Hall Effect Sensing Input and Like Polarity Haptic Feedback in the Liquid Interface System

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Abstract. Liquid Interface is an organic user interface that utilizes ferrofluid as an output display and input button embodiment. Using a matrix of Hall effect sensors, magnetic fields generated by rare-earth magnets worn on the fingertips are measured and are then converted into signals that provide input capability. This input actuates an array of electromagnets. Both Hall effect sensors and electromagnets are contained beneath the surface of the ferrofluid. By matching like polarities between the electromagnets and the rare-earth magnets, haptic force feedback by means of magnetic field repulsion can be achieved.

Keywords: Organic User Interface, Ferrofluid, Magnetic, Hall Effect.

1 Introduction

Building on the idea of previous ferrofluid artworks [2], and adhering to the characteristics of organic user interfaces (OUI) [1], Liquid Interface (LI) provides an input/output solution based on ferrofluid.

The system is composed of a pool of ferromagnetic liquid combined with a sensing and actuation mechanism. The sensing is achieved through the use of an array of Hall effect sensors. Actuation is produced by an array of electromagnets. Users can interact with the system by wearing magnetic rings. The magnetic ring position is detected by the array of Hall effect sensors, which in turn actuates the electromagnets and the audio server. The magnetic field of the active electromagnets morphs the ferrofluid to create "buttons". When a button is pressed the system generates a sound. The electromagnetic fields produced by the array repel the rare-earth magnets worn on the fingertips, giving the user a haptic response. Our previous work includes a detailed system description as well as describes a series of experiments to measure spike height versus current, distance of two adjacent spikes, transient state of the system and the static linearity of the system [4].

In order to discern the parameters in which Hall effect sensing would be most effective, a new series of experiments were conducted. These include experiments for understanding the vertical distance of rare-earth magnets from the surface embedded with Hall effect sensors, the horizontal sensing effectiveness

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to understand the quality of precision for cartesian coordination, and finally an experiment to characterize the effectiveness of the Hall effect sensors employed under the influence of multiple magnetic fields.

2 Experiments and Results

2.1 Experiment 1: Hall Effect Sensor Reading versus Vertical Distance

This experiment has been conducted using a Hall effect sensor and an electromagnet that generates an average flux density on the surface from 450 to 1950 Gauss for the range of 6V to 24V with 1.9 to 7.5A of electrical current. In the experiment we kept the power of the electromagnet at a constant voltage of 10V and a driven current of 2.44A, with the sensor on the vertical axis on top of the electromagnet. The sensor reading is measured versus the distance to the electromagnet. The value of the sensor output voltage taken is the mean value in one second. This plot shows that the sensor is most sensitive with respect to the vertical distance from 0cm to 3cm. When the distance is greater than 3cm, the change in output is much smaller. At larger distances, for example the values of 6cm and 7cm, the difference in voltage is only 0.011 volts. However such a small voltage difference is not detected by the micro-controller used for this iteration of the system.

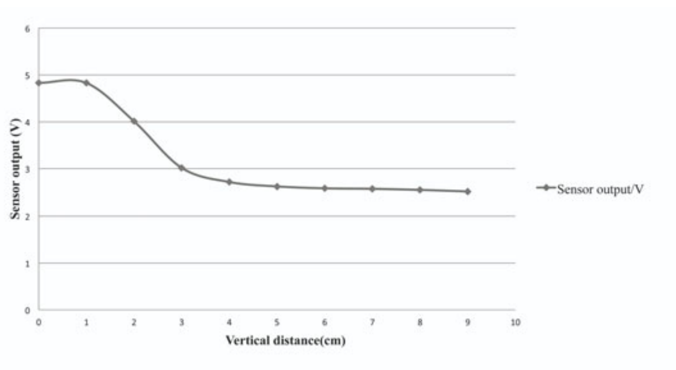

Fig. 1. Sensor output versus vertical distance

2.2 Experiment 2: Hall Effect Sensor Reading versus Horizontal Distance

Once more keeping the power of the electromagnet constant, the sensor is placed on the vertical axis of the electromagnet, at 2cm, since at this distance the sensor is most sensitive, registering the largest change in values with respect to distance moved. The plot shows that the sensor voltage is very close to 2.5 volt (zero field voltage) after 3.5cm displacement. Experiment 1 shows that the

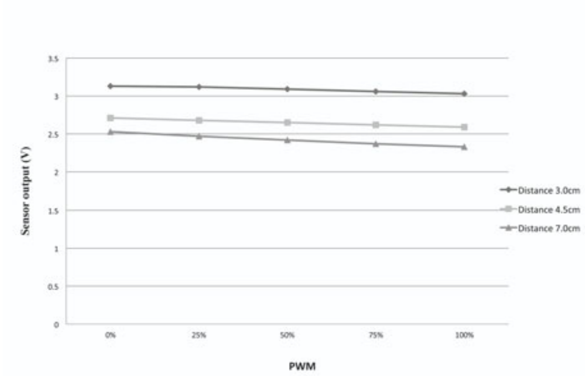

Fig. 2. Sensor output versus horizontal displacement

resolution of the system cannot distinguish any smaller change that within 0.02 volts, the magnetic field at 3.5cm and beyond are too small to cause a change in the microprocessor. This experiment shows that the magnetic field out of the horizontal area of the magnet is too small to be detected at the optimal vertical distance.

