A Stretch-Flexible Textile Multitouch Sensor for User Input on Inflatable Membrane Structures & Non-Planar Surfaces

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ABSTRACT

We present a textile sensor, capable of detecting multi-touch and multi-pressure input on non-planar surfaces and demonstrate how such sensors can be fabricated and integrated into *pressure stabilized membrane envelopes* (i.e. inflatables). Our sensor design is both stretchable and flexible/bendable and can conform to various three-dimensional surface geometries and shape-changing surfaces. We briefly outline an approach for basic signal acquisition from such sensors and how they can be leveraged to measure internal air-pressure of inflatable objects without specialized air-pressure sensors. We further demonstrate how standard electronic circuits can be integrated with malleable inflatable objects without the need for rigid enclosures for mechanical protection.

Keywords

Textile sensor, multi-touch, pressure, membrane envelopes, shape-change, fluidic interfaces, inflatables, pneumatibles.

1. INTRODUCTION

The integration of sensor technology into malleable and shape changing objects or garments enables new applications, modalities and use qualities for interaction design [7]. We propose a stretchable textile sensing layer that allows for simultaneous multi-touch *and* multi-pressure input, and demonstrate how such malleable sensor layers – in conjunction with rigid circuit boards and batteries – can be integrated into soft, inflatable objects without compromising their mechanical surface compliance or malleability.

While bendable or stretchable sensor surfaces have been presented before [16,2,3], our work combines these characteristics in a thin and lightweight textile touch and pressure sensing sheet, that can conform to dynamically changing surface geometries. One dimensional touch input on curved surfaces has been achieved with a tape-like sensor [8] that is deformable, but not stretchable and cannot compensate for larger surface deformations. *Electrick* [25] enables touch input on non-planar static/rigid objects but is not suitable for malleable objects since any change of surface geometry requires retraining of the machine learning pipeline. Elastomer-based stretchable sensors [22,23] and circuits [11] enable capacitive touch input but cannot measure force/pressure input. Other approaches for touch input on curved surfaces rely on camera vision [14,17] or optical sensors [18], which limits the design space by introducing constraints on usable form factors. Despite these initial steps towards flexible circuitry and pliable sensors, most commercially available electronic components are made from rigid materials. Thus, designers commonly resort to solid black-box enclosures for such non-malleable components [21,10,17] which might diminish the desired use qualities inherent to soft- or shape-changing interfaces. Our work addresses the issue of integrating conventional electronics with malleable devices, through a bio-inspired approach for combining soft and rigid structures. This enables the creation of entirely soft inflatable input devices with integrated functionality, without compromising their tactile and visual appearance, or the mechanical protection of the built-in electronics. Our **work-in-progress prototype** makes the following **contributions**:

- A textile sensor layer that is *both* flexible *and* stretchable and can measure force (pressure) *and* touch input (contact area/proximity) on non-planar malleable surfaces (e.g. inflatables).
- A *bionically inspired method* for *robust integration* of rigid electronic components into *malleable (inflatable) structures* without the need for additional enclosures or rigid black boxes.

2. SENSOR DESIGN & INTEGRATION

To demonstrate the capabilities of our system, we constructed a malleable, **inflatable input device** [Fig. 2] that is **soft, deformable** and has a **multi-touch** *and* **multi-pressure sensitive surface**. The device is made from multiple functional textile layers [Fig. 1] and membranes, with an air-padded, center of conventional rigid electronic components.

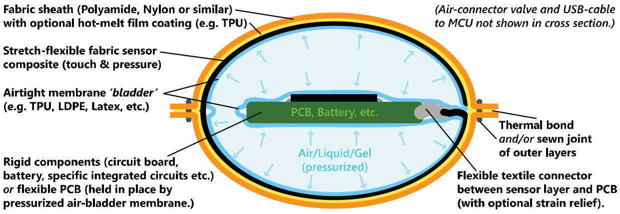

Figure 1. Schematic cross section of inflatable with malleable sensor surface and air-padded standard electronics.

The **stretch-flexible sensor layer** is constructed from three layers of conductive textile sheet materials. A stretchable, non-woven, carbon nano-coated fabric [4] that changes electrical resistance when mechanical pressure is applied, is used as the center layer. Small laser-cut patches (ø 5mm) of non-stretchable, silver-coated nylon [19] are loosely sewn to the center layer from both sides, facing each other, to form a 5 x 8 electrode matrix with a spacing of 8mm. The electrode

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patches are connected in rows on one side, and in columns on the opposite side through continuous strips of the same material. These intermediate connections are laser-cut in a horseshoe serpentine pattern [16,24] which allows for up to 60% surface elongation of the passive conductor matrix layer, while maintaining constant electrical resistance (~2.2 Ω).

