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Displacement Sensing of an Active String Actuator by an Optical Fiber †

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Abstract: We have fabricated a string-shaped actuator called "Active string" that has high contractile displacement/force by accumulating thin pneumatic artificial muscles using the string production process. However, displacement control of the active string is challenging because general bulky and rigid displacement sensors are not suitable for the sensor element of the active string. Therefore, in this report, a flexible optical fiber sensor is combined with the active string to enable sensing of its displacement. As the active string contracts, the radius of curvature of the optical fiber decreases, and light intensity propagating in the optical fiber decreases due to bending loss. The experimental results showed that the optical fiber sensor value changed with corresponding to the displacement of the active string. It shows the possibility suggests that it is possible to of displacement estimation of the displacement of the active string by the optical fiber sensor.

Keywords: thin artificial muscle; active string actuator; displacement sensing; optical fiber sensor

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1. Introduction

Thin artificial muscle is a McKibben artificial muscle with 1.8 mm in outer diameter. It has been applied to the prosthesis hand for children,the wearable support device and the soft robot because of its lightweight and high flexibility [1–3]. In addition, basic research aimed at improving the convenience of thin artificial muscle has been actively conducted [4,5].

We have fabricated a string-shaped actuator called "Active string" by accumulating thin artificial muscles using the string production process, and it has been confirmed that the generated force and contraction rate are improved [6].

However, displacement control of the active string is challenging because general bulky and rigid displacement sensors such as an encoder and a potentiometer are not suitable for the sensor element of the active string. These sensors are difficult to embed into the active string, and their rigidity interfere the advantage of the active string.

Therefore, in this report, a flexible optical fiber sensor is combined with the active string to sensing its displacement. We describe the driving characteristics and sensing characteristics of the active string with the optical fiber sensor through fundamental experiments. The sensor indicates the potential to estimate the displacement of the active string.

2. Materials and Methods

2.1. Thin Artificial Muscles

The active string actuator is realized by accumulating thin artificial muscles into a round string structure. Figure 1a shows the appearance and structure of thin artificial muscle, it is a type of McKibben artificial muscle. The artificial muscle is 1.8 mm in the outer diameter and consists of an inner silicone rubber tube and an outer sleeve braiding 24 fibers.

The braiding angle θ shown in Figure 1b is important parameter that determines the driving characteristics of the artificial muscle. And, it is defined as half of the angle between the fibers of the sleeve. The braiding angle of thin artificial muscles used in this study is 19°.

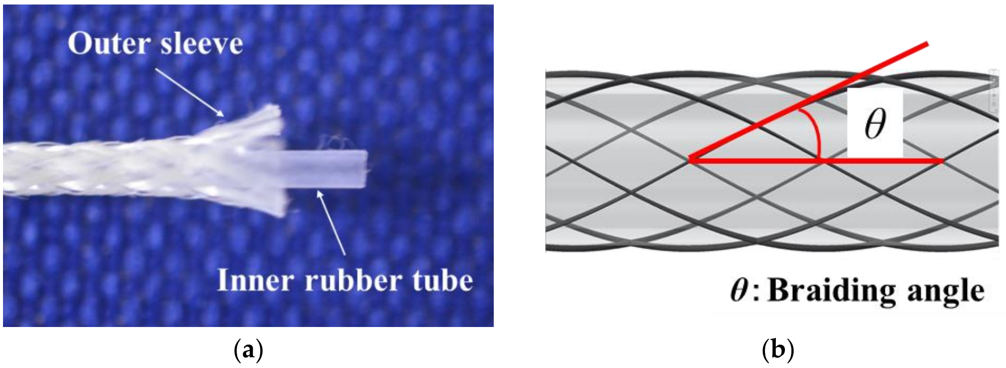

Figure 1. (**a**) Appearance and structure of thin artificial muscle and (**b**) Definition of braiding angle of artificial muscle.