2.3 Experiment 3: Characterization of Hall Effect Sensor Readings under the Influence of Multiple Magnetic Fields

In this experiment the readings of the Hall effect sensor are measured to determine the influence of the magnetic fields generated by the electromagnets and neodymium magnets. The goal of this experiment is to determine which combinations of the two magnetic fields (electromagnet and neodymium) cancel one another.

The sensor is supplied the rated of 5V and is positioned such that it is in level with the top of the electromagnet and directly next to it. Its output is connected to an oscilloscope. A non-magnetic material at varying heights directly above the

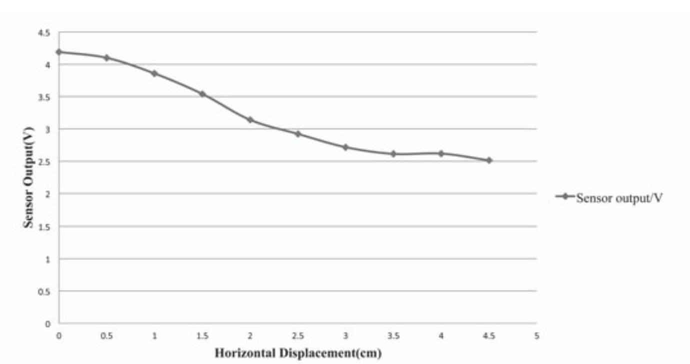

Fig. 3. Sensor reading values obtained for different distances versus PWM

sensor holds the neodymium magnet. Its pole direction is fixed, with the South Pole facing downwards. The reading of the steady-state output voltage of the sensor is recorded using the oscilloscope, while varying the height and direction of the neodymium magnet and the PWM input to the electromagnet.

First the default sensor value is taken without the neodymium magnet or electromagnet influence. Next, with the neodymium magnet pole at South Pole (facing down), the PWM values and distances are measured.Here the strength of the electromagnets field serves to decrease the reading of the sensor, whereas the position of the neodymium magnet field serves to increase the reading of the sensor. This results in a case in which the value of the sensor is unable to detect the presence of the neodymium magnet due to the electromagnet's field.

From the data we gathered, this occurs in the case when the distance of the neodymium magnet is 7.0cm. If the electromagnet is off, the reading is 2.53V, but if the electromagnet is turned on, the reading falls below the 2.50V neutral value. To circumvent this problem, we use like poles instead of unlike poles. This approach has the peripheral advantages of preventing the two magnets from attracting each other and preventing the neodymium magnet from picking up the ferrofluid as well as add haptic feedback.

3 Discussion

By using the results obtained in these three experiments, we were able devise an algorithm that performs accurate sensing of nearby magnetic fields for the Liquid Interface system. It is possible to track magnets worn on finger tips precisely as each sensor needs only to be able to detect a given magnet directly above it and will not be affected or disturbed by other magnets nearby. The sensitivity of our sensor is very effective in detecting movement within the 3cm range. It is able to detect even very subtle movements. The sensors are placed directly on top of each electromagnet while the user's fingertips carry strong neodymium magnets with like poles of each magnet/electromagnet pair facing one another. When the electromagnet is turned on, the sensor's output becomes fully saturated. If a neodymium magnet of the same pole is brought near to it, the sensor's output drops. This is detected as the presence of the user's hands.

The micro-controller firmware handles the sensing input, actuation output and communication with the server to produce music. Upon system initialization, the system first performs a calibration. This process takes up to 20 seconds. During the calibration each electromagnet is turned on to maximum power in order to find the offset value of the sensor. This offset value is then used in determining if a neodymium magnet (user's hand) is nearby when the value varies from the offset. To handle the sensing input, the micro-controller continuously polls the analog-to-digital converter modules at a frequency of once every 200 milliseconds. This is accomplished using a timer module and is to ensure that each analog-to-digital conversion is given sufficient time to complete. Complex gestures are handled by constantly storing interactions from the previous 2 seconds in the program memory. The stored interactions can then be interpreted as necessary to produce any gestures other than simple activation. To handle actuation output the micro-controller sets the PWM duty cycle for each output if necessary. Each time an interaction is recorded, the micro-controller sends a unique character to the server via an RS-232 connection. This is interpreted by the server for use in music production.

4 Conclusion

We outlined in this paper, three new experiments that enabled us to develop an input sensing mechanism based on the Hall effect. These include findings reveal the relationship between perpendicular and horizontal distances of the Hall effect sensor and the magnetic field generated by the electromagnetic array, the characterization of the magnetic Hall effect sensor readings under the influence of multiple magnetic fields, and the relationship of distance from the sensor versus PWM.

We also discussed the addition of haptic feedback facilitated by the repelling force of rare-earth magnets placed on the fingertips with like polarities matched to the electromagnets, thus providing an additional modality of feedback. This input accessory provides a means for users to interact with the LI system without the need to touch the ferrofluid, and still provides instantaneous tactile response.

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