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A Tensegrity Robot that Tumbles by Distributed Movable Masses

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1 Introduction

Tensegrity is a structure where the configuration of rigid bodies is stabilized by cables' tension. In particular, Class-N tensegrity refers to a tensegrity where rigid bodies can be represented by less than N simple struts that only bear compression [1]. Therefore, Class-1 tensegrity consists of struts and cables with a condition where struts are not connected to each other. This distinguishable property of class-1 tensegrity benefits achieving high resistance to unexpected physical contacts. This merit has been focused on mobile tensegrity robots. Their gaits can be categorized into crawling [2] or rolling [3, 4]. There are various actuation methods such as pulling a cable [4], extending a strut [5], or vibrating a strut [6], but they all have the common aim of deforming a structure.

I propose an approach of generating tensegrity robots' gaits alternative to the structure deformation principle. The proposed approach uses movable masses distributed one on each strut. Briefly speaking, it generates a rolling gait by positioning the COM outside the support polygon through the movement of the distributed moving mass. In this paper, I show a developed class-1 tensegrity mobile robot that rolls by its distributed movable masses. The demonstration shows the validity of the proposed approach.

2 Developed Tensegrity Robot

Fig.1 shows the developed class-1 tensegrity mobile robot based on a $p = 3$ minimal regular tensegrity prism. The "tensegrity prism" refers to a class-1 tensegrity using p struts, with an p-sided polygon of cables on the top and the bottom [1]. In addition, "minimal" and "regular" refers to using the smallest number of cables $3p$ and having parallel/equilateral top and bottom polygons, respectively. All cables in this robot are designed of approximately equal lengths.

Struts are 10mm square, 1mm thick, 480mm long CFRP square pipe. On the side of the strut, a flexible rack is glued. A movable mass consists of a stepper motor, a motor driver, a battery, two limit switches, a microcontroller with a WiFi module, and a chassis. The axis of stepper motor has a pinion and the movable mass unit runs on the flexible rack without slippage. The total mass of the robot is about 1.7Kg. The movable mass unit, the strut, and two end parts of the strut have approximately 490g, 25g, and 45g, respectively. Because three movable mass units occupy approximately 80% of the total mass, their position dominates the COM position of the robot.

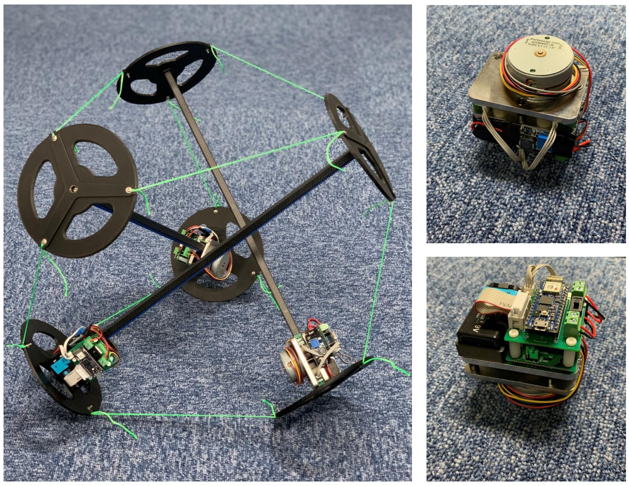

Figure 1: The developed class-1 tensegrity mobile robot based on a $p = 3$ minimal regular tensegrity prism. Left: the overview of the structure. Right: The movable mass unit.

3 Control Strategy

Let $s \in \{0,1\}^3$ be a three-dimensional binary vector that represents which end of the strut the movable mass unit is placed. Because a support polygon's vertex of a class-1 tensegrity does not include both strut's ends, the same expression can also be used for representing which three ends in the tensegrity robot constitutes the support polygon. If employed $\|s_t - s_{t-1}\| = 1$ where the $t = 1, 2, \cdots$ indicates a discrete time step, due to the shape of $p = 3$ minimal regular tensegrity prism, the following transition patterns must be followed to coincide s with the support polygon:

1. $[0,0,0] \leftrightarrow [0,0,1] \leftrightarrow [0,1,1] \leftrightarrow [1,1,1]$
2. $[0,0,0] \leftrightarrow [0,1,0] \leftrightarrow [1,1,0] \leftrightarrow [1,1,1]$
3. $[0,0,0] \leftrightarrow [1,0,0] \leftrightarrow [1,0,1] \leftrightarrow [1,1,1]$.