2.2. Production Method of the Active String

The active string, which is the pneumatic actuator and developed in our study, is configured with multiple thin artificial muscles. The string production machine shown in Figure 2, which is a machine for producing round strings, is utilized to fabricate the active string. This machine has 16 bobbins. Eight of the bobbins rotate in the clockwise direction and the other eight rotate in counterclockwise direction to produce round strings.

For fabricating the active string, 8 of the 16 bobbins is used, and thin artificial muscles are set on the bobbins to be accumulated in the form of strings.

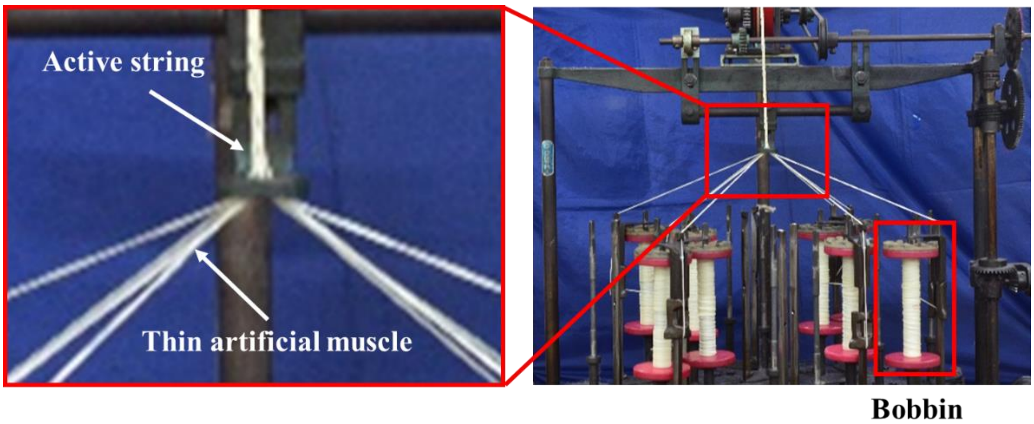

Figure 2. Fabrication of the active string using the string production process.

2.3. The Active String with the Optical Fiber Sensor

The optical fiber is utilized to obtain the active string displacement. As shown in the black dashed line in Figure 3, the optical fiber is combined in the active string spirally with crossing the thin artificial muscles, and one end of the optical fiber has a LED (OSWT 3131A, OptoSupply) for light emission and the other end has a photo IC diode (S13948-01SB, Hamamatsu Photonics) for light receiver. The active string in the initial state and pressurized state are shown in Figure 4. As the active string contracts, the radius of curvature of spiral shape of the optical fiber decreases, and the amount of light propagating in the optical fiber decreases due to bending loss. By measuring the change in the amount of light, the displacement of the active string is estimated.

