Improving Grip Stability Using Passive Compliant Microspine Arrays for Soft Robots in Unstructured Terrain

Lauren Ervin, Harish Bezawada, and Vishesh Vikas
Agile Robotics Lab, The University of Alabama

Introduction and Motivation

Microspine grippers are small spines commonly found on insect legs that reinforce surface interaction by engaging with asperities [1-3]. An array of these microspines fixed to the limbs or undercarriage of a robot can increase its ability to maneuver uneven terrains. There remains a real-life realization gap for Soft Robots' (SoRos') transition from controlled environment to complex terrains, shown in Fig. 1, that can be addressed by improving grip stability through the integration of microspines.

Fig. 1: Microspine Motivation in Unstructured Terrain

Contributions: We present a passive, compliant microspine mechanism that enhances the locomotion capabilities of mobile SoRos.

1. **We define a soft-compliant SoRo-microspine array integration method.**
2. **We enable independent, adaptable gripping of asperities per microspine with reduced complexity via a single actuator.**
3. **We perform field experiments with 3 robots on 4 surfaces. Tracking indicates microspines improve both repeatability and traversability.**

Compliant Microspine Mechanism and Array Integration

There are three critical design parameters that impact the effectiveness of the microspine mechanism shown in Fig. 2:

1. **Mechanism compliance and surface contact angle,**
2. **Soft-hard stiffness integration, and**
3. **The microspine array configuration.**

The design utilizes a two-row, stacked microspine array configuration shown in Fig. 3. This grouping offers additional gripping capabilities on steep/irregular surfaces from the top row without hindering the effectiveness of the more frequently active bottom row. **Crucially, not all microspines must interact with a surface for the array to be effective.** They are integrated into SoRos shown in Fig. 4.

