Design of High Resolution, Low-Cost, Portable Tactile Shape Display

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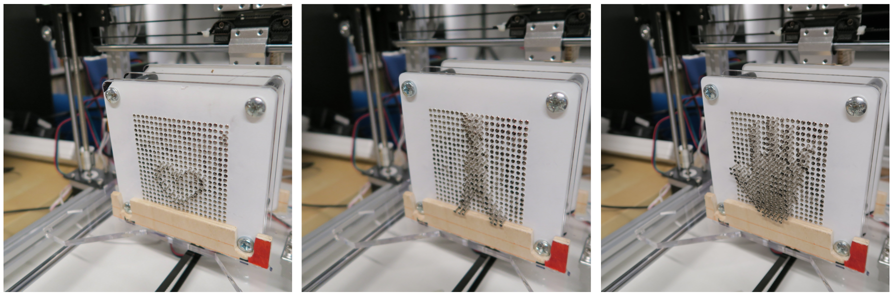

Figure 1: *Rendering of different shapes, an outline of heart, a person walking and a palm on the shape display.*

Abstract

The goal of this paper is to create a framework for manufacturing cost effective shape display platforms in order to assist future researchers in exploratory studies of portable tangible shape displays. Modern day shape displays are large, cumbersome, expensive and have relatively low resolution. This paper showcases the design and fabrication of a cost effective, portable $2.5D$ shape display whilst maintaining a relatively higher display resolution. A study of state of the art $2.5D$ shape displays was conducted to extract design parameters for the display. The construction of the display was completed using open source tools to reduce construction and implementation costs while maintaining a high level of performance.

Keywords: Shape-changing Displays; Actuated Displays; Magnetic Actuation; Reconfigurable; Shape Display

Concepts: •**Human-centered computing** → **Haptic devices;**

1 Introduction

In the modern world, data is created at a very quick rate[1]. Data is generally stored as virtual entities in large data centres across the world. Interaction with this data is mostly restricted to visual representation in $2D$ via screens ranging from a few centimetres wide (as in smart watches) to a few metres (such as in large screen televisions).

Many researchers are working on two distinct approaches in enabling users to access this vast amount of data. The first approach is to immerse humans in virtual reality, using technologies like Oculus Rift [Firth 2013]. An alternative method is to make the virtual data real via technologies like inFORM [Follmer et al. 2013] and Transform [Ishii et al. 2015].

This second approach forms the concepts of a tangible display, a type of display that, as the name suggests, is tangible. These types of displays can be physically manipulated and enable natural expression of the users. This paper reflects on an experimental Shape Display (also called as $2.5D$ display). Shape displays can be considered as an embodiment of tangible displays, wherein shapes are rendered based on digital inputs received by the device.

Shape displays have a history of over two decades, in which researchers have explored its various potentials. Numerous implementations of shape displays are available in the academic world, which have been used by researchers to carry out specific research tasks. Most of these research prototypes are expensive to manufacture and maintain which leads to limited access.

The shape display designed here consists of a $20x20$ element matrix that can be actuated with a single $3D$ moving controller scanning rows and columns. In less than a minute, it can create a $3D$ depth representation of any given source depth map image[2]. It was also important to ensure that the display was compact, easy to handle, easy to transport and remained low cost. A low-cost design of shape display enables a larger audience to engage with the technology and help improve it by utilising contributions from a wider hacker/tinkerer community.

2 Prior Work

Traditional Graphical User Interfaces (GUI) utilise senses like sight that are supplemented by sound as an additional factor for feedback. The largest sensory organ (the skin) that can sense touch, pressure, temperature with a total area of about 20 square feet[3], remains underutilized in many multi-modal interaction systems. Newer touch screen interfaces that became popular among consumers with the advent of the iPhone creates a new arena where touch based interaction on a flat two dimensional surface is the norm.

More recently, research and industry began to extend the tactile output capabilities of multi-touch screens through added haptic feedback. For example, research prototypes including Haptic Screen [Iwata 1998], Feelex [Iwata et al. 2001] and Tactile Sounds [Rovan and Hayward 2000] utilise haptic feedback mechanisms. Some commercial products also have added vibro-tactile feedback to screens or interfaces such as the Force-touch-pad[4] or Taptic Watch Engine[5].

Shape displays have been explored on their actuation mechanisms, input/output strategies and how they are a part of modern interaction methods. A list of shape displays and their parameters were explored [Leithinger et al. 2011]. The key factors for any shape display are, actuation, resolution, display density and the physi-

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[1]http://bit.ly/1NQNWwD

[2]https://www.youtube.com/watch?v=ANONYMIZED

[3]http://www.mcwdn.org/body/senseorgans.html

[4]https://support.apple.com/en-gb/HT204352

[5]https://www.apple.com/iphone-6s/3d-touch/

cal size. All implementations that can be seen across literature has certain common features. In general, independent actuation mechanisms utilise a push type actuation of the display element, using servo motors, Shape-memory alloy wire or other technologies.