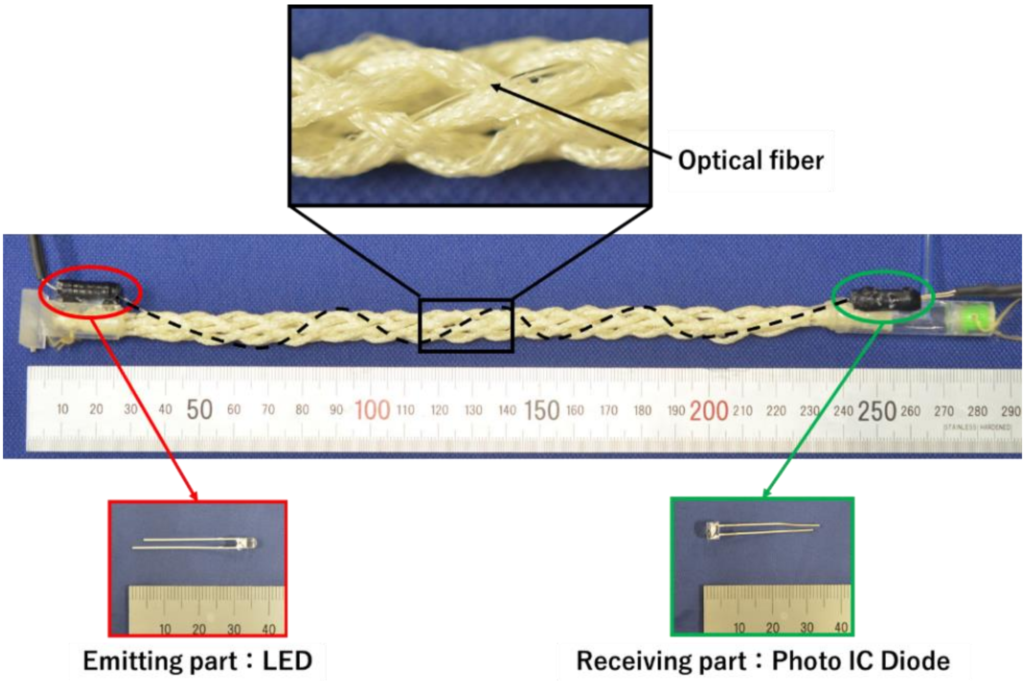

Figure 3. The active string that composite with the optical fiber sensor.

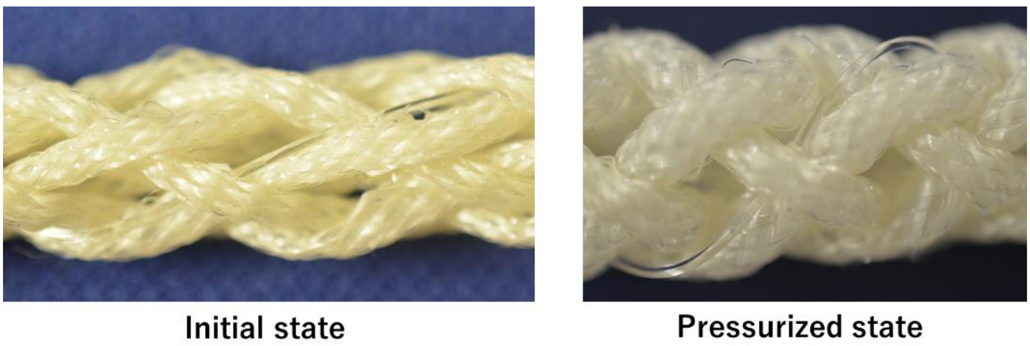

Figure 4. Zoom view of the active string.

3. Results and Discussion

Figure 5 shows the experimental setup for measuring the fundamental characteristics of the active string with the optical fiber. In the measurement, the load was set to 2 [N] so that the active string could be pulled straight and driven stably. Contraction ratio of the active string composited with an optical fiber sensor under applied pneumatic pressure shown in Figure 6. When the applied pressure is 0.4 [MPa] which is the maximum pneumatic pressure to the active string, the contraction ratio of the active string is 20.9 [%]. As shown in Figure 6, it can be seen that hysteresis occurs in the active string. We presume two main reasons of this hysteresis, one is influence of the original hysteresis of thin artificial muscles, and the other is generation of the friction force between the thin artificial muscles.

