Locomotion of a Simple Foam Robot

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1. Introduction

Robots that can easily interact with humans and natural environments are becoming increasingly essential for applications such as disaster relief, search and rescue, structure inspection, surveillance, medical diagnostic and therapy, and human machine interaction. Important characteristics will include robustness, low impact forces, and the ability to negotiate unstructured environments. One strategy towards accomplishing these goals is to build the robots using soft and flexible materials. This can make them much more approachable and less likely to damage their environment [1, 2]. In an effort to address this, foam robots have become an emerging technology in the field of soft robotics [3-6].

We present a robotic platform made from open-cell polyurethane foam for studying manufacturing and control of soft foam robots. The robot illustrates that simple geometry and actuator arrangement, combined with highly-deformable non-linear material, can produce complex movements through unstructured environments. The soft nature of the foam allows the robot to adapt to uncertainties in the environment. Its non-linear material properties are useful in exploiting dramatic shape changes without significant energy draw.

2. Robotic System

A simple morphology is chosen to primarily focus on understanding the effects of using foam as a structural material, and the role of actuator placements on the robot's locomotion. The simple design produces complex behavior with a limited number of actuators (Fig 1). The body of the robot is a $300 \times 150 \times 25$ mm slab of compressible open-cell polyurethane foam. Locomotion is achieved by two motor tendon actuators. Motors, tendon paths and anchor points are arranged in a semi-arbitrary configuration. Arbitrary is defined as comprising a large number of degrees of freedom making it difficult to predict the motion and its control. 'Semi-arbitrary' is when the motor placement, tendon paths and anchor points are chosen by previous knowledge of how the ground reactions and differential friction might affect locomotion [7, 8]. The design presented here does not require fasteners or other 'hard' connections that would make the robot more rigid than desired, nor does it use complex over-molding techniques. Instead, the components are sutured into place allowing the use of traditional casting techniques with self-expanding polyurethane foam for the robot body.

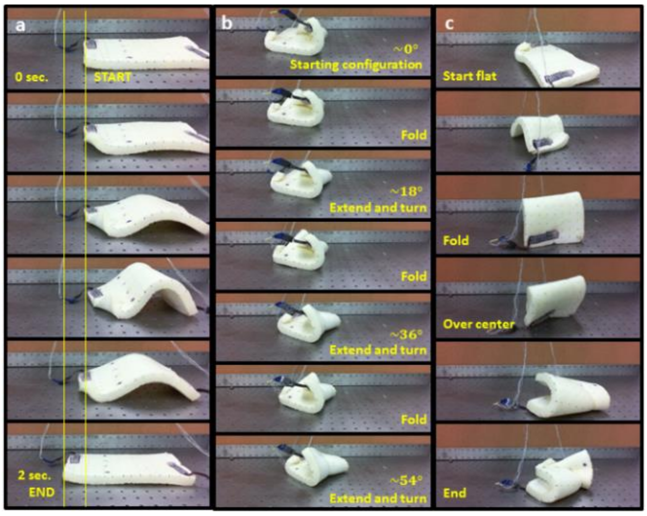

Figure 1: The motors were actuated with game controller inputs to an Arduino-controlled array of motor drivers. a) The robot demonstrating an inching gait. Forward speed is approximately 13 mm per second. b) The robot demonstrating a turning gait. Each motion of this configuration produces about 18 degrees of rotation. c) The robot folding and flipping end-over-end.

3. Performance

The robot is capable of crawling, turning, flipping and dramatic shape change (Figure 1). Forward inching speed is approximately 2.6 body lengths per minute (13 mm/sec) with an average electrical power draw of 2 Watts. Locomotion depends on differential friction and thus contact area with the substrate. Therefore, the body must be contorted into a shape that has one large and one small contact patch. Combinations of these contact patches placed in appropriate orientations generate desirable locomotion behaviors. For example, a large contact area in the front of the fold and a smaller contact area at the back results in the rear of the robot being pulled to the front during actuation (Fig 1). When the actuator is turned off, the motor unwinds and the robot lays flat. There is enough friction on the rear surface as tension is released to overcome the friction in the front and propel the robot forward. Similarly, the robot turns by first creating a large contact area on one side to make a pivot, and then actuating the opposite corner (Figure 1b).

