shapeShift: A Mobile Tabletop Shape Display for Tangible and Haptic Interaction

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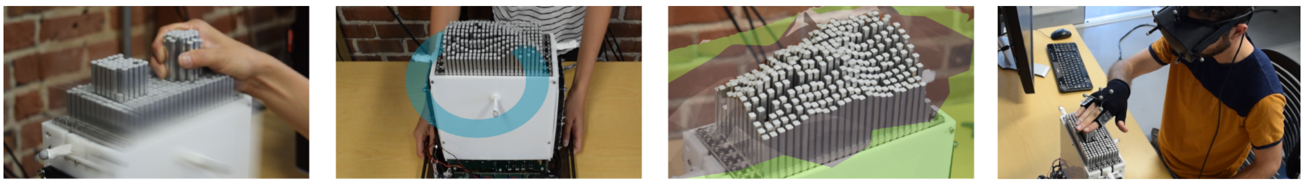

Figure 1: shapeShift is a mobile tabletop shape display that enables lateral user input and output. *Left to right*: (a) In passive mode the user can freely move the display; (b-c) or physically explore spatial data; (d) In active mode shapeShift can move on-demand - here it tracks the user's hand to simulate the presence of virtual content

ABSTRACT
shapeShift is a compact, high-resolution (7 mm pitch), mobile tabletop shape display. We explore potential interaction techniques in both passive and active mobile scenarios. In the passive case, the user is able to freely move and spin the display as it renders elements. We introduce use cases for rendering lateral I/O elements, exploring volumetric datasets, and grasping and manipulating objects. On an active omnidirectional-robot platform, shapeShift can display moving objects and provide both vertical and lateral kinesthetic feedback. We use the active platform as an encounter-type haptic device combined with a head-mounted display to dynamically simulate the presence of virtual content.

Author Keywords
Tangible User Interfaces; Shape Displays; Interactive Tabletop

ACM Classification Keywords
H.5.m. User interfaces: Input devices and strategies

INTRODUCTION
Shape displays that couple the digital and physical worlds have been an emerging research topic in HCI [8, 5, 13, 10]. Follmer et. al. introduced the concept of dynamic affordances and constraints for creating dynamic UIs through shape displays [2]. However, the affordances shown by their system, inFORM, could only react to vertical pushing or pulling input from the user. They were not able to explore dynamic UIs where controllable lateral force feedback is necessary. Actuated tangibles such as Madgets [14] and Zooids [7] are capable of tangential actuation, however these TUIs are limited by their single-purpose static physical form.

Display of spatial and volumetric information is usually limited to its projection onto a fixed two dimensional screen rather than in its actual position. Several systems have explored hand-held and self-actuated displays for exploration of spatially-oriented volumetric information using visual feedback [11] and passive haptics [12].

Other work in haptics has looked at encounter type haptic devices which allow users to investigate a scene in 2D using a tactile display [6] or 3D using a tactile display [4, 1] or a robotic end effector [15]. Our goal is to enable this same type of Robotic Graphics [9], but for gross shape approximation using an actuated pin array. The most related may be Hirota and Hirose's 4×4 pin surface display mounted on a passive gimbal [3].

In this work we address the aforementioned limitations and expand on the range of existing interactions capable with shape displays in rendering both shape content and UI elements. To explore this, we introduce shapeShift, a high-density compact shape display consisting of 288 square aluminum pins actuated by a traveling-nut linear actuator. While shape displays remain limited in size and cost, shapeShifts self-contained hardware and small form factor allow it to be highly mobile. shapeShift is capable of touch input, large lateral mobility and display continuity, and both vertical and lateral force feedback.

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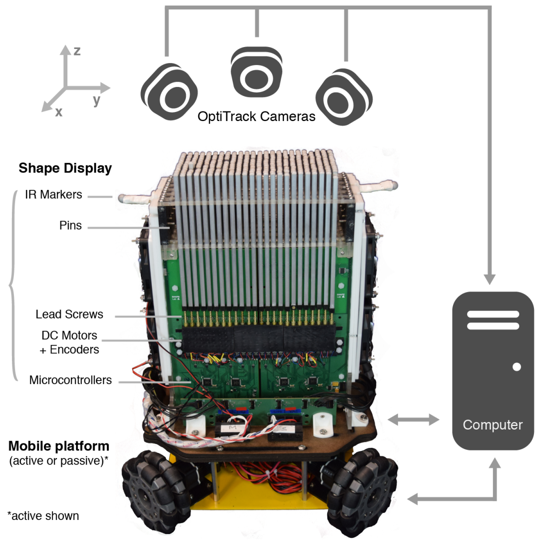

Figure 2: shapeShift renders physical shapes using 288 actuated square pins (4.85 mm width, 7 mm pitch). Passive and active mobile tabletop platforms enable lateral motion, with user interaction and platform motion both tracked using an IR motion capture system.

