A Reconfigurable Ferromagnetic Input Device

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ABSTRACT

We present a novel hardware device based on ferromagnetic sensing, capable of detecting the presence, position and deformation of any ferrous object placed on or near its surface. These objects can include ball bearings, magnets, iron filings, and soft malleable bladders filled with ferrofluid. Our technology can be used to build reconfigurable input devices – where the physical form of the input device can be assembled using combinations of such ferrous objects. This allows users to rapidly construct new forms of input device, such as a trackball-style device based on a single large ball bearing, tangible mixers based on a collection of sliders and buttons with ferrous components, and multi-touch malleable surfaces using a ferrofluid bladder. We discuss the implementation of our technology, its strengths and limitations, and potential application scenarios.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces. - Input devices and strategies.

Keywords: Reconfigurable input device, ferromagnetic sensing, malleable surface, tangibles, multi-touch.

INTRODUCTION

Input devices are a critical part of the computing experience, and so have understandably been the subject of much research, leading to many different forms and functions, from mice and keyboards, to joysticks, styli, touch screens and even tangible interface objects (for a detailed history see [2]).

In this paper we present a new type of *reconfigurable input device* [28] where, unlike common input devices such as mice, joysticks and touch screens, the physical form of the input device is freely constructed by combining together physical objects. Our novel hardware works by detecting changes in the magnetic flux immediately above the sensing surface. As a result, it is possible to detect the presence, changes in position, and deformations of any ferrous objects, including ball bearings, iron filings, magnets, and ferrofluid. In the latter case, we have experimented with a variety of malleable bladders where users can push their fingertips into the surface, pinch the surface or interact using the side or palm of their hands.

Our technology allows users to rapidly construct new input devices simply by placing ferrous objects ontop of the sensing surface. This could allow users to create a trackball-style device, built using a single large ball bearing, a tangible mixer that uses a collection of sliders and buttons with ferrous components, or even a multi-touch malleable surface using a ferrofluid bladder. We feel that the ability to change the physical interface not only makes for a more diverse user experience, but also allows the device to be tailored to particular application scenarios.

Figure 1: (left) hardware prototype which can sense ferrous objects such as (right) ferrofluid bladder, iron filings, large ball bearings and a box of small (2mm) ball bearings.

In the remainder of this paper, we present an overview of related work, followed by implementation details of our current design. We then discuss application scenarios for such reconfigurable input devices, and conclude with a discussion of future work.

RELATED WORK

There has been much research in detecting both touch and tangible objects, particularly in the context of interactive tabletops and surfaces. Early examples of capacitive sensing systems offering multi-touch capability are given by Lee [9] and more recently by Rekimoto [21], and commercial products by N-Trig [13]. Some of this work has demonstrated limited sensing of 'tagged' physical objects [21]. Resistive overlays and conductive foam, whose resistance changes when compressed, have demonstrated multi-touch and pressure sensing [3, 10, 22, 26] but cannot readily support objects beyond fingertips.

Optical approaches typically based on cameras and infrared (IR) illumination can be used to detect the location and shape of objects on a surface including fingertips [5, 11]. Some of these surfaces have been built using malleable materials [8, 12, 25, 28] to provide users with more tactile interaction. Other systems such as Illuminating Clay [17] offer users the ability to shape and manipulate real clay, which is simultaneously augmented with digital projection.

Other techniques for pen input and tangible object tracking include inductive sensing, as used by Wacom [30], Sensetable [15] and Audiopad [16]. A more advanced object tracking platform was used by Zowie Intertainment [23]. Smart Table [27] employed an array of Hall Effect sensors, capable of tracking the location and orientation of physical objects tagged with magnetic tape. Electromagnetic sensing has also been used to track active devices in 3D, e.g. Polhemous [19] and recently the Sixense game controller [24].

In this paper we present a new type of technology for object sensing on a surface. This work can be thought of as complementary to these existing techniques, and offers some unique properties for practitioners. Specifically, the technology can detect the presence and location of 'untagged' or passive ferrous objects, as well as the deformations caused within such objects.

PRINCIPLE OF OPERATION OF SENSOR COILS

Our hardware is based on the principle of ferromagnetic sensing, a technique that is used, for example, in electric guitar pickups. In our current design, we have adopted the use of a 2-D array of sensor coils, each capable of producing a measurable output.

The operation of the sensor coils is based on a loosely coupled magnetic circuit, formed by a permanent magnet, the sensor coil and the ferromagnetic interface object. At rest, the magnetic flux through the coil is constant and hence no voltage is induced in the coil. However, user interaction with the interface object causes disturbances in the magnetic flux which in turn induces a small voltage in the sensing coil; Figure 2 illustrates this effect.