3 Motivation and Use Cases

Most shape display fabricated today are heavy, cumbersome, and costly. The author aims to create a shape display that is portable, lightweight and at the same time can achieve a high resolution and display density albeit with slow refresh rates. The author envisions such shape displays can be used in rapid prototyping of $3D$ elements in $2.5D$ space, for conveying design concepts and ideas. Another potential use would be in education as well as research to render mathematical equations like surface equations or providing a tactile sensing display for the visually impaired. Given the use cases of more *statically* displayed shapes, it was designed to work in a low refresh rate environment.

4 Design Factors

The factors chosen for design defines how this shape display stands out with its unique features among the other displays explored in literature.

High Resolution : Most shape displays explored in literature has a resolution lower than $13x13$. The paper aims to explore resolutions from $20x20$ to $96x62$ and beyond.

Display Density : The paper seeks to achieve high display densities by using compact designs, effective packing of display elements and by using smaller display elements.

Manipulation : The aim is to create a shape display that can be easily physically manipulated which results in easier access to explore the shape via tactile senses.

Size Factor : The prototype is intended to be easily physically manipulatable, and easily handled, which would put a constraint on the size and weight of the shape display.

Actuation & Speed : The shape display must be able to display any shape within reasonable speed, i.e. low frequency updates but facilitate easy update methods by providing suitable actuation methods.

Low Cost : The shape display needs to be accessible by researchers constrained by a budget. So this project was challenged to have a design that would keep the entire cost of actuation and shape display unit minimal. *Table 1* itemizes the bill of material for *one* unit of shape display. It is to be noted that a single actuator can be used with several displays; in-effect lowering the cost per display.

Open Source : The paper aims to use as much open source technologies in both hardware as well as software.

5 Prototype Development

Here the paper explore the development of actuation methods, the locking system that enabled tangible interaction along with other key design aspects.

5.1 Actuation Mechanisms

The display system developed used an actuator that performs a scanline type of process, in which each line is processed in succession, and each element actuated to the right height as determined by the input before moving onto the next line of elements.

Items	Spec. / Qty	Price
Materials		
Acrylic Sheets	3mm	£6
Corkboard	3mm	£5
Pins (display elements)	45mm	£4
Actuators		
Hictop	1 unit	£250
	Bill of Materials	**£265.00**

Table 1: *Bill of Materials for one unit of Shape Display including the actuation mechanism.*

The key concept of this type of physical actuation is to ensure proper contact with the surface of the display element and to ensure that this contact is maintained till the actuation height is achieved. Tweaks in design had to be made to allow for the natural sag that might appear in the displays either due to spacing of layers, gravity or by fabricating the display for higher tolerances. This resulted in designing an actuator that was large enough to endure the tolerance of the natural sag but at the same time small enough to not disturb neighbouring elements.

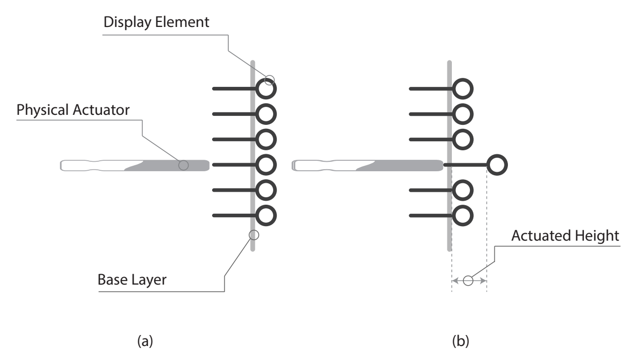

Figure 2: *Schematic of physical actuator*

5.1.1 3D Printer as a CNC based Actuation Driver

In order to ensure low cost, it was decided to use a $3D$ printer as an actuator and for which a *HICTOP Prusa i3*, DIY $3D$ printer was used. The device offered a high accuracy platform for CNC with an accuracy of about $0.1mm$ with a workable area of $2700x2000x1700mm$, which was large enough for the actuation of the envisioned shape display.

Custom parts were designed to mount the actuators See *figure* 3 below showcasing the design and the pictures for how the shape display was mounted on the $3D$ printer.

A mount was fabricated on the *base platform* of the $3D$ printer so that it was easy to mount the display onto the machine and for easy removal once the shape was rendered on it. Particular attention in the design and implementation of the mounting mechanism ensured that the mount was easy to use and assured that the calibration of the system remained as initially designed. A poor mounting mechanism can easily cause a distorted shape to be rendered on the shape display.

