DRACO

Design of Resilient Architectures for Computing

Designing a Pneumatic Shape Display

Aryan Tulsi, Dr. Mike Borowczak

DRACO Lab, Dept. of Electrical & Computer Engineering, University of Central Florida

thedracolab.com • mike.borowczak@ucf.edu • ENG1-263, UCF

UCF

College of Engineering and Computer Science

1. INTRODUCTION & MOTIVATION

Shape displays are a class of human machine interface that physically renders digital information on a tangible surface.[1] Unlike traditional visual displays, shape displays allow users to interact with information through touch and the manipulation of dynamic physical geometry. They enable new interaction techniques for design, education, and accessibility.

Existing systems demonstrate the potential of dynamic surfaces to represent data, act as control interfaces or allow the user to interact directly with simulation.[3] However, most work thus far has focused on large, complex actuator arrays such as mechanical pin displays.[3] These solutions require substantial mechanical infrastructure. As a result, compact high resolution shape displays remain largely unexplored, limiting the broader adoption of this technology outside of specialized applications.

Current research remains limited but is focused on creating more scalable systems through other techniques. Our project investigates whether pneumatic actuation can enable a compact, scalable, and low-cost approach to dynamic shape displays.

2. RESEARCH QUESTION

This work explores the following Research Question:

Can pneumatic actuation be used to create a compact and scalable display capable of rendering a dynamic, height-controlled physical surface?

To address this question, the project aims to:

- Design a pneumatic shape display architecture capable of rendering height fields.
- Develop a modular grid of actuated elements that can independently change height.
- Evaluate whether such a system can provide meaningful physical representations of digital data.

3. BACKGROUND & RELATED WORK

Current shape display systems typically use large arrays of motorized pins to render dynamic physical surfaces. While these systems demonstrate the potential of tangible interfaces and physical data visualization, their mechanical complexity and cost make compact implementations difficult.

The inFORM display, developed at the MIT Media Lab, demonstrates how these arrays can produce dynamic "2.5D" surfaces that users can physically manipulate and explore. However, the system is large and not easily portable.[1]

Alternative approaches aim to reduce this complexity. The Formable Crust Shape Display developed at Stanford University embeds actuation directly into the surface rather than using discrete actuators. Electric forces lock portions of the surface while an inflatable pouch raises the remaining areas.[2] While this approach reduces mechanical bulk and enables smoother deformation, it suffers from limited actuation height.

Despite these advances, compact and accessible shape displays remain largely unexplored. This project investigates whether pneumatic actuation can provide a simpler and more scalable approach.

4. SYSTEM DESIGN

The proposed system consists of a grid of inflatable chambers with internal stretch sensors. When pressurized, each chamber expands vertically, allowing the system to render a dynamic height-controlled surface.

Key components include:

- Pneumatic Chambers – Extensible tubes arranged in a grid that can be inflated or deflated to change the local surface height.
- Valve System – Electronically actuated valves regulate airflow to the pneumatic chambers in a multiplexed fashion to minimize system cost and complexity.
- Stretch Sensors – Within each chamber is a sensor that allows for the measurement of chamber height.