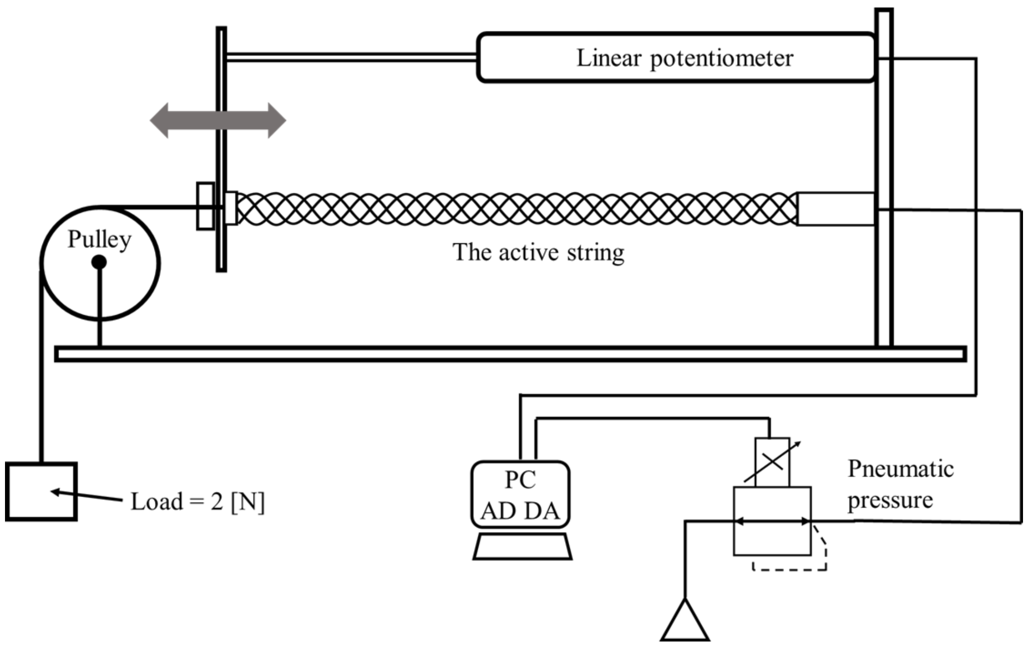

Figure 5. The measurement system.

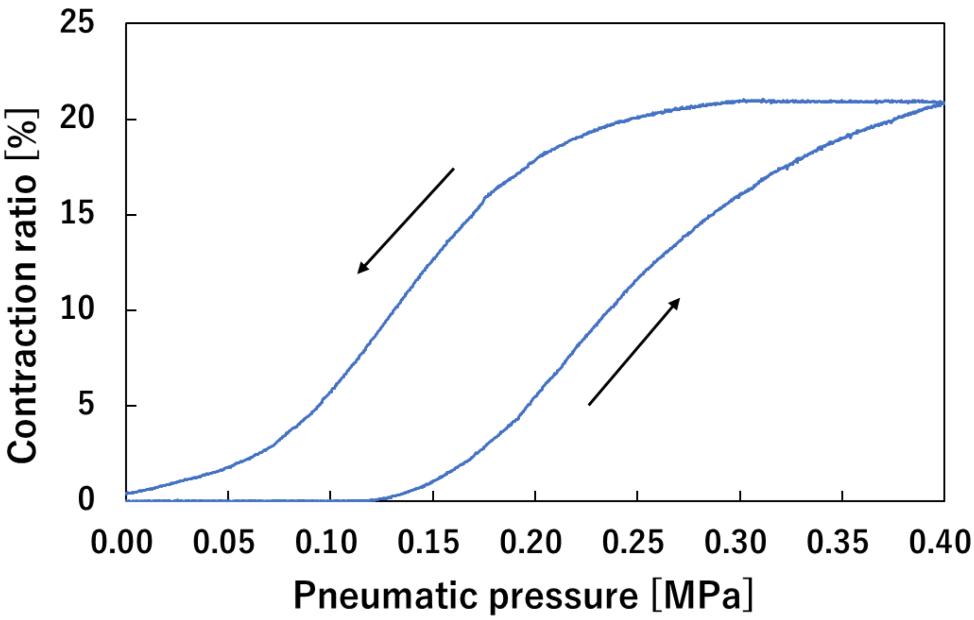

Figure 6. Relationship between applied the pneumatic pressure and the contraction ratio of the active string.

In addition, the relationship between contraction ratio of the active string and sensor value (voltage change of the photo IC diode) is shows in Figure 7. It shows that the sensor value acquired by the optical fiber sensor increases with the increase in contraction ratio of the active string. Although hysteresis occurs, the possibility to estimate the displacement of the active string by embedding the optical fiber sensor with the active string.

