Designing a Soft, Mobile Interface for Multimodal Human-Robot Interaction

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Figure 1: (a) Lipstip-style bladder mounted on a Martha robot. The soft bladder interface can distinguish social gestures such as (b) hugging and (c) punching, and displays graphics as touch affordance like (d) putting on a smiley face to encourage interaction, and (e) displaying information for direct feedback.

ABSTRACT

Research has shown that soft robotics can provide benefits for safe and comfortable human interaction. In previous work, we developed a soft inflatable interface that can be attached to a mobile robot. The main structure can deflate into a small disk, allowing the robot to maneuver in confined spaces. It can also inflate to a vertical human-scale column to encourage human interaction. In its inflated state, the bladder supports tactile, audible, and visual interaction with users. In this paper, we discuss the challenges encountered and solutions developed when creating the interface, specifically in integrating sensing, display, and actuator functions. We went through several design iterations to develop a safe and useful configuration for human interaction, focusing on two potential use cases: a guide robot and a companion social robot.

KEYWORDS

soft robot, human-robot interaction, inflatable, tactile, guide robot, companion robot

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1 INTRODUCTION

In this paper, we discuss the challenges and solutions involved in designing a soft inflatable interface, specific to sensors, display, and actuation [5]. The goal of our design was to have a soft human-scale interface, or bladder, on a mobile robotic platform that allows it to:

(1) Change shape depending on context. When inflated, the robot can act as an information display and perceive physical touch. When deflated, it fits in confined spaces, improving mobility and discouraging human interaction.

(2) Encourage physical touch from human users, such as hugging, punching, petting, etc. The bladder should have the ability to sense meaningful touch gestures that are related to the user's mental states or instruction input.

(3) Display information by projecting on the bladder's surface; when combined with touch sensing, it allows users to directly interact with the projected information, e.g. through pointing gestures.

The mobile rover, 'Martha' [5], used in this paper was designed explicitly for affordable, fast, and autonomous navigation in a

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human-centric environment. In this rover, integration with the robotic base prompted additional design requirements and constraints for the bladder: Ideally, the bladder should be (1) lightweight and portable, (2) easily detachable from the rover for access and maintenance of internal parts, (3) affordable, and (4) soft and translucent.

To better illustrate the function of the bladder, we describe two use cases in human-robot interaction (HRI) contexts. Use case 1: The bladder on its rover base can serve as a guide in complex environments such as airports. The human-sized scale of the bladder makes the robot easily noticeable, with the projected information clearly identified from afar. Its soft and deformable structure allows the robot to safely navigate through the crowd and protect users from injuries in case of collision. The robot may display various types of information for the purpose of spatial guidance, including (1) embedded information like "follow me" in combination with the robot's movements, (2) referential information such as an arrow pointing to a destination, and (3) abstract information such as a map of the building or a description of the route. Use case 2: The bladder with its ability to recognize touch gestures and generate visual, sound or movement responses can potentially serve as a social companion robot. It provides a soft and huggable physical interface that offers safe and favorable touch experience, supporting users to communicate attitudes and emotions through social gestures. With the ability to inflate and deflate to different scales, it can adapt to users of different heights and preferences. A deflated bladder allows the robot to easily fit under the shelf for storage or transport.

2 CONTEXT-BASED CHANGING OF PHYSICAL APPEARANCE

2.1 Designing a human-sized soft inflatable bladder

Our final bladder is the result of several design iterations. Key challenges were the speed and stability by which the bladder could inflate and deflate, as well as the resulting physical appearance at full inflation. Quick shape changes to promote agile behavior which suit dynamic human-dominated environments; stability encourages interaction.

The first bladder design was based on origami (Fig. 2a). While this was ideal for deflated compactness; the hard creases suffered from fatigue, it was slow to fabricate, and the design did not accommodate easy growth. Next, we attempted spring-based growth by incorporating springs into the circumference of the bladder fabric to enable quick and low energy deployment. However, the spring-based bladder would wobble significantly when the rover moved and generally felt less organic and not feel as safe as we would have liked.

Next, we tried incorporating inflatable Polyethylene tubing along the length of the bladder to hold it upright (Fig. 2b); active valves allowed us to shut off power once the cylinder was fully inflated. Unfortunately, the design proved to be unstable during inflation, and the tubes would pinch during deflation preventing full decompression.