We show its mobility in both active and passive mode. In passive mode, the display is mounted to a platform with caster wheels which allow the user to freely move the display. In active mode, the display is mounted to an omni-directional robot platform controlled by a computer program (Figure 2).

INTERACTIONS

Lateral I/O. Handles can be used to move the display in the X-Y dimension (passive mode) or they can move to provide user feedback (active mode). In addition, active movement can be used to display objects that move spatially such as a moving car or rolling ball (Figure 1a).

Grasping and Manipulating Objects. In passive mode, rendered objects can be freely grasped and manipulated laterally, allowing for richer and less constrained interactions.

Exploring Spatial Data. The display can be moved to explore spatial data such as terrain maps that extend beyond the boundaries of the display, while preserving spatial positioning (Figure 1b). This can be combined with a head-mounted display (HMD) to enhance the visual display. Physical tools can also be used as proxies to modify the surface.

Encounter-Type Haptic Interface for VR. The display in active mode can track the user's hand and be combined with an HMD to dynamically simulate the physical presence of virtual content. As the user reaches to touch a virtual surface, the robot platform tracks their hand and the display renders the surface beneath the user's moving hand Figure 1.

SYSTEM & IMPLEMENTATION

A system schematic is shown in Figure 2. The display consists of 288 square aluminum pins ($4.85\,\mathrm{mm} \times 4.85\,\mathrm{mm}$) arranged in a 12×24 grid with a pitch size of $7\,\mathrm{mm}$. Each pin is $152\,\mathrm{mm}$ in length and can extend upwards up to $50\,\mathrm{mm}$.

Each pin is actuated by a DC Motor (TTMotors, 1:25, $6\,\mathrm{mm}$) revolving a $3\,\mathrm{mm}$ pitch screw, and is coupled to a nut which travels along the screw. Guide grids at the top of the display ensure the pins are aligned and cannot rotate.

The motor is coupled to the screw via a 3D printed shaft with quadrature encoder tick marks. Two photo interrupters mounted onto a custom-designed printed circuit board (PCB) and aligned with the rotating shaft are used to obtain quadrature readings proportional to the pin's linear position. The average position accuracy per pin is $0.35{\pm}0.22\,\mathrm{mm}$. The average pin speed is $63\,\mathrm{mm/s}$ traveling upwards and $68\,\mathrm{mm/s}$ downwards.

Each PCB has four ARM Cortex-M4 $72\,\mathrm{MHz}$ microcontrollers (NXP, MK20DX256VLH7) managing the system logic and control of six motors - therefore each PCB handles 24 pins. These PCBs are modular and can be stacked in the X dimension to increase the display size. All microcontrollers communicate in serial with full duplex RS485 standard on a shared bus. One microcontroller serves as master which communicates through USB serial with the computer program and forwards the messages to the slaves.

To track the display as it moves in the environment, we use a system of overhead OptiTrack cameras and attach IR reflective markers around the display. In passive mode, the display is mounted to a platform with a set of three caster wheels, allowing the user to move the display. In active mode, the display is mounted to an omni-directional robot platform (Nexus Robot 10008) and the feedback loop is closed with OptiTrack tracking data. An ATMega328 microcontroller controls the robot platform, which has a max speed of $600\,\mathrm{mm/s}$.

A Unity application is used to import 3D models, interface with OptiTrack data, and calculate pin positions through a ray casting script. The application runs two additional parallel threads to handle USB serial communication. One thread communicates with the master microcontroller and the other communicates with the robot platform.

CONCLUSION

We have presented shapeShift: a compact, high-resolution mobile tabletop shape display. We explored potential interactions in both passive and active mobile scenarios, including active hand-tracking for haptic interaction in VR. Future work will continue to explore the diverse dynamic interactions afforded by high-fidelity mobile shape-changing interfaces.

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