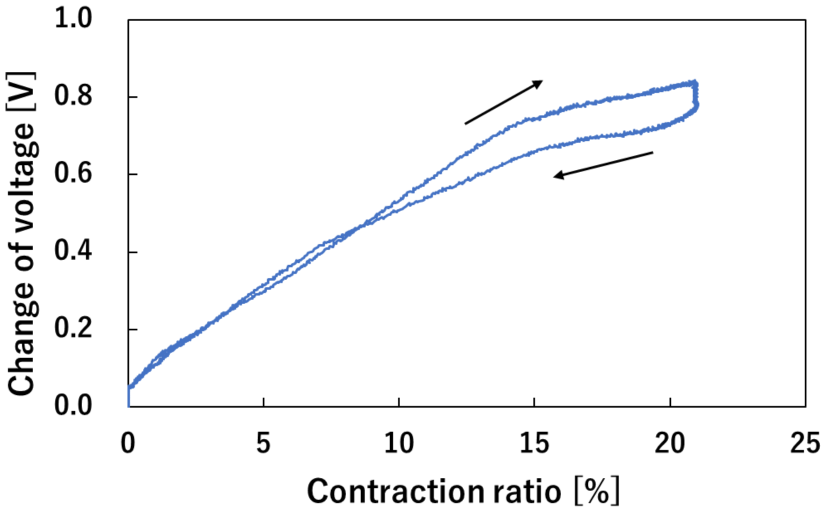

Figure 7. Relationship between the contraction ratio and the sensor value.

4. Conclusions

In this report, a flexible optical fiber sensor is combined with the active string to enable sensing of its displacement. The optical fiber is easy to embed to the active string spirally between thin artificial muscles, and does not interfere with the motion of the active string. Fundamental experiments were carried out. The experimental results showed that the sensor value acquired by the embedded optical fiber sensor changed with corresponding to the displacement of the active string. It suggests that it is possible to estimate the displacement of the active string by the optical fiber sensor.

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References

1. Taniguchi, H.; Takemoto, N.; Yakami, R.; Wakimoto, S.; Oshikawa, T.; Morinaga, K.; Kanda, T. Realistic and Highly Functional Pediatric Externally Powered Prosthetic Hand Using Pneumatic Soft Actuators. *J. Robot. Mechatron.* **2020**, *32*, 1034–1043, doi: 10.20965/jrm.2020.p1034.
2. Takada, M.; Wakimoto, S.; Oshikawa, T.; Ueda, T.; Kanda, T. Active Cloth Fabricated by a Flat String Machine and its Application to a Safe Wheelchair System, Journal of Robotics and Mechatronics. *J. Robot. Mechatron.* **2020**, *32*, 1010–1018, doi: 10.20965/jrm.2020.p1010.
3. Li, W.; Nabae, H.; Endo, G.; Suzumori, K. New Soft Robot Hand Configuration with Combined Biotensegrity and Thin Artificial Muscle. *IEEE Robot. Autom. Lett.* **2020**, 3, 4345–4351, doi: 10.1109/LRA.2020.2983668.
4. Kurumaya, S.; Nabae, H.; Endo, G.; Suzumori, K. Design of Thin McKibben Muscle and Multifilament Structure. *Sensors Actuators A Physical.* **2017**, 261, 66–74, doi.org/10.1016/j.sna.2017.04.047.
5. Koizumi, S.; Kurumaya, S.; Nabae, H.; Endo, G.; Suzumori, K. Braiding Thin McKibben Muscles to Enhance Their Contracting Abilities. *IEEE Robot. Autom. Lett.* **2018**, 3, 3240–3246, doi: 10.1109/LRA.2018.2851025.
6. Tian, W.; Wakimoto, S.; Kanda, T.; Yamaguchi, D. Fabrication of "Active String" using Thin Artificial Muscles by String Production Process, Mechanical Engineering Congress (MECJ-21), Online, Japan, 5–8 September 2021; S117-05. (In Japanese)