論文 / 著書情報
Article / Book Information

Title	Proposal and Feasibility Evaluation of a Quasi-static Omni-Directional Mobility Robot using Multiple Elastic Telescopic Arms
Authors	Kazuhiro Tsukahara, Hiroto Kodama, Yuji Fujitsuka, Daiki Ueda, Takahiro Aruga, Gen Endo
Citation	Proceedings of the 2026 IEEE/SICE International Symposium on System Integration, , , pp. 745-749
Pub. date	2026, 1
Copyright	(c) 2026 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.
DOI	http://dx.doi.org/10.1109/SII64115.2026.11404549
Note	This file is author (final) version.

Proposal and Feasibility Evaluation of a Quasi-static Omni-Directional Mobility Robot using Multiple Elastic Telescopic Arms

Kazuhiro Tsukahara[1], Hiroto Kodama[1], Yuji Fujitsuka[1], Daiki Ueda[1], Takahiro Aruga[1], and Gen Endo[1]

***Abstract*— Mobile robots capable of operating in environments where human work is difficult, such as elevated locations or rough terrain, have been developed, including rough-terrain mobile robots capable of three-dimensional locomotion by fixing end of a tether to the environment and winching it in. However, such robots still face issues, for example, automation of tether end fixation and release. To address these issues, we consider Elastic Telescopic Arm (ETA) as an effective solution. In this paper, we propose a robot capable of three-dimensional movement using multiple ETAs. The proposed robot extends several ETAs mounted on its body, grips rigid environmental structures with grippers at their tips, and moves the body to arbitrary positions in three-dimensional space by controlling extension and contraction of the arms. To verify the feasibility of this principle, we conducted contraction experiments on the arm while under tensile load. Furthermore, to demonstrate the usefulness of the ETA in rough-terrain traversal, we performed a proof-of-concept experiment using a prototype equipped with a single ETA mounted on a four-wheeled mobile robot. The experiment confirmed that the use of the ETA enabled the robot to climb stairs that it could not climb on its own.**

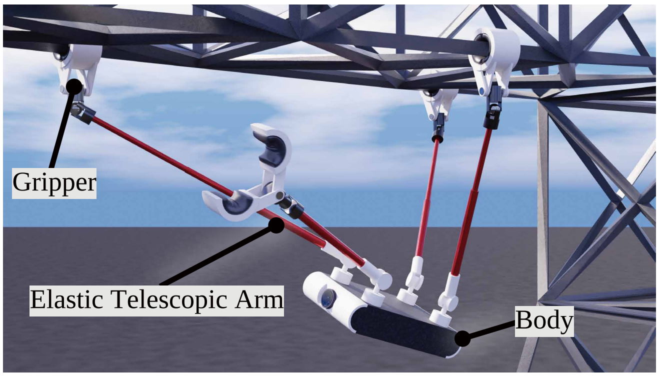

Fig. 1: Conceptual drawing of the proposed robot ”Quasi-static Omni-Directional Mobility Robot.”

I. INTRODUCTION

Various methods have been proposed to enable robots to operate in environments where human work is difficult, such as elevated locations or rough terrain. One such method allows a robot to traverse rough terrain that would otherwise be impassable by anchoring the end of a tether to the environment and winching it in [1]–[5]. However, issues remain in automating the fixation and release of the tether.

Casting manipulation [1], in which a hook, anchor, or small robot connected to end of tether is thrown toward a target location, has been used to connect robots to environments and move them by winding the tether. For example, a prototype robot [2] is equipped with wheels or crawlers, a gripper-throwing mechanism, and a tether-winding mechanism. A gripper at the tether end is thrown to grasp rigid structures such as trees, thereby fixing the tether and assisting locomotion by winding it in. This enables traversal of steep slopes that would be otherwise difficult for wheels or crawlers alone, and its feasibility has been demonstrated with the prototype. However, due to the tether's weight and resistance to deformation, the probability of hitting the target is only about 20 %, and concerns over gripper strength prevent tether-assisted slope climbing while gripping. To address the former issue, rather than improving throwing accuracy, a hook-type design—where claws latch onto the target—has been explored to increase the fixation success rate of the thrown tether end [3]. The integration of such hooks into mobile robots has also been proposed and prototyped [4].

CubiX [5] is a robot where a drone is attached to the tether end extending from the robot. The drone autonomously flies to the fixation point, wraps the tether around the environment, and secures it. While this approach allows precise fixation through drone control, it suffers from several limitations, such as the need for clearance, susceptibility to wind, the necessity of carrying a battery on each drone, and potential failure due to tether entanglement.

To overcome these issues, we consider Elastic Telescopic Arm (ETA) [6] to be an effective solution. The ETA is a telescopic arm with a long reach and flexible bending capability, resembling a fishing rod. It can support its own weight structurally, enabling a long reach without the need for energy to maintain extension. Also, it can passively bend to follow its external environment- features that are simple yet distinct from other mechanisms. Additionally, the ETA features a hollow structure that allows cables to be routed inside, providing a wired connection to the gripper at the arm tip. This configuration enables power supply and control of the gripper through the wired connection.