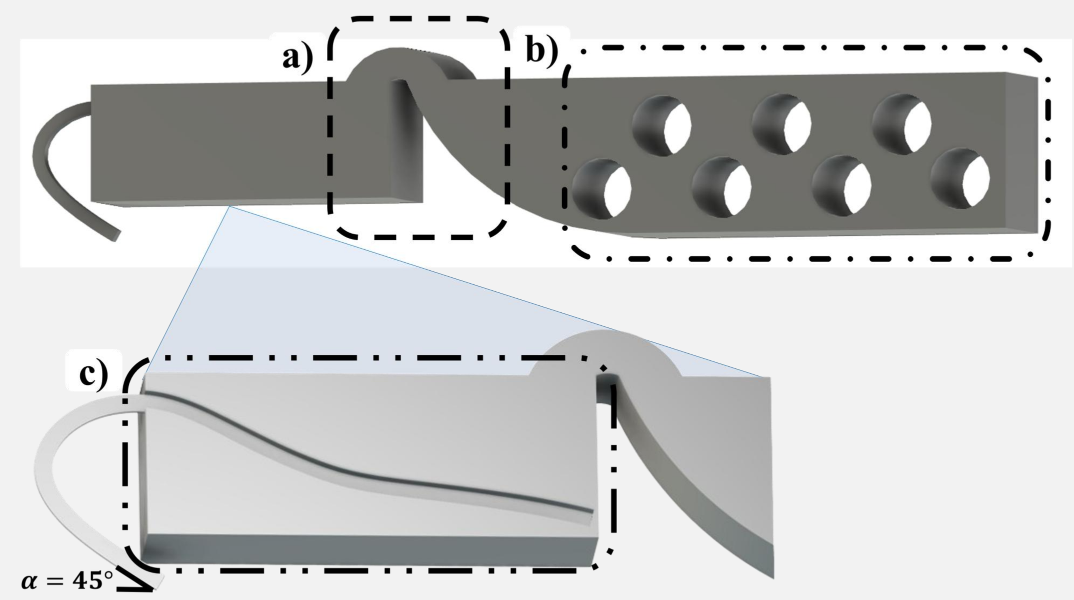

Fig. 2: Compliant Microspine Mechanism

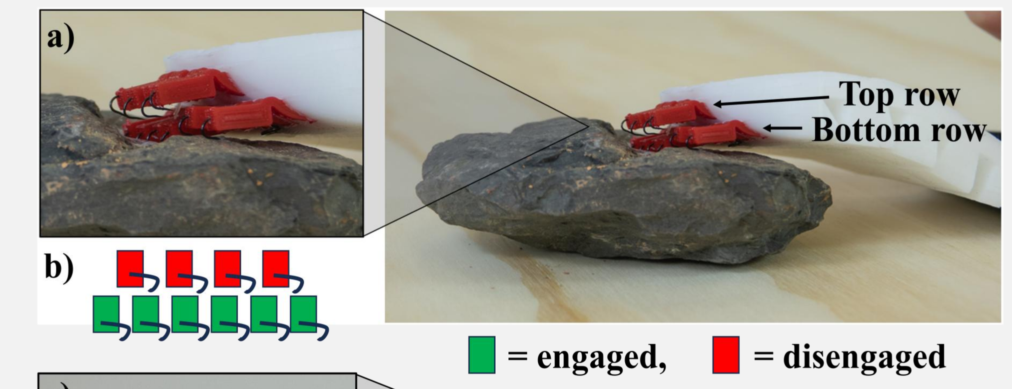

Fig. 3: Two-Row Microspine Array

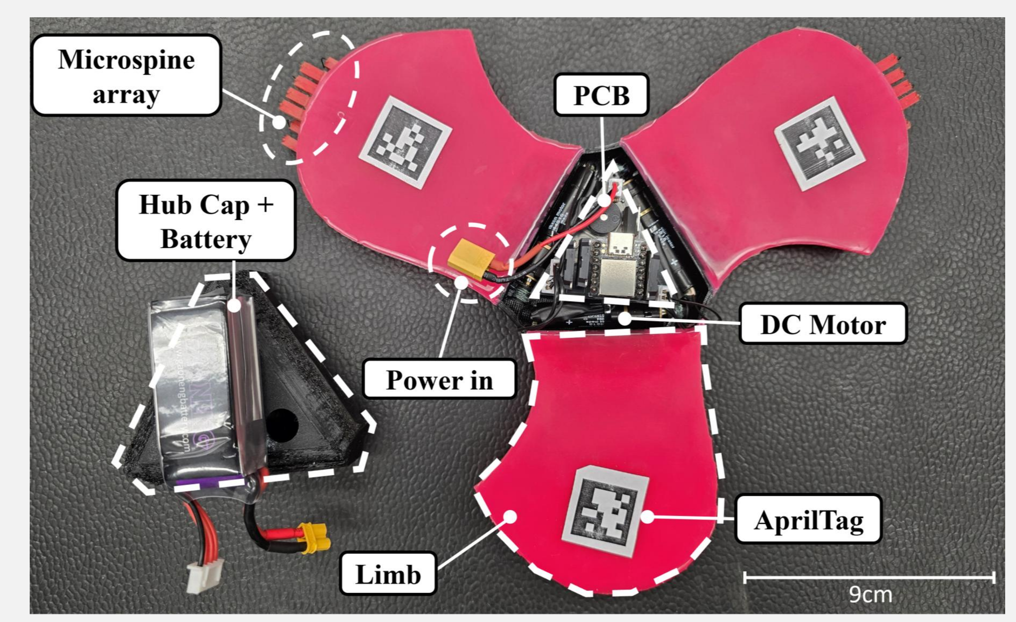

Fig. 4: SoRo Mechatronics

Field Experiments

- Field tests were performed on four different surfaces:
  1. Concrete 2. Brick 3. Sand 4. Forest floor
- A push-pull translation gait (actuation of one limb then the other two) is used [4].
- 3 trials (60 gaits/trial) are performed per prototype (three total) and surface (four total), resulting in **a total of 36 trials** with tracking shown in Fig. 5.