5. OVERVIEW

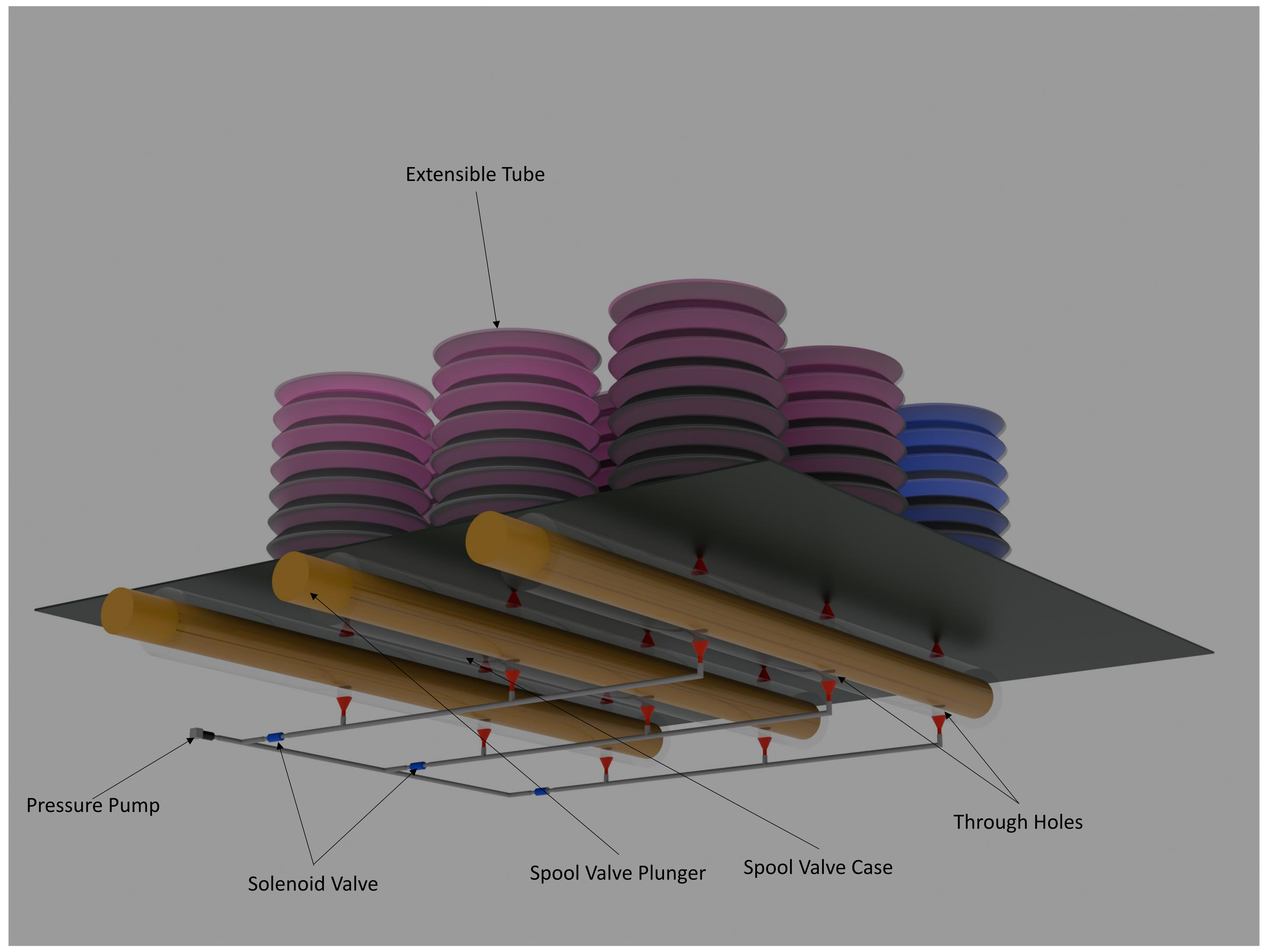

Figure 1: Overview of External System Components

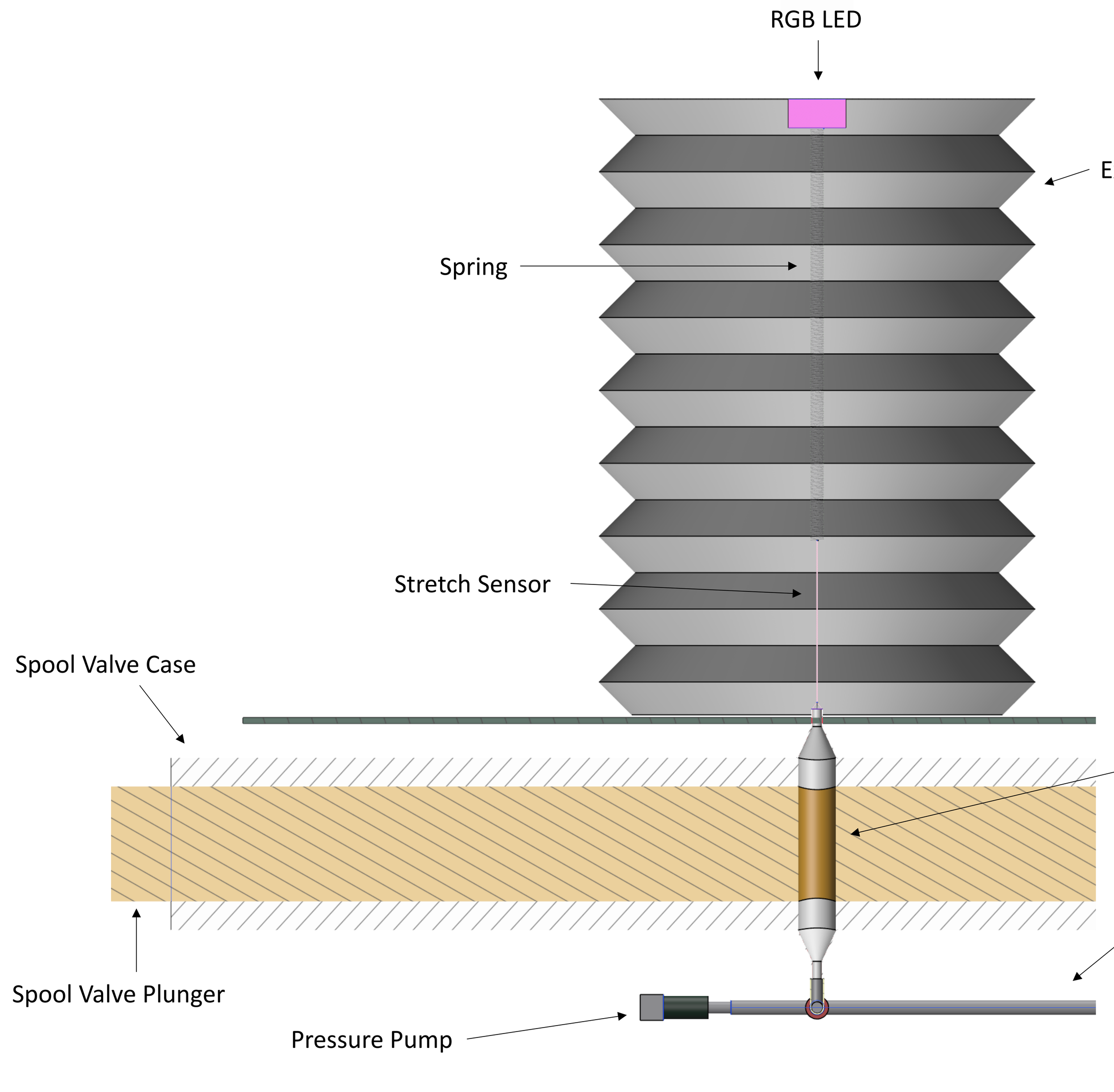

Figure 2: Overview of Internal Components

6. DISCUSSION

The pneumatic shape display architecture offers several advantages compared to traditional motorized systems:

- Reduced mechanical complexity – Pneumatic actuation replaces large arrays of motors with a shared pressure system.
- Lower cost potential – Pneumatic components such as valves and tubing may be less expensive than large numbers of electromechanical actuators.
- Scalability through miniaturization – Tubes and valves are simple to fabricate at smaller sizes.

However, there are some disadvantages:

- Height Control Errors – The use of simple stretch sensors may limit the accuracy and precision of height measurements.
- Slow Actuation – A shared pressure system may limit how quickly individual chambers can be adjusted.
- Material Fatigue – Repeated deformation of the flexible surface may lead to long-term durability issues.

These tradeoffs suggest that pneumatic actuation may be most suitable for compact shape displays where reduced complexity and cost are prioritized over high-speed actuation. Many of these limitations may be mitigated through improvements in system architecture, sensing, and material design. However, further experimentation will be required to evaluate the performance and practical limitations of pneumatic actuation for dynamic shape rendering.

7. CONCLUSIONS & IMPACT

