

Leveraging compliance in origami robot legs for robust and natural locomotion

X. Deng, C. Sung

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Abstract

Making legged robots walk and run like humans and animals has been a challenging task of robotics research. Previous work has proposed a bio-inspired dynamical template [Holmes et al. \(2006\)](#) that describes the body movement of animals' running as a point mass bouncing on an elastic leg. In this template, stiffness is the key parameter that characterizes the bouncing motion by associating the ground reaction force with leg compression.

Legged robot designs that similarly make use of elastic energy in this way have demonstrated greater robustness and efficiency of locomotion [Saranli et al. \(2001\)](#) than their rigid counterparts. However, these designs are often complex and take quite a bit of effort to produce. In contrast, origami-inspired robots are able to naturally incorporate compliant mechanisms while being relatively fast to fabricate. Furthermore, origami-inspired robots have unique advantages in terms of their lightness, low cost, and re-configurable features, which in turn can make origami-inspired robots more accessible for prototyping and design investigation.

Inspired by the dynamical template of animal's running in [Holmes et al. \(2006\)](#), we have developed a compliant origami robot leg with the following objectives: 1. The leg adapts to unforeseen physical interactions and uneven terrains; 2. The adaption to physical collisions reduces unexpected impacts in comparison to stiff legs; 3. Nonexpert designers without technical backgrounds can easily design and fabricate the legs for their robotics applications. In this paper, we describe our leg design that satisfies these objectives, and we present parameterized designs that allow users to specify body structure and stiffness for their particular application.

Leg Design

The proposed origami robot leg design includes two key components: an extendable leg and revolute ankle, both with intrinsic spring mass dynamics. As shown in Fig. 1a, from a high level perspective, the designed actuators resemble two commonly used dynamical templates: a spring-loaded inverted pendulum and a torsion spring. The combined design allows automatic whole leg adjustments to unknown physical interactions at the foot while reducing impacts as opposed to a rigid leg.

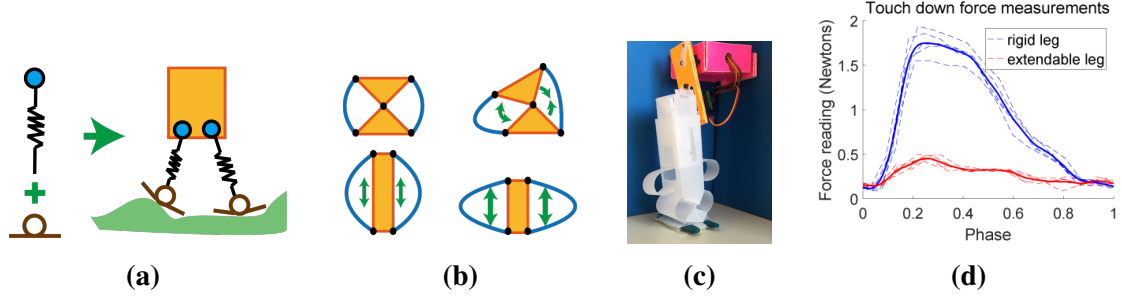


Figure 1: (a) High level design idea of proposed origami leg. (b) Cross-sectional view of extendable leg and ankle. (c) Fabricated prototype. (d) Impact forces for rigid vs compliant origami leg.

Leg Stiffness. Bending faces are the key component of our designs. Fig. 1b shows a cross-sectional view of our joints in orange, with blue lines corresponding to external bending components. The bent material results in a spring-like restoring force that pushes the joint to its equilibrium position. The restoring force increases with the magnitude of deflection, and the stiffness of these faces depends on their length and material thickness. Joint stiffness can thus be adjusted by adjusting face lengths during the design phase or through on-site active control.

Design Parameterization. We have developed parameterized fold patterns for each of the 3D primitive shapes (prismatic and rotational joints Sung and Rus (2015) and bending faces) that constitute the designed extendable leg and ankle. The parameters can be adjusted to create legs of varying dimensions and stiffness. An example of a fabricated leg is shown in Fig. 1c.

Experiments

To quantitatively understand how the proposed origami leg can help for adaptive locomotion against unforeseen physical interactions while reducing the impacts (objectives 1 and 2), we measure the contact forces when the foot comes into contact with the ground for a single leg executing a periodic motions. Compared to the rigid leg of the same design (joints fixed), impact forces between the foot and the ground were reduced by approximately a factor of four (ref. Fig. 1d). We are currently continuing experimental measurements and will have complete characterizations of the impact forces experienced by the leg, as well as a full quadrupedal robot design for the full submission.

References

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