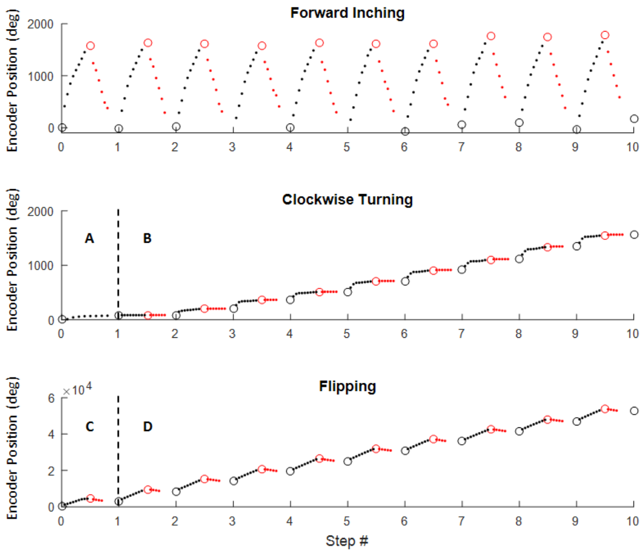

Figure 2: Encoder data for forward inching, clockwise turning and flipping behaviors. Black is compression of the robot and red is the extension. Black open dots are the beginning and end of a single step and red open dots are mid step. A is the compression phase where the robot is distorted to the preferred shape for rotation and B is the movement phase where the robot takes steps and turns. C is the first step where the robot flips and D is the motor trying to step but making no progress while upside-down.

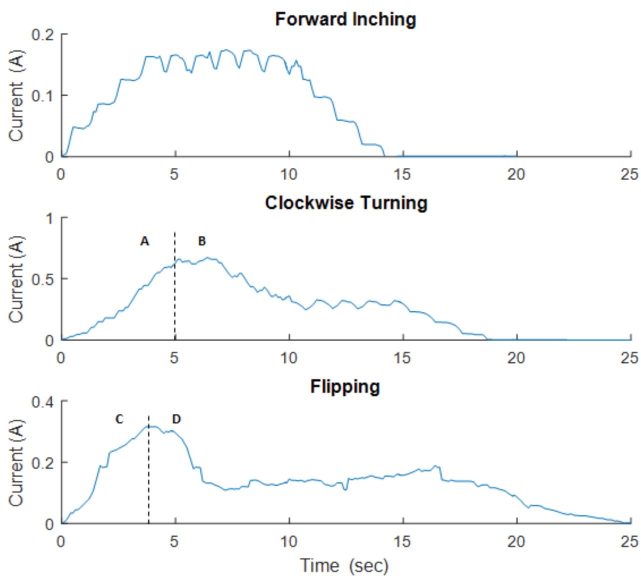

Figure 3: Current data for forward inching, clockwise turning and flipping behaviors. A, B C and D phases are the same as described in Figure 2.

New behaviors emerge as these differential friction and tendon placement properties are further exploited by actuating the robot at different rates. The strain response of open-cell foam is bi-linear and heavily strain-rate dependent. When the parameters for forward inching are changed, an end-over-end flipping behavior emerges (Figure 1c). Additionally, tendon routing and its interaction with body can change the deformed shapes and generate a large number of deformations from a small number of actuators.

Motor encoder position and current were recorded for each of the three behaviors over 10 iterations (or steps) (Fig. 2 & 3). For forward inching the repetitive, stepping gait is evident in both encoder and current data. Each step comprises a forward motion of the motor for compression and bending and backward motion for relaxation (Fig. 2). Likewise, current draw increases to 0.2A and it rises and falls over the ten steps during forward inching.

However, the data for turning and flipping, while distinct from forward inching, show little distinction from each other in the motor encoder data (Figure 2). Indeed, they are difficult to tell apart without consulting the current plots (Figure 3). The turning gait has a slow compression phase A and rising and falling current peaks evident in phase B (Fig. 3), this is not easily seen in the encoder data. On the other hand, the flipping gait shows one large step in the current data during Phase C, during which the structure goes over center and inverts. In phase D, the system no longer moves using this gait (Fig 3). Thus, the current is relatively constant until the motor shuts off at about 18 seconds. Thus, both motor current and encoder data are useful for identifying, and, potentially, in future work, controlling motion.

4. Conclusions

A simple, soft, foam robot with semi-arbitrary motor tendon arrangement was developed in order to demonstrate that complex and unpredictable behavior emerges from shape change in the form of folding and compressing the robot. By varying actuator input parameters, the robot demonstrated forward inching, turning and flipping behaviors. The actual number and types of achievable behaviors is unknown due to the large number of degrees of freedom of the foam body, possible orientations and attachments points of the actuators, and placement of additional components (e.g. electronics, power sources, etc). We show that both motor encoder and motor current data may be useful for motion sensing and control. In the future, high-level control will be implemented [8, 9] with the expectation of producing efficient locomotion for unstructured environments.

5. References

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