Demonstrating ShapeBots: Shape-changing Swarm Robots

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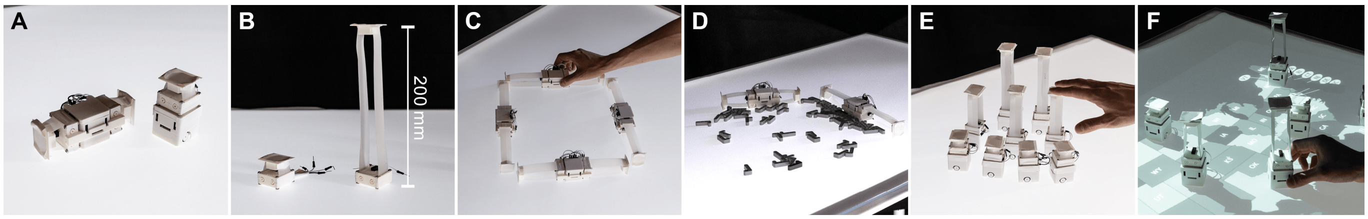

Figure 1. ShapeBots exemplifies a new type of shape-changing interface that consists of a swarm of self-transformable robots. A) Two ShapeBot elements. B) A miniature reel-based linear actuator for self-transformation. By leveraging individual and collective transformation, ShapeBots can provide C) interactive physical display (e.g., rendering a rectangle), D) object actuation (e.g., cleaning up a desk), E) distributed shape display (e.g., rendering a dynamic surface), and F) embedded data physicalization (e.g., showing populations of states on a US map).

ABSTRACT
We introduce *shape-changing swarm robots*. Shape-changing swarm robots can both *individually* and *collectively* change their configuration to display information, actuate objects, act as tangible controllers, visualize data, and provide affordances. To demonstrate this idea, we present ShapeBots, a concept prototype of shape-changing swarm robots. Each robot can change its shape by leveraging small linear actuators that are thin (2.5 cm) and highly extendable (up to 20cm) in both horizontal and vertical directions. We illustrate potential application scenarios for ubiquitous and distributed shape-changing interfaces.

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);**

Author Keywords
shape-changing user interfaces, swarm user interfaces, tangible interactions; ubiquitous shape-changing interfaces

INTRODUCTION
This paper introduces *shape-changing swarm robots*, a new class of shape-changing interfaces that can both *collectively* and *individually* change their shape for human-computer interaction, inspired by and built on top of existing swarm user interfaces [2, 5, 7, 8, 11]. These distributed and self-transformable robots collectively present information, act as controllers, actuate objects, represent data, and provide dynamic physical affordances (Figure 1).

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SHAPEBOTS
ShapeBots is a self-transformable swarm robots with modular linear actuators. One technical challenge to enable shape-changing swarm robots is the development of small actuators that have a large deformation capability. To address this, we developed a miniature reel-based linear actuator that is thin (2.5 cm) and fits into the small footprint (3 cm x 3 cm), while able to extend up to 20 cm in both horizontal and vertical directions. The modular design of each linear actuator unit enables the construction of various shapes and topologies of individual shape transformation. Based on these capabilities, we demonstrate a set of application scenarios that illustrates how a swarm of distributed self-transformable robots can support everyday interactions.

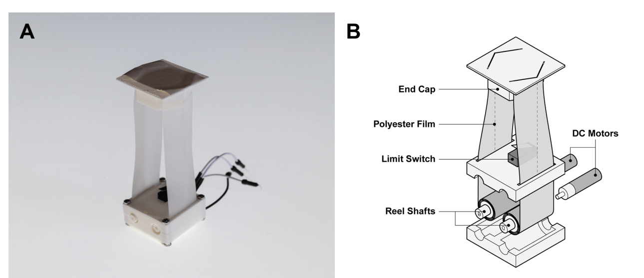

Figure 2. The ShapeBot's linear actuation unit.

Figure 2 illustrates the design of our linear actuator. It is inspired by a retractable tape measure, which occupies a small footprint, but can extend and hold its shape while resisting loads along certain axes. We developed a reel-based linear actuator that employs small DC motors (TTMotor TGPP06D-700, torque: 900g/cm, diameter: 6 mm, length: 22 mm). The linear actuator comprises two reels of thin sheets (e.g. 0.1mm thick polyester sheet). Two DC motors (TTMotor TGPP06D-700) rotate in opposite directions to feed and retract the sheets. Each sheet is creased at the center along its length, and is connected to a cover cap that maintains the fold. This crease increases the structural stability of the linear actuator, similar to how a tape measure remains stable when extended. Thus the linear actuator can push and drag lightweight objects without bending and extend vertically without buckling.