Finally, we settled on a design based on a yard inflatable, commonly used for Halloween in the US. While this method required continuous power for sustained inflation, it eliminated concerns regarding bladder leakage. Our bladder is made of lightweight Ripstop Nylon (48 g/m^2) Fig. 2c). At the base of our rover sits a quiet air fan that inflates the bladder to full size (about a meter tall) in 40s and deflates in 50s. To keep the inflatable stable during inflation and deflation, three equally-spaced internal winches were attached to the rover. The winches drive cables that are fastened to the top of the inflatable interface and these are kept tight to prevent the bladder from deforming. During deflation, the winches pull in the bladder, while the fan is run at 50% duty cycle so that the cables remain taut. Each winch uses a small motor that has magnetic encoders to prevent them from over- or under-extending. This bladder design was much easier and faster to fabricate than the previous versions. The parts used are all cheap and easily accessible, with the entire robot costing less than 1.2K USD [5]. The interface has only one sheet of fabric which improves the visual appearance and the quality of the projected image. More recently, we have been utilizing the cables to experiment different movements of the bladder (Fig. 2d); by reeling in one motor while keeping the other cables taut, we can make the bladder look as if it is showing different movements, e.g., bowing.

3 SENSING AND DISPLAY ON THE DEFORMABLE BLADDER

This section presents the design of a touch sensing and information display system on the surface of the bladder. We discuss some challenges and limitations of some commonly-used systems and present our solutions.

3.1 Achieving full-body touch sensing on soft bladder with ShadowSense

To integrate touch sensing ability on a robotic system, commonly used methods embed various sensors such as force sensitive resistors (FSRs) and capacitive resistors in the robot skin [2, 8]. However, these methods are not appropriate for our design as they would require many sensors to cover the full interface, increasing price and manufacturing complexity. Furthermore, embedding tactile sensors is less feasible for surfaces made from soft, deformable materials. For example, FSRs usually require a rigid backing to produce significant signals. In addition, the stiff sensors would interfere with the intended softness and act against a huggable tactile experience. Several sensing alternatives have been explored for soft robotics, such as force sensing by measuring global air pressure [1]. However, this method detects quite limited spatial information, such as the precise location of the touch.

To address the challenges involved in implementing touch sensing on the soft bladder, we developed ShadowSense, a method that captures shadows generated from human touch and infers social gestures from the shadow images [4]. We positioned a camera with a 170 degree field-of-view fisheye lens inside the bladder, at the center of the rover base facing up towards the inner surface of the bladder. The fisheye view allows it to capture any shadows on the top and parts of the sides of the inflatable. In our previous work, we presented solutions with Convolutional Neural Networks and skin color segmentation to process shadow images, infered touch gesture and tracked touch position [4]. The algorithm was able

Figure 2: (a) Origami design. (b) Cylinders with valves sewn in along the sides of the bladder. (c) Fan-powered tubular bladder. (d) Experimenting with cable-driven motions on lipstick-style bladder.

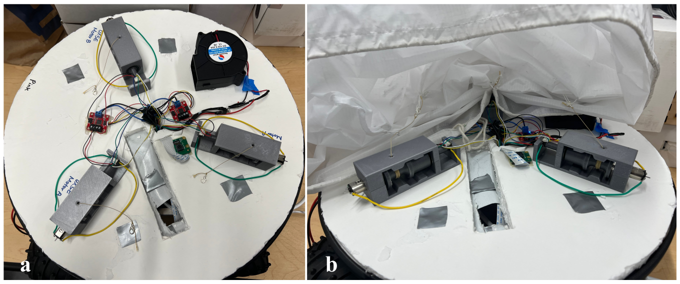

Figure 3: Winch-driven cables hold the bladder stable during inflation and deflation. Each winch uses a motor with encoders to ensure the cables extend equally. Cables are aligned and attached internally along the sides of the bladder.

to detect different touch gestures including hugging, palm touching, pointing, punching, two-hand touching under varied lighting conditions with an average of 92% accuracy.

