, Jerey Tzu Kwan Valino Koh, Eishem Bilal Naik, and Adrian David Cheok, "Hall Effect Sensing Input and Like Polarity Haptic Feedback in the Liquid Interface System", in Proceedings of the international joint conference on Ambient Intelligence, AmI ’11. Amsterdam, Netherlands, 2011.

[3] Arduino. Arduino. [Online]. http://www.arduino.cc/en/

[4] Weiss, M., Wacharamanotham, C., Voelker, S., and Borchers, J. 2011. FingerFlux: near-surface haptic feedback on tabletops. In Proceedings of the 24th Annual ACM Symposium on User interface Software and Technology (Santa Barbara, California, USA, October 16 - 19, 2011). UIST '11. ACM, New York, NY, 615-620.

[5] Tactile Explorer, [Online]. http://www.tactile-world.com/

[6] El Saddik, A., Orozco, M., Eid, M., Cha, J., Haptics Technologies Bringing Touch to Multimedia, Series: Springer Series on Touch and Haptic Systems, 2011.

[7] Magnetech Corporation. Magnetech Corporation. [Online]. http://www.magnetechcorp.com/Opposite_Pole.htm

[8] MOSFETs, [Online]. http://www.falstad.com/circuit/e-nmosfet.html

[9] Engelbart, D. C. et al. (1968). A Research Center for Augmenting Human Intellect. (demonstration) Stanford Research Institute, Menlo Park, CA. http://sloan.stanford.edu/MouseSite/1968Demo.html

[10] A. El Saddik, “The potential of haptics technologies,” IEEE Instrumentation & Measurement Magn.,vol. 10, pp. 10-17, Feb. 2007.

[11] Bau, O., Poupyrev, I., Israr, A, Harrison, C. TeslaTouch: Electrovibration for Touch Surfaces. Proceedings of UIST 2010: ACM: pp. 283-292.

[12] Fewell, M. "Area of Common Overlap of Three Circles." Australian Dept. Defense. Oct. 2006. http://www.dsto.defence.gov.au/publications/4815/DSTO-TN-0722.pdf. Retrived January 10, 2013

[13] D.E. Manolakis, “Efficient Solution and Performance Analysis of 3-D Position Estimation by Trilateration, ” IEEE Trans. on Aerospace and Electronic Systems, Vol. 32, No. 4, October 1996, pp. 1239-1248.