SweepScreen: Sweeping Programmable Surfaces to Create Low-fi Displays Everywhere

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Abstract
SweepScreen is a digital paintbrush enabling the printing of low-fidelity lasting free form images. It is made of a row of electromagnets that turn on and off in a specific pattern while the user sweeps across the magnetophoretic surface, thus producing a custom image. Despite being low fidelity (black & white, static images), SweepScreen works on passive surfaces to create bistable images. It can therefore replace physical paper on notice boards, packaging or other labeling systems. It can also be used to fast prototype static free form displays to better understand interactions with new display form factors. This could be of interest for the shape-changing community which struggles to access manufactured free form displays. We present our concept and proof-of-concept prototypes that can print images on flat free form surfaces. We show the results of performance evaluations to test the viability of the device and finish with a discussion about current limitations.

Author Keywords
Free Form Displays; Printing; Fast Prototyping; Magnetophoretic; Shape Changing Interface.

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

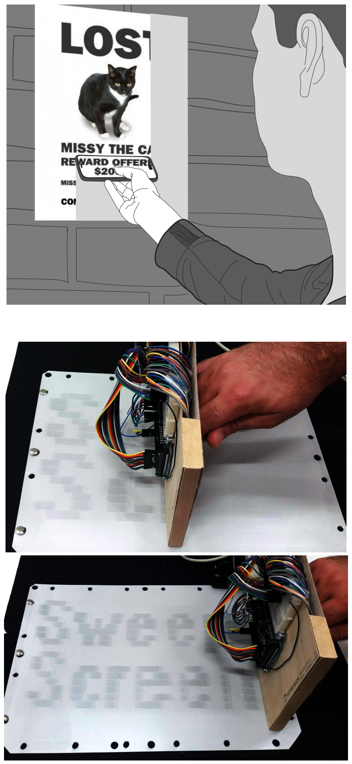

Figure 1. SweepScreen is a digital paintbrush for printing low-fidelity, bistable, free form images, e.g. a user sweeps it onto a notice board to leave a message. Our prototype creates a low-resolution image via a row of 20 electromagnets and an optical sensor.

Introduction

“Display everywhere in any shape” is a vision of future interactive systems shared by many researchers (e.g. [26][24]), but despite some progress made by manufacturers, the technology is still confined to research labs or yet to be developed. This is a substantial issue for researchers as technological advances drive most research on new paradigms. Without working prototypes, researchers struggle to envision uses of technologies, limiting their uptake and stifling scientific understanding of how users interact with them. A solution is to use a projection system, although this is not always ideal as relying on ephemeral setups (mounted projector) is dependent on lighting conditions and often has casting shadow issues.

We propose SweepScreen; an alternative solution to printing lasting free form images. SweepScreen produces images on magnetophoretic surfaces when swept across (Figure 1). These surfaces contain tiny cells filled with an opaque white liquid containing black magnetic particles. When a magnetic field is applied it draws the particles to the top, thus showing a “black pixel”. SweepScreen contains a row of electromagnets that, when moved across a magnetophoretic surface, flash in a specific pattern to create a custom image.

Although, due to manual sweeping, SweepScreen can only create black and white and static images, it has many advantages. The image created is passive and electronic-free, can be flexible and is bistable, i.e. the image lasts even with no power supplied. These advantages have many applications such as creating digital paper on-the-go or fast prototyping of static free form displays to conduct empirical evaluations. These evaluations focus on extending our understanding about interaction with new display form factors.

Related work

Display technologies

For practical reasons, digital displays are manufactured in a rectangular form, however, there is a current trend towards free forms displays [4][5]. These displays are based on technologies such as Liquid Crystal Displays, Organic Light Emitting Displays (OLED), electrophoretic displays (Eink) or magnetophoretic displays, with the latter two being closely related to our work.

