A Haptic Display for Medical Simulation Using Particle Jamming

Andrew A. STANLEY[1], James C. GWILLIAM[1], Timothy N. JUDKINS[2], PhD, and Allison M. OKAMURA[1], PhD

[1]Mechanical Engineering, Stanford University, *astan@stanford.edu*
[2]Robotics and ElectroMechanical Systems, Intelligent Automation, Inc.

Abstract. Medical simulators that allow the user to explore and manipulate artificial tissue with the bare hand require simultaneous control of geometry and mechanical properties of physical surfaces. We present a novel haptic display that forms controllable lumps at various locations on a surface, a feature that could prove useful for simulating palpation tasks. The lumps are created by controlling positive and negative air pressure applied externally and internally to cells filled with granular material. The "particle jamming" behavior of granular material under vacuum influences both surface mechanical properties and geometry. Such encountered-type haptic displays have the potential to present a large variety of physical sensations in a single medical simulator.

Introduction

In many medical procedures, clinicians rely upon the sense of touch to make a diagnosis or treatment decision. Yet, current medical simulators are limited in the variety of physical sensations they can generate; virtual reality simulators are typically limited to interaction via a rigid instrument, and classic mannequins do not permit large changes in geometry and material properties. Encountered-type haptic displays (e.g. [1]) allow the user to move freely in a large workspace without wearing or holding onto a haptic device. An end-effector capable of adjusting its physical properties would maximize the variety and realism of procedures than can be simulated.

The technique of "particle jamming" was recently introduced to quickly and repeatably alter the physical properties of an object. A flexible membrane is filled with a granular material such as coffee grounds or glass beads, and then air is vacuumed from the interior, resulting in a controllable increase in stiffness. Several research groups have used this technique in various applications, including a universal gripper [2], an endoscope [3], a wearable haptic display [4], and robot locomotion [5].

Methods & Materials

Our prototype particle jamming haptic display, shown in Fig. 1, consists of an array of hollow silicone rubber cells filled with coffee grounds, each connected from below to a vacuum line (26 inHg). Toggling each line between vacuum and atmospheric pressure allows for individual control of each cell to transition between the jammed (vacuumed) and unjammed (ambient) state. The array of silicone cells lies over a chamber with an adjustable internal pressure, monitored with an air pressure regulator (SMC-ITV2031-21N2L4, SMC Corporation).

We constructed the array of hexagonal jamming cells using an investment casting process similar to that described in [5]. After laser cutting primary molds from acrylic, we poured silicone (Platinum Silicone, Tap Plastics) to create a soft rubber secondary mold that we used to shape the hexagonal wax tablets (Cerita Casting Wax) (Fig. 2a). Wax tablets were then suspended using 4-40 threaded rods and nuts in another acrylic mold (Fig. 2b), which we subsequently filled with a softer silicone (Dragon Skin 10 Fast Silicone, Smooth-on) (Fig. 2c). Melting out the wax in an oven at 200^{o} F leaves vacant regions in the silicone in the shape of the tablets (Fig. 2d) to be filled with coffee grounds. A thin acrylic structure supports the array between the cells.

Results

The resulting haptic display consists of 12 individually vacuumed hexagonal cells, each measuring 0.5 inches per side, sealed over a single pressure chamber. Selectively jamming certain cells provides variable stiffness properties across the array, and adjusting the chamber air pressure beneath the array allows the generation of a variety of surface geometries (Figs. 3,4). Increasing the chamber pressure while all but *n* cells are jammed results in *n* distinct lumps, which can then be jammed rigid before the chamber pressure is decreased and the flat cells are unjammed to soften them. The chamber could also be negatively pressured to result in distinct dents. In addition, jamming cells that have been deformed by positive or negative pressure changes the mechanical properties of the cells while in the deformed state. We tested a prototype from approximately 0-12 psig chamber pressure without failure. The current prototype's performance is primarily limited by air leakage out of main chamber and into vacuumed cells.

Conclusions & Discussion

A novel haptic display utilizing the particle jamming technique provides an entirely pneumatically actuated surface with individually controlled jamming cells that can be integrated into an encountered-type haptic medical simulator. This device could prove particularly useful for simulating tumors or other lumps in palpation tasks, as well as wounds and other concave features. Future work will test different geometries and methods to optimize cell size, shape, thickness, and packing density.

Acknowledgments

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References
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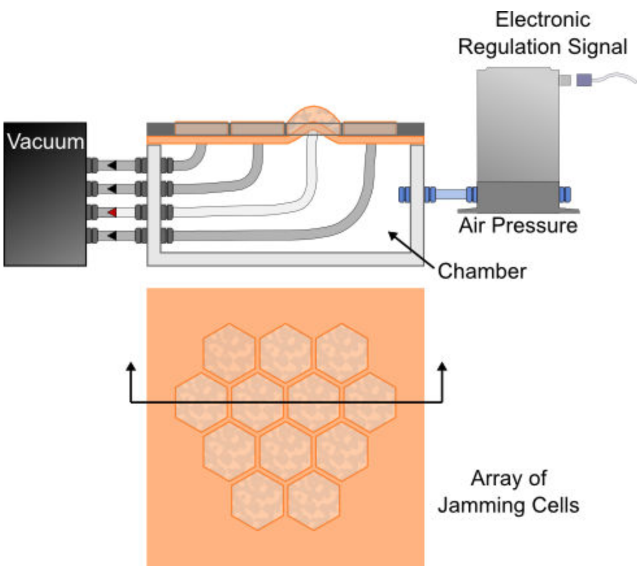
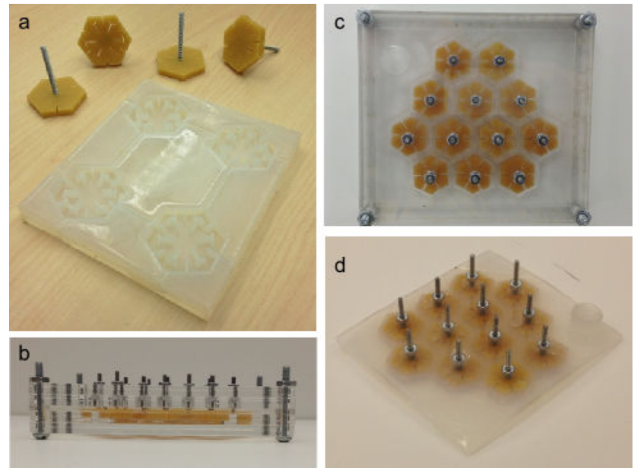
Illustrations



#1. Particle jamming haptic display setup. An array of particle jamming cells are sealed above the pressure chamber, which is regulated electronically. Each cell can be individually jammed or released by toggling its vacuum line between the vacuum and atmospheric pressure, respectively.



#2. (a) Wax tablets are created from a rubber mold. (b) Tablets are suspended with screws while silicone is poured around them. (c) Top view of the mold before pouring silicone. (d) After the silicone is cured, the wax is melted out to leave hollow spaces to be filled with coffee grounds.

#3 (a) All cells are vacuumed and the chamber is unpressurized. (b) Two cells are released (unvacuumed) and the chamber is pressurized, resulting in two cells expanding to form protrusions.

#4 All cells are released (unvacuumed). The chamber pressure from below causes the cells to reshape and protrude.