With ShadowSense, we envision that a robot could serve as a socially intelligent companion (use case 2), being able to sense touch gestures and respond accordingly. For example, when the robot detects a "poke" on its back, it could turn around to face the human. A "sliding" gesture on the bladder could instruct it to move in the corresponding direction. A "hug" could let the robot happily circulate around the user, while a "punch" may scare the robot to run away (Fig. 1 b, c). Having a soft interface and implementing ShadowSense allows for a playful experience when interacting with the robot and can potentially benefit educational or entertaining applications.

3.2 Displaying information on the surface with an internal projector

An internal projector allows the robot to directly display visual information on its bladder (use case 1). When combined with ShadowSense, the ability to display such visual information, ranging from instructional messages to faces or images, augments touch interaction, and allows users to more explicitly communicate with the robot.

Although they typically leverage rigid surfaces, projection-based interfaces have been widely researched in human-computer interaction systems where users can interact with image projection through gestures like dragging, tapping, and sliding [9]. We encountered several challenges when implementing the projection on our soft bladder. First, the bladder is deformable and curved, so the projection needs to be adjusted according to its shape. Second, projection may interfere with the touch sensing system as the light emitted from the projector may distort touch shadows.

To address the first issue, we applied calibration and transformation of projected images based on the surface property. Geometric distortion correction can be applied on projected images to improve the quality of projection on curved surfaces. However, as the bladder changes between different states of inflation this method may not work consistently. The current prototype only allows for the distortion correction under a static, fully inflated state. Future work will target real-time calibration and correction of the projected image to improve information display at intermediate inflation.

4 DESIGN EXTENSIONS FOR HUMAN-ROBOT INTERACTION STUDIES

To further encourage ways to use our rover as an information and interaction device, we are currently developing a new bladder in the shape of a lipstick (Fig. 1a, Fig. 2d). We imagine this slanted top face to serve as a better visual platform for information transfer between the rover and the user. Using the cable/winch mechanism and allowing each motor to run independently of each other, we can make the bladder perform visual gestures, like bowing. With much room to explore in the field of HRI, especially regarding soft robotics, more features can be added to this new interface to help explore: how people respond to differently shaped interfaces, and how the color, texture, and size of a bladder affect interaction. While we have open sourced the platform to encourage collaborations, we have yet to proceed on tests with human subjects. Next, we instead discuss how findings from related work may help shape future versions of the bladder.

We hypothesize that our two use cases would benefit from differing appropriate physical appearances. Past work has shown that "creature"-like robots are well suited for human interaction, especially when the human user is meant to teach the robot [3]. Also of interest, a study that examined the effect of a robot's appearance in interaction with children with autism clearly highlighted their initial preference for a plain faceless robot [7]. For our companion robot use case, an animal or creature-like shape would be fitting. While our design itself does not look like an animal, the projected image gives us the freedom to alter the robot's appearance. Involving other ways of making a creature-like appearance with soft robotics, particularly inflatables, would be an interesting challenge. In the case of the guide robot, a physical appearance that is less child-like may lead to more successful cases of interaction, where success would mean complete and accurate portrayal of information and delivery of tasks.

The softness of the interface itself have been shown to encourage more social interaction compared to stiff interactions; similarly colors may affect how people bond with the robot [6]. The same study indicated a wide variety of ways people touch soft robots, which can also be taken into account when designing more versatile versions of the interface. Many human interaction studies involving soft robotics have yet to be explored, and we hope this platform will support such research in the future.

5 SUMMARY

In this paper, we described the design iterations done towards a soft inflatable interface. After attempts at using origami, springs, and air cylinders, we came to a simple, robust, and affordable inflation mechanism which fits onto the back of a small autonomous rover. The absence of hard and stiff components, and the relatively quick inflation and deflation time makes this bladder an effective information and interaction tool with human users. Our method of detecting touch gestures eliminates the need for embedded sensors on the interface itself, and the use of an internal projector allows the robot to alter its appearance and provide clear visual information. In the future, we want to continue exploring the opportunities afforded by our soft interface. As mentioned previously, our bladder has not been involved in any human testing. As we are currently exploring morphological changes, we want to assess how the shapes and movements of a soft inflatable interface affects humans' feelings, emotions, and thoughts when interacting with them.

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