By replacing large arrays of mechanical actuators with a shared pressure system and valves, the design aims to reduce the complexity and cost of traditional shape display systems. If successful, this approach could enable more accessible and scalable displays for applications such as data visualization, educational tools, and tangible human-computer interaction. The proposed design highlights the potential for pneumatic actuation to provide an alternative pathway toward compact shape display technologies.

8. FUTURE WORK

The current work focuses on the conceptual design of a pneumatic shape display architecture. The following steps will focus on constructing and evaluating a prototype system to validate the feasibility of pneumatic actuation for dynamic surface rendering.

- Prototype Construction – Fabricate a small-scale pneumatic chamber array to validate the mechanical design and behavior.
- Valve Control Implementation – Develop the electronic control system for regulating airflow through the valve array and coordinating with sensing to achieve desired heights.
- Characterization – Measure response time and assess repeatability of adjustments.

REFERENCES

[1] D. Leithinger, S. Follmer, A. Olwal and H. Ishii, "Shape Displays: Spatial Interaction with," *IEEE Computer Graphics and Applications* , pp. 5-11, 2015.

[2] A. M. Rauf, J. S. Bernardo and S. Follmer, "Electroadhesive Auxetics as Programmable Layer Jamming Skins for Formable Crust Shape Displays," in *2023 IEEE International Conference on Robotics and Automation (ICRA)*, London, United Kingdom, 2023.

[3] D. Leithinger, S. Follmer, A. Olwal, A. Hogge and H. Ishii, "inFORM: Dynamic Physical Affordances and Constraints through Shape and Object Actuation," in *Proceedings of the 26th annual ACM symposium on User interface software and technology*, St. Andrews, United Kingdom, 2013.