Eink [3][7][9] consists of thousands of microcapsules located on a substrate. They contain positively charged white particles and negatively charged dark particles dispersed in a clear liquid and when a negative electric field is applied, the white particles move to the top of the capsule to create a white spot (respectively black). The microcapsules are bistable, i.e. no energy is needed to maintain their state. Eink displays cannot achieve the speed and colour fidelity of OLED ones, but they are flexible, bistable and energy-efficient which is ideal for displaying monochrome images or text.

Magnetophoretic displays are made of cells sandwiched between two substrates. The cells and filled with an opaque liquid that contains black magnetic particles. When a magnetic source (e.g. a pen in Magna Doodle toys) is moved on the surface, the particles are attracted to it and move to the top of the cell, thus creating a black pixel. The invention goes back to 1974 when Lee [13] presented a prototype where images are formed by subjecting the display to pre-configured stamps. Such displays use non "exotic materials", are easy to manufacture at low cost and in large quantity and can display stationary images with no power [13]. Xerox published a patent for a specialized ink using a similar principle [10] and indicated that the ink could be used to create displays, although no detail is given.

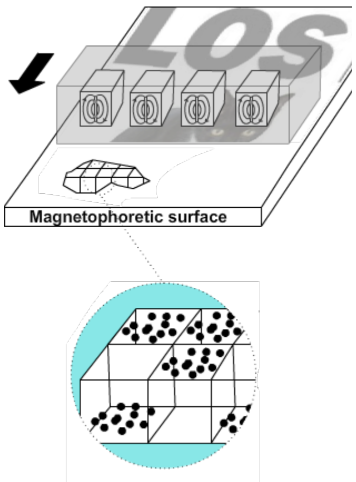

Figure 2. The row of electromagnets allows an image to be created on the surface which is filled with cells that contain a white opaque liquid with dispersed black magnetic particles.

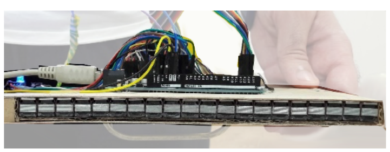

Figure 3. Our prototype consists of a row of 20 electromagnets and an optical sensor linked to an Arduino board.

The main limitation with these technologies is that they are confined to research labs, not easy to manufacture and also relatively difficult to program. In this paper we use a similar technology but innovate in the way it is accessed and utilised, i.e. as a brush. In particular, we focus on static displays rather than digitally controlled.

Fast prototyping of displays

Simulating digital displays can be done via projection ([6][19][23][18][26][9]). Such systems are ephemeral (need power), require an unobstructed path between projectors and surfaces (casting shadows), and are not reliable in certain lighting conditions. Other works combine rectangular displays ([15][3][1][11]), but the topologies are limited and the visuals hindered by the screen borders. Alternatives include 3D printed optics [2], thin-film electroluminescence [16], thermo-chromic displays [14], or LED-Matrix displays [7]. Their downside is the time required to build them (although reduced complexity in manufacture), and the relative difficulty in controlling them. Work has also been undertaken towards printing static images, e.g. Graffiti fur [6], which involves the raising or flattening of fibers in a fur to create a drawing. Sweepscreen goes one step further by creating touchable surfaces so users can manipulate them without the risk of flattening fibers. Other commercial handheld printers use traditional inks to print text anywhere (e.g. [27][28]).

SweepScreen concept

SweepScreen (Figure 2) is a device that is held in the hand and swept over a magnetophoretic surface (previously described). The device consists of rows of electromagnets combined with a movement sensor and when the device is moved, the electromagnets flash with a certain pattern to create an image on the magnetophoretic surface.

Despite being low-fidelity (black and white and static images), SweepScreen has several advantages: (1) the image is passive and electronic-free, (2) it is bistable, i.e. it can display stationary images with zero power consumption, (3) it can have different shapes, i.e. it is not limited to rectangular and flat topologies and (4) it is flexible and relies on simple materials. We also believe that magnetophoretic surfaces can be (5) easily manufactured using a modified 3D printer to print honeycomb structures that are subsequently filled with a white opaque liquid containing magnetic particles.