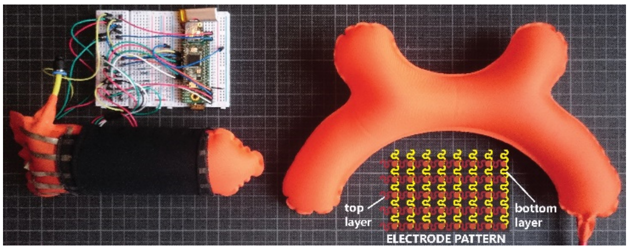

Figure 2. Inflatable input device with integrated stretch-flexible sensor and electronics (right), early prototype (left). (Serpentine sensor matrix pattern for reference).

The sensor composite is placed in-between the outer textile sheath [6] and wrapped around a separate air-bladder (0.05mm TPU-film). Together, these structural layers form the **inflatable membrane envelope.** Both were fabricated individually on a **custom-built CNC-machine** [Fig. 3] that leverages a heatable, all-metal ball caster for **thermal bonding of air-tight thermoplastic membranes** (TPU, LDPE).

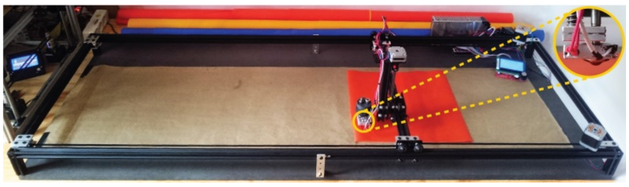

Figure 3. Portable CNC-machine for fabricating inflatables.

While using known fabrication methods [13], our CNC-machine is a **portable and lightweight design** with an (extendable) working area of 1350mm x 300mm and is constructed from low-cost 3D-printer components, mostly based on open-source designs [12]. **Air-chamber layouts** for fabrication are drawn as 2D-vector shapes in common vector graphics software and converted to *G-code* machine instructions with industry standard CAM software [5] and customized machine settings. The machine has been in frequent operation at our lab and at workshops since January 2016.

To **robustly integrate rigid components,** such as circuit boards and off-the-shelf components, **into malleable inflatable structures**, we leverage a fundamental **bionic principle** [1]: *two adjacent membrane envelopes with equal internal fluidic pressure yield a planar boundary surface* [see Fig. 4]. Rigid objects that are placed along this internal surface are safely encapsulated and held in place by air pressure. The mechanical compliance and malleability of the outer sheath remain unchanged, while the air-cushions protect the circuitry [Fig. 1]. To re-charge or to program the device, a cable (e.g. USB or similar) can optionally be inserted between two air-chambers to contact the circuitry. The device can also made fully sealed and untethered, when wireless charging- and programming ports are integrated. The durability and mechanical resistance of the *eTextile* materials used in our sensor has been demonstrated in commercial applications and devices [2,9], though with non-stretchable sensor layers.

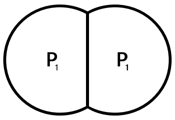

Figure 4. Planar surfaces emerge between air-cells of equal pressure (P_1).

To **obtain user input** from our prototype, the combined **touch and pressure profile** [Fig. 5] is acquired through the sensor layer at a sampling rate of 200Hz for the entire sensor surface (with much headroom), allowing for low-latency user-input. Successive voltage measurements are taken at the intersection of each electrode row (*transmitter*) and column (*receiver*) in the sensor matrix. These point samples are obtained similar to the approach described in [15,3]. The transmitting electrode is set to output a voltage, while the receiving electrode, on the flipside of the sensor sheet, is configured as an analogue-input, using the on-board ADC on a Teensy microcontroller [20]. All other electrodes are set to ground in a high impedance state, effectively rendering them invisible when taking a measurement at a given intersection. On powering up the system, an initial baseline calibration is performed to equalize point measurements. Sensor noise is further reduced by a digital (IIR) low-pass filter. To increase spatial resolution of the sensor, the filtered and scaled sensor readings are interpolated in X and Y direction, using a bilinear interpolation algorithm, and the centre of mass for each rectangle of four measurement points is calculated [see Fig. 5]. A common blob-detection algorithm can then **track multiple fingers** and identify **touch-** or **pressure-areas** with high precision. Additional **capacitive measurements** are obtained for each row and column to detect presence, approximate proximity, and the position of the user's fingers on, or above, the surface. This data can be used to implement additional interactions (such as **basic mid-air gestures**) and to increase the overall sensing precision. The overall **internal air pressure** of the inflatable can be estimated by integrating the measurements from all currently un-touched sensor points.

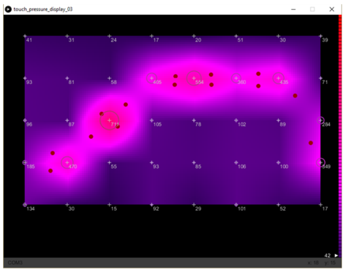

Figure 5. Interpolated touch and pressure data visualization from a 5 x 8 electrode matrix, indicating multiple finger touches.

3. CONCLUSION & OUTLOOK

We outlined the design of a **textile multi-touch** and **force/pressure sensor layer that is stretchable up to 60% and can conform to dynamically changing surface geometries**. We demonstrated how the sensor – including additional rigid electronics – can be **integrated into inflatable objects** without affecting their tactile qualities. The system is capable of **robust, low-latency input-sensing on non-planar, malleable surfaces**.

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