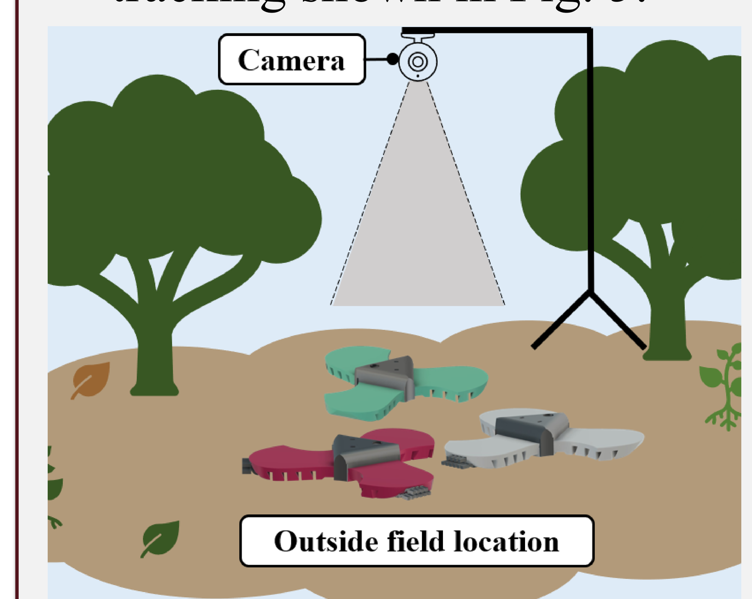

Fig. 5: Experimental Setup

Qualitative Results

Experiments validate the integration of the compliant microspine array **1. increases grip stability 2. surface interaction 3. terrain traversal.**