APPLICATION SCENARIOS

Interactive Physical Displays and Data Representations

One interesting application area is interactive data physicalization [4]. For example, Figure 3 shows seven robots that transform individually to represent a sine wave.

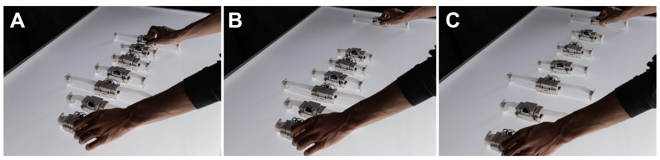

Figure 3. An interactive and animated sine wave.

ShapeBots also support transforming data into different representations such as bar graphs, line charts, and star graphs. The user can place and move robots, which enables embedded data representations [15]. For example, ShapeBots on the United States map can physicalize data associated with the map; each robot can change its height to show the population of the state it is on (Figure 4).

Figure 4. Embedded data physicalization on a map.

By leveraging the ability to display an image at a larger scale, ShapeBots can also act as an interactive physical display.

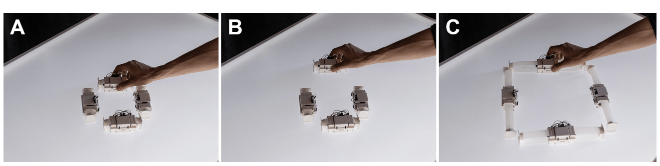

Figure 5. Interactive shape change.

Figure 5 demonstrates ShapeBots' input and output capabilities as an interactive tangible display. In a similar way, ShapeBots can provide a physical preview of a CAD design. For example, Figure 6 shows a user designing a box. ShapeBots physicalizes the actual size of the box.

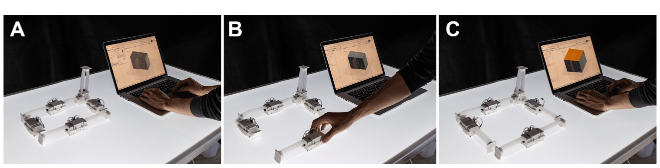

Figure 6. Physical preview for the CAD design.

Object Actuation and Physical Constraints

Another practical aspect of ShapeBots is the ability to actuate objects and act as physical constraints. As an example, Figure 7 shows two robots extending their linear actuators to wipe debris off a table, clearing a workspace for the user.

Figure 7. Clean up robots.

ShapeBots can be employed as a tangible gaming platform. Figure 8 illustrates two users playing a table football game using two extended robots.

Figure 8. Tangible game controllers.

Distributed Dynamic Physical Affordances

In another scenario, the ShapeBots brings tools to the user. For instance, when the user needs a pen, a robot extends its actuators and pushes the pen to the user (Figure 9A-B). These robots can also be used as tools.

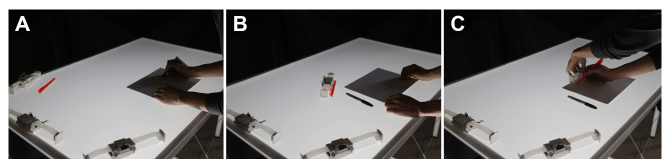

Figure 9. Shape-changing Tools.

By leveraging the capability of locomotion and height change of each robot, ShapeBots can create a dynamic fence to hide or encompass existing objects for affordances. For example, Figure 10 illustrates this scenario. When the user pours hot coffee into a cup, the robots surround the cup and change their heights to create a vertical fence. The vertical fence visually and physically provides the affordance to indicate that the coffee is too hot and not ready to drink.

Figure 10. Distributed dynamic physical affordances.

FUTURE WORK

For future work, we are interested in making it easier to detach and reconfigure with a magnetic connection [1], investigating the use of wireless power charging [14] or other continuous power supply methods [6], and evaluating the benefits and limitations of the current approach for the specific applications of data physicalization [4, 8] and accessibility assistance [3, 12]. Finally, we will explore connection mechanisms for graspable and reconstructable line-based shape-changing interfaces [10, 9, 13].

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