These three transition patterns are rotationally symmetric by 120 degrees when there is no passive deformation of

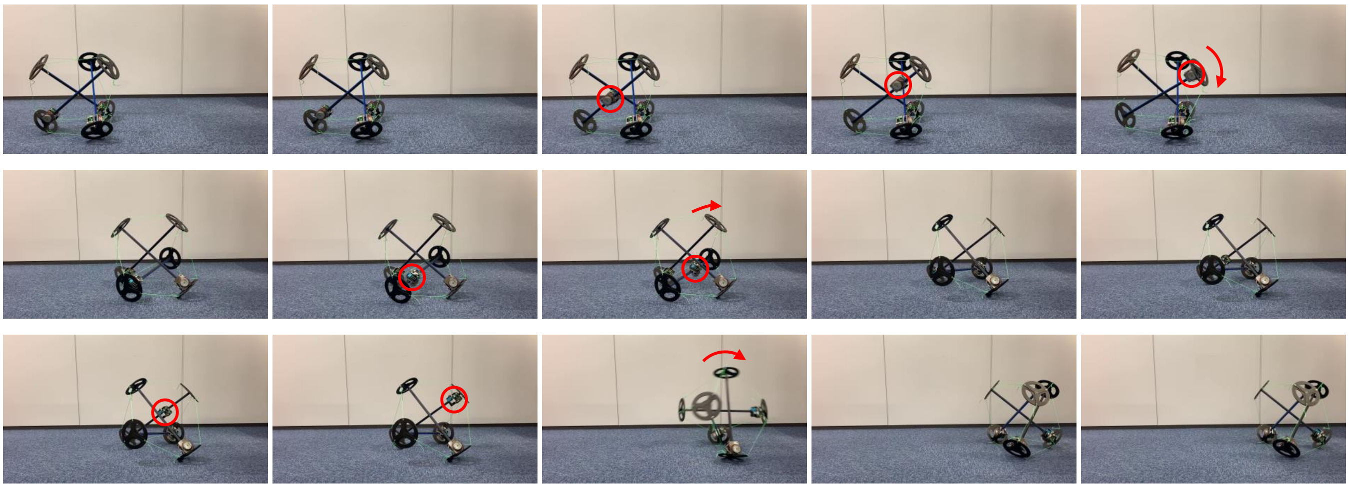

Figure 2: Sequential snapshots of the rolling gait of the developed class-1 tensegrity robot.

tensegrity and the tumbling is quasi-static. In addition, there is no option to choose which side of the support polygon to tumble around, except for the state of being supported on the top or bottom polygons. This paper employs this simple control strategy to verify that the developed class-1 tensegrity mobile robot can tumble by its distributed movable masses. The demonstration shows the validity of the proposed approach. This paper employs this simple control strategy to demonstrate that the developed class-1 tensegrity mobile robot tumbles and moves ahead by distributed moving masses.

4 Demonstration

Fig.2 shows the sequential snapshots of the tumbling behavior of the developed tensegrity robot by the simple control strategy. In this figure, the position of the moving mass unit is highlighted by a circle, and the direction of the tumbling is highlighted by an arrow. Following the simple control strategy, only one of the three mass units moves at a given time. The mass unit starts moving from the end of the strut that makes up the support polygon, and when it reaches the other end, the COM leaves the support polygon and tumbles. Therefore, as long as this simple control strategy is followed, the three movable mass units are located at the three vertices of the support polygon in equilibrium. This success demonstrates the validity of the proposed approach of using movable mass units to achieve the rolling gait of the tensegrity robot.

5 Discussion

Conventional class-1 tensegrity mobile robots use flexible cables to let actuators deform the structure. In this case, the restoring force of the cable is antagonistic to the actuator, so the cable must be flexible to some extent. On the other hand, if the cable is flexible, a large displacement of the actuator is required, so the cable must also be stiff to some extent. Due to this tradeoff, the conventional approach offers little design freedom in cable stiffness. On the other hand, the proposed approach is not affected by this tradeoff because the actuator does not pull the cables directly. In fact, the developed class-1 tensegrity mobile robot uses a highly stiff braided polyethylene line as the cable. Conversely, it can be made flexible enough to deform even under gravity. Investigating the adaptability obtained by making the structure flexible is an important future work of this research.

6 Conclusion

This paper proposed an approach to generating tensegrity robots' gaits that uses movable mass units. To confirm the validity, a class-1 tensegrity mobile robot employing the approach was developed, and it successfully demonstrated the rolling gait.

References

[1] R. E. Skelton and M. C. Oliveira, *Tensegrity Systems*. Springer Nature, 2009.

[2] C. Paul, F. J. Valero-Cuevas, and H. Lipson, "Design and control of tensegrity robots for locomotion," *IEEE Transactions on Robotics*, vol. 22, no. 5, pp. 944–957, 2006.

[3] M. Shibata and S. Hirai, *Rolling Locomotion of Deformable Tensegrity Structure*. WORLD SCIENTIFIC, 2009, pp. 479–486.

[4] K. Kim, A. K. Agogino, and A. M. Agogino, "Rolling locomotion of cable-driven soft spherical tensegrity robots," *Soft Robotics*, vol. 7, no. 3, pp. 346–361, 2020, pMID: 32031916. [Online]. Available: https://doi.org/10.1089/soro.2019.0056

[5] Y. Zheng, Y. Li, Y. Lu, M. Wang, X. Xu, C. Zhou, and Y. Luo, "Robustness evaluation for rolling gaits of a six-strut tensegrity robot," *International Journal of Advanced Robotic Systems*, vol. 18, no. 1, p. 1729881421993638, 2021. [Online]. Available: https://doi.org/10.1177/1729881421993638

[6] J. Rieffel and J.-B. Mouret, "Adaptive and resilient soft tensegrity robots," *Soft Robotics*, vol. 5, no. 3, pp. 318–329, 2018, pMID: 29664708. [Online]. Available: https://doi.org/10.1089/soro.2017.0066