SoRX: A Soft Pneumatic Hexapedal Robot to Traverse Rough, Steep, and Unstable Terrain

Zhichao Liu, Zhouyu Lu, and Konstantinos Karydis
University of California, Riverside
Introduction:

Studies have shown that incorporating compliant legs can significantly improve the speed and stability in varying environmental conditions [1].

Introduction:

**Springy C-leg**

![Image](image1.png)

U. Saranli et al., 2001

**Tunable Device**

![Image](image2.png)

K. C. Galloway et al., 2009

**Direct Drive Robots**

![Image](image3.png)

T. Apgar et al., 2018

**Artificial Muscles**

![Image](image4.png)

T. Takuma et al., 2008

These compliant legs come together with rigid parts

Limit the contact area along the length of legs

Reduce the ability to adapt to the environment

Zhichao Liu et al. (ICRA 2020)
Related Work:

**Soft Pneumatic Actuator**

Bend and squeeze to fit the shape around obstacles

**Shape Memory Alloys**

Reduce the contacting stress over surroundings and the robot

**3D-Printed Soft Actuator**

Appropriate for locomotion in uneven and/or sensitive environment [1].

**Leg and Wheel**

- R.F. Shepherd *et al.*, 2011
- S. Mao *et al.*, 2016
- D. Drotman *et al.*, 2017
- A. Sadeghi *et al.*, 2016

---


Zhichao Liu *et al.* (ICRA 2020)

SoRX: A Soft Pneumatic Hexapedal Robot
Related Work:

**Soft Pneumatic Actuator**
- R.F. Shepherd et al., 2011

**Shape Memory Alloys**
- S. Mao et al., 2016

**3D-Printed Soft Actuator**
- D. Drotman et al., 2017

**Leg and Wheel**
- A. Sadeghi et al., 2016

**Limits:**
- a. one degree of freedom
- b. unable to traverse rough terrain

**Limit:** require multiple leg configurations for rough terrain.

**Limit:** require rigid wheel for rough terrain.
Related Work:

Cable-driven Soft Legged Robots

Limits:

a) no stiffness varying property

b) the necessary motors may make the robot top-heavy and unstable [1].


J. M. Bern et al., 2019

Zhichao Liu et al. (ICRA 2020)
Summary:

In this work, we develop:

- A novel 2-degree-of-freedom soft pneumatic actuator with stiffness-varying property
- A novel Soft Robotic hexapedal robot (SoRX)

SoRX Size:  
- 230 mm (L)  
- 140 mm (W)  
- 100 mm (H)  

Weight:  
- 650 g
The actuator has two parts:

a) Bending Part (PneuNet\cite{1})

b) Extension Part (Hyper-Elastic Bellows\cite{2})

Simulation in SOFA \cite{3} with Soft Robot Plugin \cite{4} to guide the design.

Fabrication:

- **3D-printed Molds:**
  Onyx material reinforced with carbon fiber.

- **Casted Actuators:**
  Silicone elastomer *(Dragon Skin 10 FAST, Smooth-On)* and adhesive *(Sil-Poxy, Smooth-On)*.

*Fabrication time < 1.5 hrs*
Performance:

**Extension Test**

The actuator can elongate by 48 mm at 30 kPa.

**Bending Test**

The actuator can bend 91 deg at 60 kPa.
Performance:

We measured the force generated by the actuator to illustrate the stiffness-varying property.

The actuator can apply 10.67 N at 20 kPa.

The robot can lift a maximum weight of 3.26 kg with an alternating tripod gait.
Gait Analysis:

A pressurization and depressurization sequence in air sources.

An effective cyclic control trajectory.
Experiments:

- Running
- Step Climbing
- Traversing rough terrain
- Traversing steep terrain
- Traversing unstable terrain
Running:

*Top speed of 0.44 body lengths per second (BL/s), or 101 mm/s on flat ground.*
Running:

**Speeds for Soft Robots**

<table>
<thead>
<tr>
<th>Robots</th>
<th>Speed [BL/s]</th>
<th>Speed [mm/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SoRX</td>
<td>0.44</td>
<td>101.0</td>
</tr>
<tr>
<td>Quadrupedal[1]</td>
<td>0.14</td>
<td>20.0</td>
</tr>
<tr>
<td>Puppy[2]</td>
<td>0.12</td>
<td>15.6</td>
</tr>
<tr>
<td>Multigait[3]</td>
<td>0.05</td>
<td>6.7</td>
</tr>
<tr>
<td>Five-limb[4]</td>
<td>0.003</td>
<td>0.43</td>
</tr>
</tbody>
</table>

SoRX is the fastest soft pneumatic legged robot to date.

SoRX: A Soft Pneumatic Hexapedal Robot

Zhichao Liu et al. (ICRA 2020)

Step Climbing:

SoRX can overcome obstacles up to 15 mm tall passively.
Rough Terrain:

0.171 body lengths per second (BL/s) for sandy terrain

0.198 body lengths per second (BL/s) for rocky terrain
Transitioning Mixed Terrain:

0.292 body lengths per second (BL/s) for a mixed terrain with the same gait pattern.

Terrain traversal speeds for Quadrupedal[1] and SoRX

Steep and Unstable Terrain:

- A 10-degree inclined slope.
- A 15-degree inclined groove.
- An unstable platform vibrating with a speed of approximately 200 mm/s.

SoRX is the first soft pneumatic legged robot to climb a slope.
SoRX: A Soft Pneumatic Hexapedal Robot to Traverse Rough, Steep, and Unstable Terrain

Thank you!