

# SoftBot: A soft-material flexible robot based on caterpillar biomechanics

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## 1. Soft Materials in Robots

Most machines are built from stiff materials that are jointed or mounted on pivots to allow movements. When soft materials are used in such machines they usually act as springs or dampers to provide stability. The incorporation of such deformable materials can make movement control more difficult because conventional control systems are derived from rigid body mechanics. In contrast, most animals are composed predominantly (or solely) of soft materials that have co-evolved with a neural control system to generate smooth, adaptable and robust movements. The goal of the current project is to achieve similar performance in a new class of robots (SoftBots) by designing them from soft materials. A key feature of the SoftBot is that the control system is engineered using biologically inspired neuromechanical control systems that exploit complexity in the materials themselves.

A soft-material flexible robot will be an essential tool for the medical field in the future. Surgeons of all specialties would benefit from a deformable, controllable, and sterile robot for exploratory surgeries, drug deliverance, endoscopies, angioplasties, and a multitude of other medical applications. This robot will also solve issues such as patient comfort, cost, and elapsed surgery time. Based on the mechanics of the caterpillar *Manduca sexta*, this SoftBot will be able to maneuver in any direction, deform to fit into tight spaces, and carry heavy payloads. However, this technology is not limited to the medical field; it could also be applied towards many other disciplines such as search and rescue missions conducted by military after tragedies such as building collapse or floods.

## 2. Soft Bodied Design

Designs for the SoftBot are governed by the ability to deform, maneuver, and to be easily scalable and manufactured. Mimicking the caterpillar, the SoftBot is divided into three main components: the body wall, the actuators (muscles), and the control system (nervous system). The body is a contoured cylinder constructed from highly elastic silicone rubber. The local properties of the body wall can be made

anisotropic through the addition of woven polymer fibers during casting. The body wall is thickened and contoured in segments to resemble the caterpillar and to promote useful deformations. This shape will eventually be optimized using structurally based constitutive models [1, 2] of the caterpillar and robot.

Shape memory alloy (SMA) coils are bonded directly to the inside of the body wall providing linear actuation that is remarkably similar to that of *Manduca* muscle [3]. Appropriate strains (30-100%) and forces (0.1-1N) can be obtained by coiling and heat setting the SMA wire. The body wall serves as a bias (recoil) spring and actuation of adjacent springs can also re-extend SMA coils actively. The body contains an inner compartment (the “gut”) to hold components of the control system and additional payload. The space between the “gut” and body wall can be pressurized to transmit forces and regulate stiffness. Softbot is expected to be fault tolerant [4], capable of extreme mobility (including shape changing) and exceedingly simple to build.

Each actuator is controlled using a pulsed current source driven by a master oscillator to maintain the overall cadence of a crawl. This rhythm is coupled to a second oscillator whose frequency and duty cycle can be varied to generate square wave bursts. Alterations in these parameters are used to control the overall amplitude of the force and contraction of the actuators or to move the work-loop responses into a different operating range. In addition to conventional finite state machine commands based on *Manduca* motor patterns, more complex movements will be generated using genetic algorithm optimization of the control parameter values.

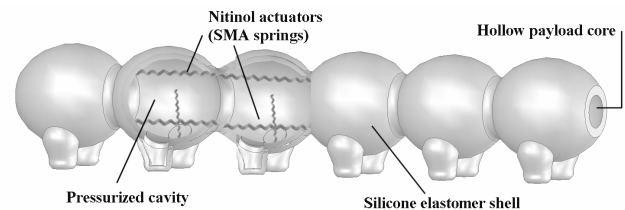


Fig. 1. Overall layout of SoftBot in partial cutaway longitudinal section.

### 3. Other Engineering Challenges

Some of the most challenging aspects of soft robot construction arise at the interface of different materials. It is particularly difficult to incorporate electronic components based on metals and semiconductors with flexible polymers. Future SoftBots will therefore use compliant electronics and miniaturized hardware that can be embedded in a distributed array within the soft materials. Another challenge is in developing a sensing system for adaptive autonomous movement and navigation. *Manduca* is equipped with a vast array of mechanosensors for proprioception and extrareception. By examining the encoding of information in these receptors and its effect on central motor patterns we can design an analogous feedback system for SoftBot. Finally, *Manduca* itself is highly scalable growing in mass 10,000 fold without changing its musculature or central control system. We expect SoftBot to be similarly scalable and miniaturization will allow the use of a different set of fabrication techniques. To this end we are developing integrated SMA/polymer membranes for use in microscale soft robots.

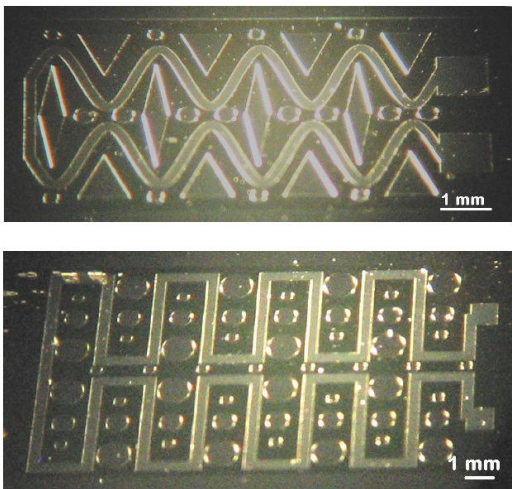


Fig. 2. Two of the SMA-elastomer actuator patches at an intermediate step in the microfabrication process.

Previous authors have described nitinol actuators for a variety of MEMS applications [5]. However, we are aware of no example of the application of microfabricated nitinol patches to robotic locomotion. A number of designs for the actuator patches are under investigation. All designs consist of a nitinol (Ni-Ti alloy) microwire on a flexible polyimide base. The overall dimensions of the patches vary from 7.75 x 3.5 mm to 22 x 10 mm. The substrate is the 6  $\mu\text{m}$  thick photodefineable polyimide, which provides both the flexible support and the restoring spring for the actuator. The nitinol

microwire is 1  $\mu\text{m}$  thick co-sputtered nickel-titanium alloy. It varies in width from a maximum of 0.8 mm to a minimum of 0.1 mm. The polyimide is photodefined in a mesh structure so that the sheet is much more compliant in tension and compression than a flat sheet. The nitinol microwire meanders across the polyimide structure in what may be considered a planar imitation of a coil spring. The combination of the meandering wire and the mesh-like polyimide substrate should allow significantly larger deformations than would be achieved otherwise. Micrographs of two of the designs appear in Figure 2.

Microfabrication of the SMA-elastomer composite actuators is being carried out using surface micromachining techniques. Characterization of the SMA actuators is also ongoing. Modeling efforts are also underway, based on the constitutive laws described by Brinson [6]. These composites will make it possible to build a SoftBot small enough to invade the oral cavity and navigate through the intestine.

### References

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