Figure 2 illustrates how SweepScreen is used. It can be clipped onto a phone on which the user first draws an image. By sweeping the device onto a surface it prints an image. There are many ways in which SweepScreen can be also used as digital paper instead of physical paper, thus reducing the paper waste and filling in the gap of our craving for the affordance of physical paper [20]. It can also be used for rapid prototyping static free form displays as explained previously.

Proof-of-concept prototype

Our prototype is made of a row of 20 electromagnets mounted onto a structure (Figure 3). It creates images on flat free form surfaces by tracking the position of the device and flashing the electromagnets appropriately.

We took apart a Tomy Megasketcher drawing board toy for the magnetophoretic surface (32x25 cm). The cells that contain the tiny iron particles are smaller in size than the Magna Doodle toy, thus the image has a higher definition (Figure 6). 20 electromagnets were disassembled from electromechanical relays from TE Connectivity. Each can be powered by a 5VDC power source with 0.037A, which fulfils the requirements needed by the Arduino Mega 2560 microcontroller (each digital output operates at 5VDC and can provide

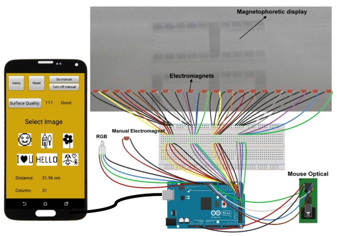

Figure 4. Implementation summary.

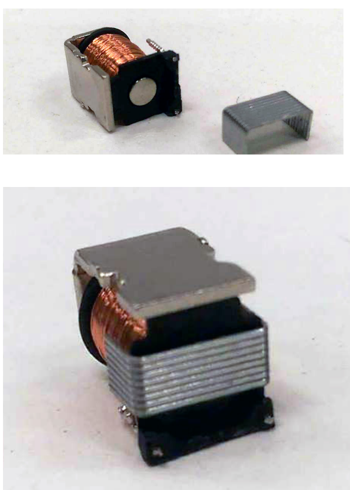

Figure 5. Unmodified relay electromagnet (top); modified relay electromagnet (bottom).

up to 40mA of electric current). When the Arduino provides an electrical current to the pins connected to the electromagnets, they produce a magnetic field sufficient enough to attract the particles to the top of the magnetophoretic surface.

We added ferromagnetic staples onto the top of the iron core of the solenoid due to the following reason: as the relay electromagnets are enclosed in plastic with a centered circular iron propping from underneath them (Figure 5-top), if two electromagnets are neighbours, there is a gap between the two circular cores and when the device is swept, any particles of the magneto-phoretic surface that are within this space will not be influenced by a magnetic field, resulting in a dotted image. To overcome this issue, the iron cores were covered by ferromagnetic staples (Figure 5-bottom), thus, the electromagnets can apply a magnetic field with a size equal to the size of the staples (9 x 5mm).

An Arduino Mega 2560 board controls the input signals from the optical sensor that estimates the position of the device. It causes the electro-magnets to flash in a pattern. We used an optical mouse sensor (ADNS-5020, 1000 dpi), as it is cheap, simple and highly accurate. Figure 4 shows our UIs created via RoboRemo, which allows an Arduino to be controlled via Bluetooth, internet or USB. We used a USB connection so that the Arduino is powered by the smartphone and the prototype standalone. The device has a RGB LED to indicate the state of the “sweeping” (red = image selected, green = image being drawn, blue = end).

To erase the surface, we changed the polarity of the electromagnet, but this did not alter the attraction of the particles as they are made from iron and are attracted to both poles. We therefore erased the screen by turning it over and printing a black image.

Performance evaluation and considerations

Resolution: We added ferromagnetic staples to widen the size of the magnetic field created by the electro-magnet. The height of a pixel is 9mm; however, its width depends on how long the electromagnets remain in the same state. This duration can be changed as a factor of the optical sensor movement, i.e. the width of a pixel can be adapted to the user’s desires and can shrink or stretch the image. Figure 7 shows that at low durations, images are not visible as the electromagnets draw the columns in dimensions smaller than their size. In order for the image to be printed with its normal size (square pixels), the duration must be ~10mm. In the case of the 15mm or 20mm, the image is stretched.