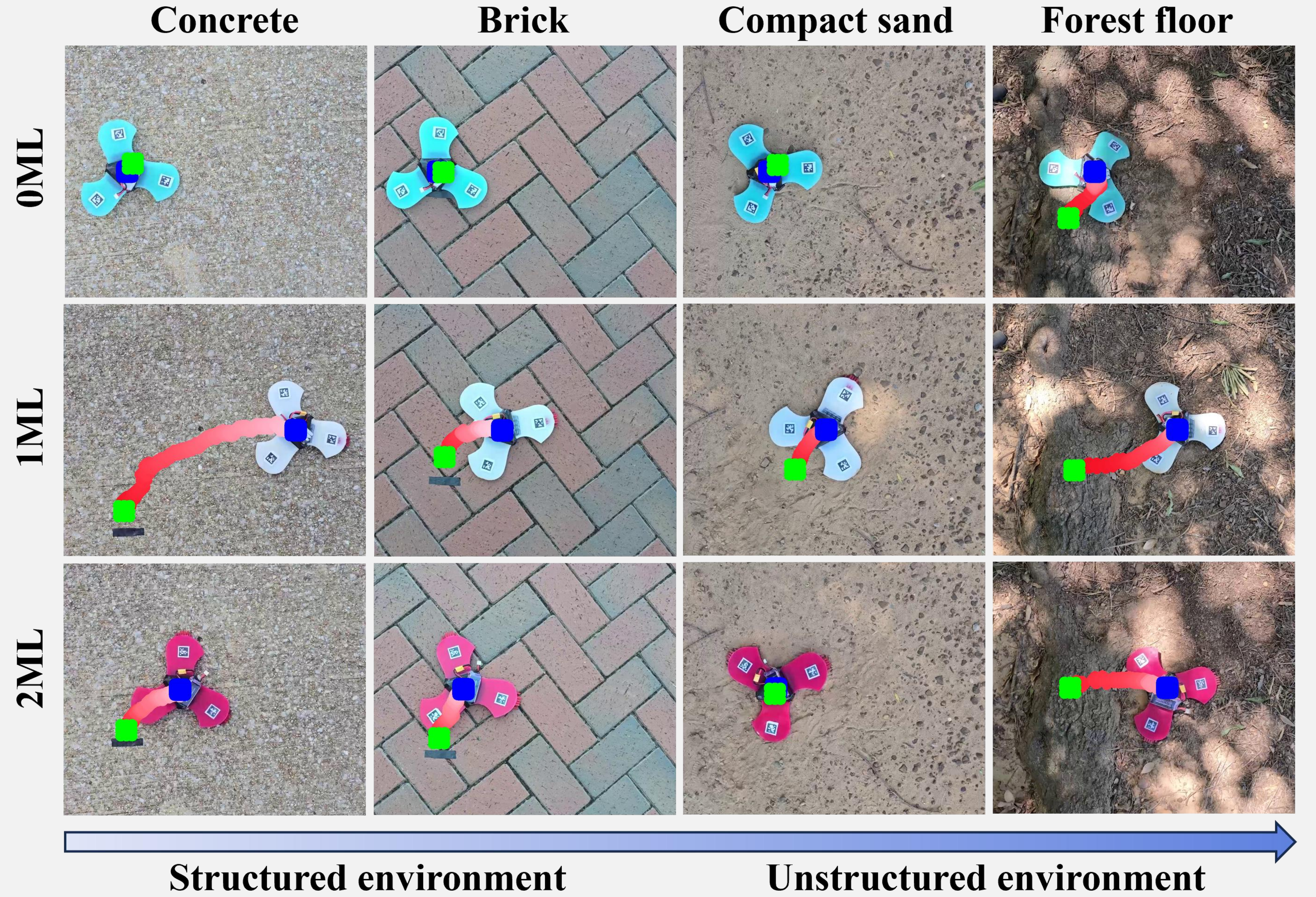

Fig. 6: Experimental Qualitative Results

Quantitative Results

Three prototypes: 0ML (baseline), 1ML (array in one limb), and 2ML (arrays in two limbs) in Fig. 7.