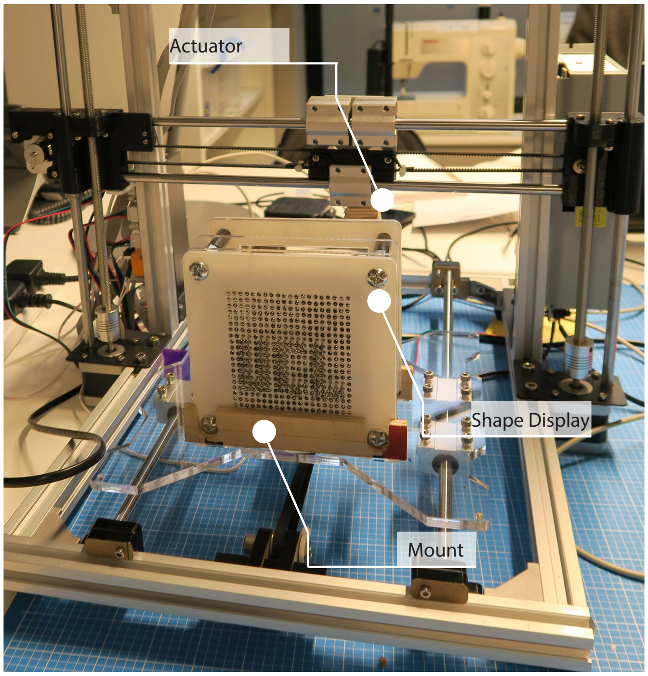

Figure 3: *Shape display mounted on $3D$ printer used as a CNC machine*

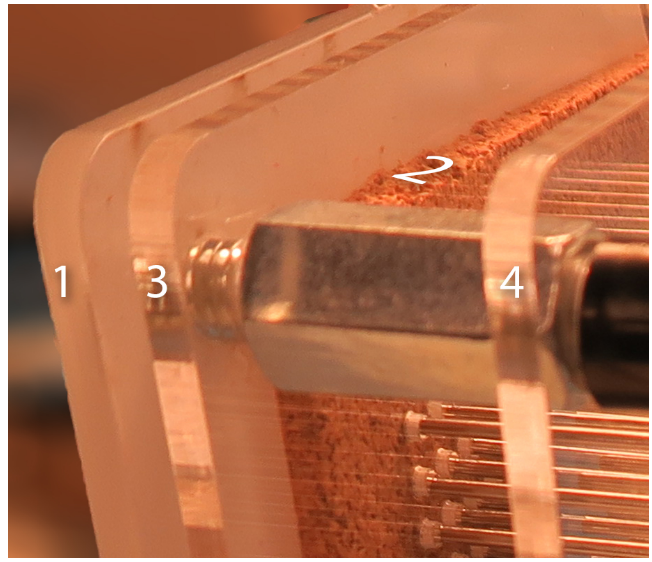

Figure 4: *Sandwiched Friction Layer installed in a shape display. The corkboard based sandwich layer* (2) *is installed between the base layer* (1) *and support layer* (3). (4) *is the mounting support layer.*

5.2 Design Aspects

5.2.1 High Friction Locking Mechanism

The locking mechanism in a shape display provides rigidity to the actuated display elements. Once a lock is engaged a user can exert pressure on the actuated surfaces and potentially manipulate the surfaces as required. To create a usable shape display, it was important to implement a locking mechanism.

A high friction shape display offers the convenience of creating a shape display that can be contoured by hand at any stage of the display rendering, thereby providing a mechanism for input for the shape display.

Different materials offer different amounts of friction based on the ability of the materials to retain its original shape after being stretched at various distances. Based on extensive experimentation with materials of different physical properties, it was found that corkboard offered the best performance for the display and thus it was chosen for the build.

5.2.2 Display Layout

The design principles required the display to have highest possible display element density within a display. Two formats (*figure* 6) for laying out the display elements in a shape display were designed. The first type is *Linear Design*. Linear type design is a straight forward design concept where the display elements are arranged in a linear fashion. This was fairly straightforward to fabricate and implement. Although the design proved to be simple to implement, the pixel density of such a display was low.

The second design fomat called *Brick Type*; the name is derived from the style used for brickwork while building a structure. Brick type design allowed us to pack a high density display with up to 5952 display elements packed at a density of about $16.30PPI$. Which is the highest density that could be achieved with the chosen display element. With smaller display elements it would be possible to push the density to a higher number. Fabricating such high resolution panels using acrylic material proved to be difficult due to warping of the material from locked up heat during laser cutting, though this was fixable, it was time consuming. It is to be noted that the shape display with the highest display element count as discussed in literature, is the Xeno-Vision Mark III [Page 2005] that is configured with 7000 display elements at a density of about $2.00PPI$ at a significantly higher price point.