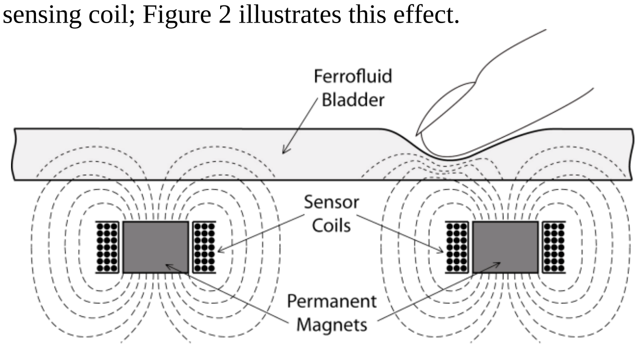

Figure 2: Cross section through sensor coils, showing disturbances to the magnetic field.

These changes in magnetic flux can be used to determine if and where a ferrous object is placed on the surface, and interestingly detect changes in the physical shape of the object. The key characteristic of the object is that it is ferrous or ferromagnetic. We have experimented with a range of ferrous objects including large ball bearings, an open-topped box partially filled with small ball bearings, deformable bladders filled with either ferrofluid or iron fillings, magnetic styli, and other objects containing magnets or ferrous components.

HARDWARE

This section provides an overview of the analogue sensor and digital interface boards, shown in Figure 3.

Figure 3: (a) Analogue sensing board, (b) digital interface board

Sensor Coils and Analogue Amplification Stage

Each sensor coil is 5mm high x 10mm in diameter and consists of 90 turns of 0.2mm enameled copper wire, wound around a small plastic former. In the centre of the former is a 5mm diameter neodymium permanent magnet, as shown in Figure 4.

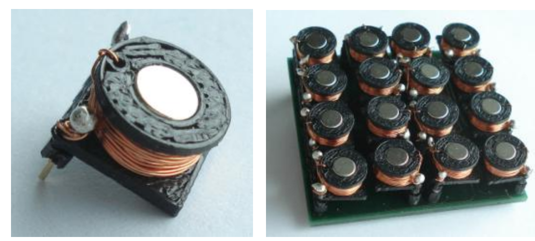

Figure 4: (a) Individual sensor coil, (b) 16 sensor coils mounted on the reverse of the analogue board.

The induced voltage in each coil is typically only a few millivolts, therefore each sensor coil has a dedicated amplification stage, formed using an instrumentation amplifier, as shown in Figure 5.

The current design of the analogue board supports 16 sensing coils, arranged to allow multiple boards to be tiled together; we have initially tiled 4 boards, which provides a total of 64 sensors spaced equally on a 12.5mm pitch covering an area of 100mm x 100mm.

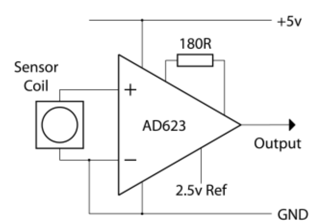

Figure 5: Schematic of amplification stage.

Finally, it is also worth noting that the polarities of the permanent magnets are currently arranged in a checkerboard pattern. This approach was taken as it leads to a more even distribution of fluid when a ferrofluid bladder is used as the interface. A simple polarity mask is subsequently applied in software to compensate for this arrangement.

Digital Interface

The amplified sensor output signals are fed, via a short ribbon cable, to a digital interface board which includes a 16-channel 12-bit analogue-to-digital converter (ADC). The digitized sensor values are then sent to a host computer via a USB interface. An onboard PIC microcontroller controls this process, including both the input multiplexing of the ADC and formatting of the data packets, which are sent out by a serial UART chip at a rate of 55HZ. Each digital interface board and sensor array draws little power, on average 27mA. Although not currently implemented, the microcontroller also provides the possibility for additional logic to be included at the hardware level, such as initial processing of the digitized sensor data.

Data pre-processing

A custom C# library running on the host computer receives the sensor data from multiple interface boards and aggregates the values into a single array. To provide applications with clean and reliable data, a number of pre-processing stages are performed. Firstly, quiescent background values, sampled for each sensor, are subtracted from the raw sensor values. Secondly, a noise threshold is applied to the sensor values to discount small sensor readings. Next, a polarity mask is applied to the data to compensate for the checkerboard arrangement of magnets mentioned above. Finally, the data is upsampled by a factor of 3 using bi-cubic interpolation before being made available to other applications via a shared memory buffer.