Fig. 7: Three Prototype Array Configurations

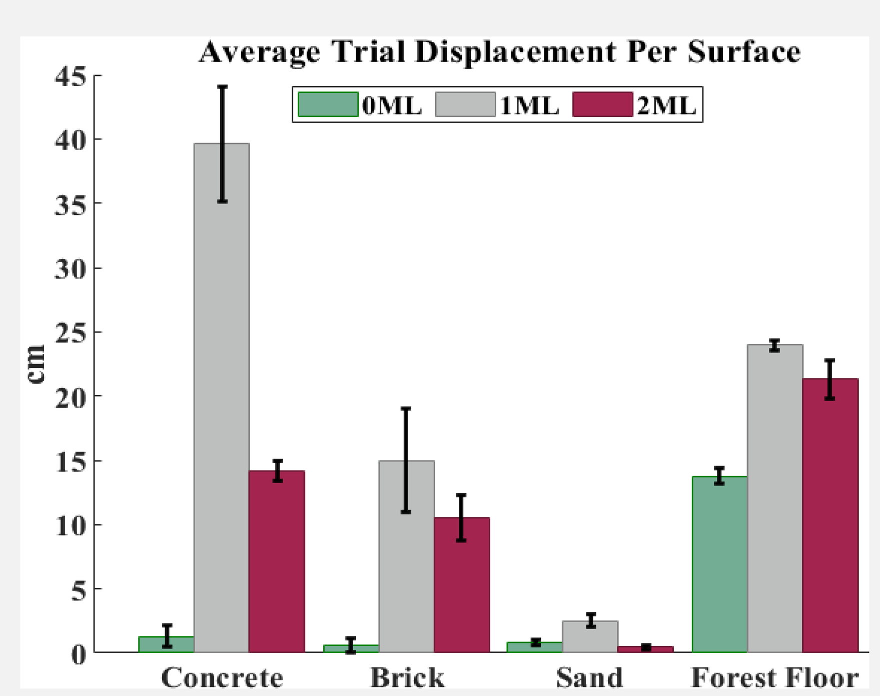

Fig. 8: Average Displacement

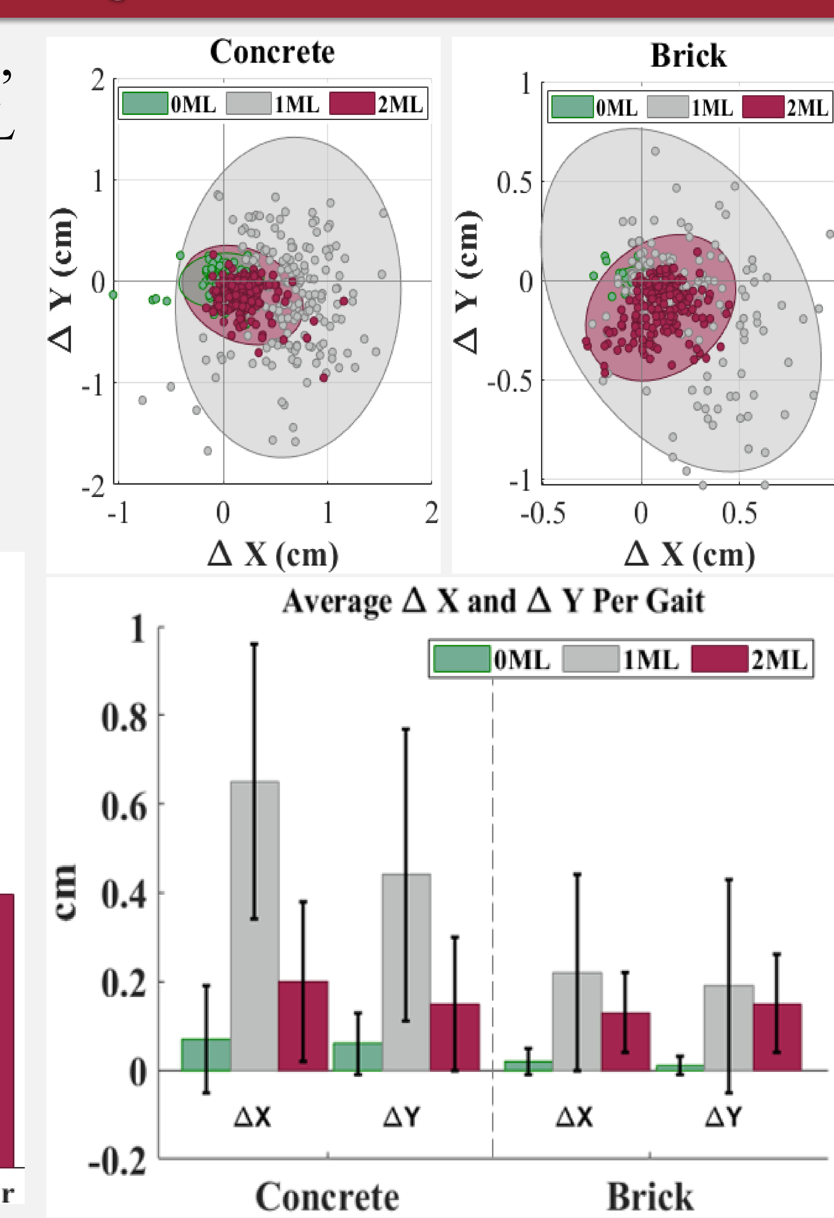

Fig. 9: Gait Analysis

Fig. 8 shows the average displacement and σ of the three trials per prototype/surface combo.

- On concrete, 1ML traversed >30x and 2ML ~11x over 0ML.
- On brick, 1ML traveled ~25x and 2ML 18x more than 0ML.
- On sand all SoRos struggled, but 1ML still traveled >3x 0ML.
- In the forest, 1ML & 2ML overcame debris blocking 0ML.
- In each trial the robots move 60 gaits, resulting in a total of 2,160 gaits. Consistency is analyzed by examining ΔX, ΔY for every gait shown in Fig. 9. **The relative σ for 1ML, 2ML is lower than 0ML, indicating improved grip + repeatability.**

References

[1] Sangbae Kim, M. Spenko, S. Trujillo, B. Heyneman, D. Santos, andM. Cutkosky, "Smooth Vertical Surface Climbing With DirectionalAdhesion," IEEE Transactions on Robotics, vol. 24, no. 1, pp. 65–74,Feb. 2008.

[2] A. T. Asbeck and M. R. Cutkosky, "Designing Compliant SpineMechanisms for Climbing," Journal of Mechanisms and Robotics,vol. 4, no. 3, p. 031007, Aug. 2012.

[3] P. Nadan, S. Backus, and A. M. Johnson, "LORIS: A Lightweight Free-Climbing Robot for Extreme Terrain Exploration," ICRA, pp. 18480–18486, May 2024, doi: 10.1109/icra57147.2024.10611653.

[4] C. Freeman, A. N. Mahendran, and V. Vikas, "Environment-centriclearning approach for gait synthesis in terrestrial soft robots," 2024.[Online]. Available: https://arxiv.org/abs/2402.03617

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