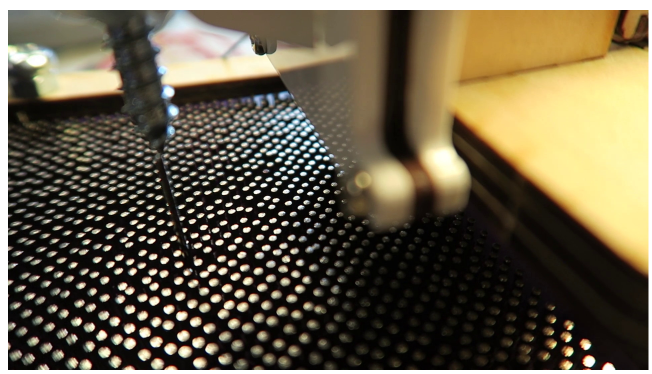

Figure 5: *Example of a shape being rendered on a very high resolution Shape Display with* 5952 *display elements at* $16.30PPI$

Once the capability of manufacturing a very high resolution, high density shape display was proven, it was it was decided to use linear pattern of $20x20$ resolution for rest of the development. As it was far less time consuming to fabricate several units of shape displays.

6 Limitations

Understanding the limitations of the technology helps to explore the use cases for which the technology is feasible. One of the biggest

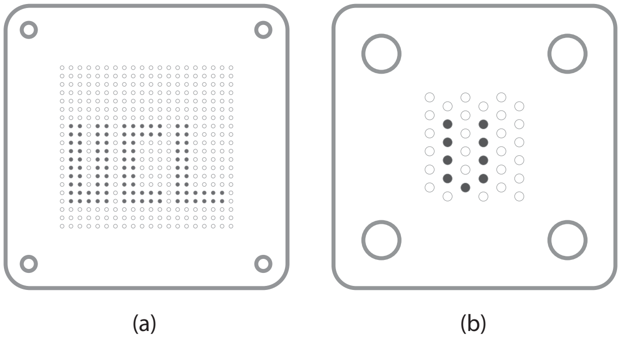

Figure 6: *Shape display designs*(a) *A* $20x20$ *Linear Type Design* $\times$ (b) *A* $6x6$ *Brick Type Design. Note that even in lower resolution brick type design is more adept at displaying curves*

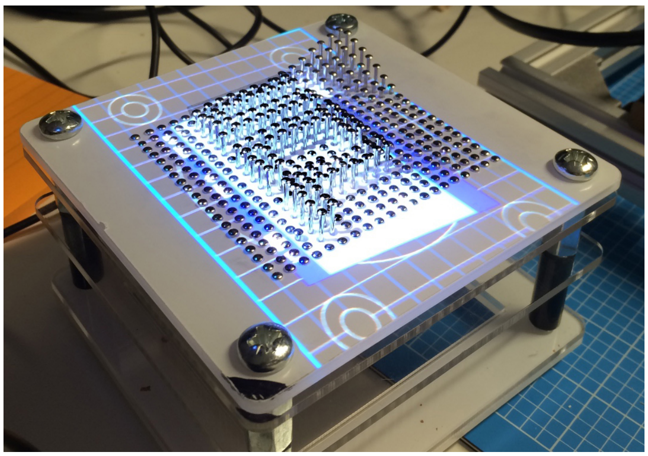

Figure 7: *Additional data being projected onto an actuated shape display rendering the text "UCL"*

disadvantages of shape displays is its lack of ability to render overhangs. Overhangs can be described as parts of objects that are freely hanging in $3D$ space. Current technologies of shape displays cannot render overhangs. However, we can minimise the impact of smaller overhangs by using additional output methods like projected information (*figure 7*).

The current system implements a single actuator for the whole display. This can be perceived as a cost saving method as well. The impact of the single actuator causes the system to perform slower than having multiple actuators.

Limitation of the single actuator can be potentially solved by using multiple actuators, in a divide and conquer technique. For example, if the design allows for four actuators, each actuator can handle rendering the partial shape in its respective quadrant. Additionally, the CNC speed can be increased to actuate faster; specifically, while using sandwiched friction layers, thereby decreasing render time.

7 Conclusion

The shape display was fabricated using open source and cost effective actuation mechanisms by appropriating $3D$ printer as a computerised numerical control method. The design choices made throughout the paper based on the design principles helped to manufacture a display that has one of the highest display densities as well as overall resolution along with portability of the display.

This display can be used as a workbench or as a platform for further experimentations and evaluation studies of tangible displays. More importantly this paper provides a researcher in the field of tangible shape display an *easy*, *tweakable*, *configurable* and *cost effective* platform for future development.

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