APPLICATIONS SCENARIOS

To demonstrate the utility of our technology, we have created two sample applications. A virtual sculpting application whereby indentations within a block of virtual clay are made as the user displaces a deformable ferrofluid bladder – providing a tactile feeling of molding or sculpting of the virtual clay (see Figure 6). As an alternative, iron filings can be used to give a looser, drier interface similar to sculpting sand or grit. Also, small hand tools such as scrappers and trimmers can be augmented with magnets to enable them to be used during the sculpting process [18].

Our second application, a simple synthesizer, created in Max/MSP, illustrates how the variation of surface material can create differing interfaces which share characteristics of analogue musical instruments. The ferrofluid bladder must be struck by the musician to excite the sensors and create sound, the vigor of this strike affecting the sound produced; this is analogous to striking a piano key. In contrast, a large ball bearing when pulled, rolled, and lifted across the surface allows the user to alter the nuances of a continuous drag interaction; akin to a bow being pulled over the string of a violin. Interestingly, qualities of instruments which do not require direct physical interaction, such as the Theremin, are possible to simulate by moving magnets above the sensor grid.

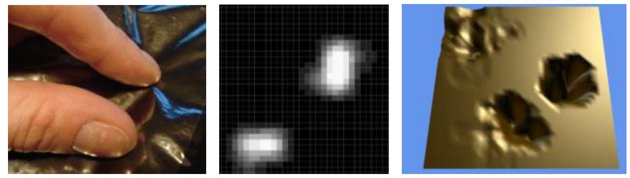

Figure 6: (a) A user interacting with the ferrofluid bladder, (b) visualization of processed data, (c) virtual representation in the sculpting application.

These are however simple applications and we feel our sensing technology is generic enough to be used in many other contexts. What particularly excites us is the ability to use such a sensor as a reconfigurable input device. For example, with the ferrofluid bladder placed on the sensor, we create a malleable multi-touchpad which, for example, could be used by artists to manipulate 3D objects. By sensing any ferrous object, we can create tangible experiences, such as board games where ferrous physical game pieces can be sensed and augmented with digital feedback, without needing to be explicitly 'tagged'. Physical sliders with ferrous handles or physical buttons with ferrous components can be placed on the surface to create a tangible music mixer. The location of the handles or whether the buttons are pressed can be reported by the sensor, alongside the position of the objects.

Another property of our device is that it can sense the movement of ferrous objects both on and above the surface. For example, a large ball bearing can be used as a novel trackball input device, which can also be lifted up off the surface, for example to navigate in the Z-axis in a 3D game, as well as move forward/backward/ left/right. In addition, we can support stylus interactions by employing pens with ferromagnetic tips.

FUTURE WORK

There are a range of interesting directions for the further development of our technology, including applications which exploit above-the-surface sensing. Another area we are investigating is extending Bennett's BeatBearing [1] interface to create a tangible electronic music sequencer. Arranging the device vertically also opens up new possibilities, for example, an augmented whiteboard could sense the presence of ferromagnetic tangibles.

Secondly, we are investigating the potential for ferromagnetic sensing on non-planar surfaces; for example, small bladders of ferrofluid incorporated into a joystick could enable interaction through the intensity of a user's grip. In addition, our early experiments suggest that our system, coupled with ferrofluid, could be utilized in the creation of flexible and moldable interaction surfaces.

A final key area we are investigating is the combination of our sensing technique with an array of electromagnets to create an actuated physical interaction surface [20]. Results from our initial experiments with the actuation of ferrofluid, and previous work [4, 31], suggests the possibility of providing haptic feedback to the user. In the context of our sculpting application for example, actuated areas of ferrofluid could be used to indicate the shape of the virtual model. We could provide force feedback to the trackball input device or even actuate the ferrofluid underneath a touching finger. Alternatively, raised areas of the physical interaction surface could represent interface elements such as buttons, which unlike [6] and [7], are reconfigurable. Finally, sensing could be combined with the movement of solid ferromagnetic objects in a similar manner to the Actuated Workbench [14].

CONCLUSIONS

We presented a novel input device based on ferromagnetic sensing. The sensing surface of the device can be overlaid with different materials to provide distinct forms of interaction. Ferrofluid, for example, presents the user with a tactile feeling of interacting with a compliant gel like material, whilst ball bearings allow the user to interact through the direct displacement of physical objects which can be handled and lifted from the surface. This is a generic sensing technique, which we hope will be utilized by practitioners to develop novel input devices and applications.

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