Sweep speed: We investigated how fast the image can be painted. We used a pixel size of 9 x 10 mm and printed the world “hello” at different speeds using a stopwatch. We started the timer at the beginning of the sweep and ended it when the LED indicator turned blue. Figure 8 shows that images were clearer at 7.1 seconds, i.e. 4.5 cm per second. This speed seems reasonable in our informal tests, but further studies need to investigate this in depth. The sensor estimates the distance at faster *speeds,* but the actuation of the electromagnets is not fast enough to attract the particles of the image. As a result, the magnetic field is insufficient, and the image is low contrast.

Energy consumption: The smartphone provides the required power to the Arduino without the need for an external power source. The electrical current that each pin provides to a single electromagnet was 37mA. In the worst-case scenario, all the electromagnets are turned on simultaneously and the total amount of energy consumed is 3.7W. This power consumption is very low and can be provided by a conventional smartphone, providing evidence that the device can be portable and energy-efficient at the same time.

Robustness: The magnetophoretic image has a plastic transparent layer which makes it bendable and flexible without affecting the image (Figure 9) and there was no degradation of the image after several days. The black particles are light compared to the thickness of the liquid and the gravity is not enough to pull them to the other side. What is written will remain undisturbed.

Conclusion and future work

We present SweepScreen, a digital paintbrush enabling low-fidelity, lasting images to be printed on free form surfaces. We presented initial evaluations showing that the device can draw a clear, high-contrast, full-screen size picture at a minimum speed of 4.5 cm per second. It has low energy consumption and can be easily attached to a phone as a clip-on gadget. The image is electronic-free, passive and bistable as well as totally reusable and flexible. Our prototype has a limited pixel size and further design iterations may increase the image resolution. An improved version would clearly not compare to the resolution of conventional displays, but this is not our aim. It would be interesting to allow the user to print in multiple parts in order to create an assembled picture. This additional functionality would also need improvement in user feedback (where to print, how fast to print and how users understand how to use the technology). Also note that our evaluations were done using a specific type of magnetophoretic surface and that other surfaces might provide different results. The optical sensor could also be replaced by a camera to automatically detect the parts of the image already printed in order to adapt the flashing pattern of the electromagnet accordingly. We want to explore how to print grayscale images by varying the magnetic field intensity. We also wish to study how a device with a user driven update rate would be accepted by a large population of individuals. Finally, we are also interested in exploring how to 3D print magnetophoretic structures, both surfaces and 3D objects, via a modified 3D printer and how the design of SweepScreen can be changed to allow for printing on non-flat surfaces.

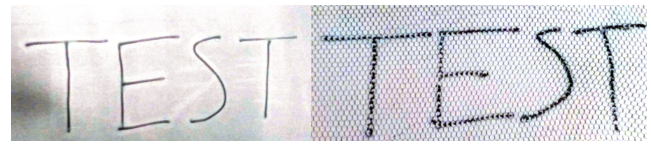

Figure 6. Tomy Megasketcher (left); Magna Doodle (right).

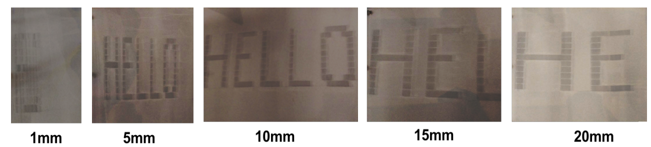

Figure 7. Effect of changing the duration each electromagnet is flashed (the numbers refer to the width of a pixel).

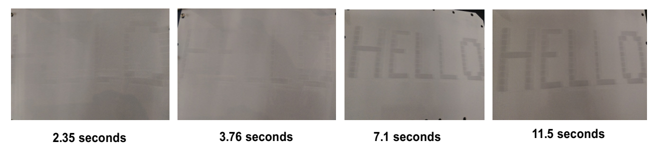

Figure 8. Effect of different sweep speeds.


Figure 9. Display is bent without affecting the images.

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