In this paper, we propose a robot, shown in Fig. 1, capable of traversing three-dimensional space by sequentially gripping the environment with multiple ETAs and their tip grippers. As a first step toward proof-of-concept, we also develop a prototype consisting of a four-wheeled mobile robot equipped with an ETA to verify its applicability to rough-terrain traversal.

---

[1] All authors are with the Department of Mechanical Engineering, Institute of Science Tokyo, 2-12-1 Ookayama, Meguroku, Tokyo 152-8552, Japan `tsukahara.k.962d@m.isct.ac.jp`

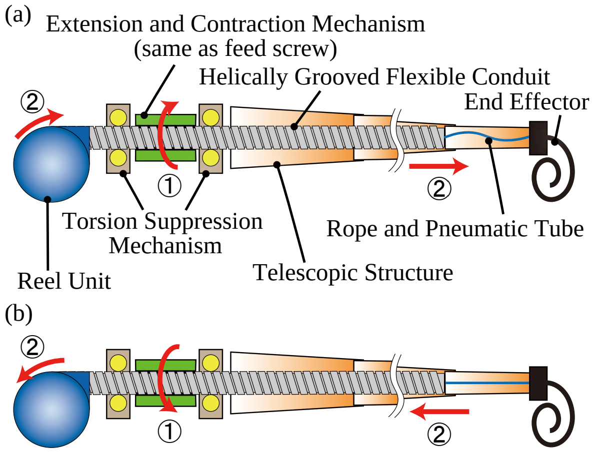

Fig. 2: Movement of ETA. (a) Extension. (b) Contraction.

II. Elastic Telescopic Arm

The Elastic Telescopic Arm (ETA) is a fishing-rod-like arm with a telescopic structure consisting of multiple cylindrical segments of different diameters nested inside each other, capable of elastic bending. The operational principle of the ETA is illustrated in Fig. 2. The extension and contraction of the ETA are driven by a metallic flexible tube with an external helical groove, which we refer to as a helically grooved flexible conduit. By using the conduit as a feed screw shaft and rotating a nut (serving as the feed nut) engaged with the helical groove via a motor, the conduit is pushed or pulled. The tip of the conduit and the tip of the telescopic structure are connected by a rope; extension is achieved by pushing the telescopic structure forward with the conduit, while contraction by pulling back the tip of the telescopic structure through the rope. During operation, friction between the nut and the conduit causes the conduit to twist about its axis. To suppress this, a torsion-suppression mechanism is installed before and after the feeding unit. This mechanism sandwiches the conduit between two rubber rollers, and by pressing the rollers against the conduit using springs or screws, friction is generated to prevent twisting. An end-effector such as a gripper can be mounted at the arm tip. Because the conduit is hollow, electric wiring and pneumatic tubes can be routed inside, allowing power and signals to be supplied from the base. This enables operation of the end effector. At the rear end of the arm, a reel mechanism is provided to store the conduit. This reel is a passive free-rotation type, enabling it to rotate in sync with the feeding amount of the conduit without the need for an additional actuator.

Thanks to the telescopic structure and the flexible, bendable conduit, the ETA can be compactly stored when contracted while achieving a large extension-to-contraction ratio. Moreover, the arm is composed of plastic pipes, enabling passive bending to follow the contours of the external environment. These features make the ETA mechanically simple yet distinct from other arm mechanisms. Automatic extension and contraction of up to 8.6 m vertically without manual assistance [6] and up to 5 m vertically with a 5 kg payload at the tip [7] have been demonstrated.

III. Proposed Quasi-Static Omni-directional Mobility Robot Using Multiple Elastic Telescopic Arms

The proposed robot is shown in Fig. 1. The robot consists of multiple ETAs and a body that houses cameras, control units, batteries, and other power sources. Each ETA base is equipped with joints allowing rotation about the pitch and yaw axes, actuated by motors. A gripper for anchoring to the environment is mounted at the tip of each ETA. By extending multiple ETAs to grip sufficiently rigid environmental structures with the grippers and controlling the extension and contraction of the arms, the robot can lift its body. Repeating this process enables locomotion through three-dimensional space.

ETAs are considered effective for rough-terrain mobile robots for five main reasons:

(1) **High fixation reliability due to quasi-static actuation**

In dynamic systems such as casting manipulation, control can be applied only during the brief moment of the throw. In contrast, the ETA operates quasi-statically, allowing continuous position control of the tip during extension and contraction, thus offering high technical feasibility for environmental fixation.

(2) **Long reach**

The ETA has been shown to extend up to 8.6 m vertically [6] and can extend in any direction—horizontal, vertical, or otherwise. This capability allows the robot to move in arbitrary directions in three-dimensional space. Furthermore, the high elasticity of the ETA enables flexible extension. By attaching a bending mechanism, tip position control becomes possible [8], allowing the robot to grasp targets located beyond obstacles.

(3) **High tip payload capacity**

The ETA has achieved a payload of up to 5 kg when extended 5 m vertically [7]. Since the ETA uses a feed-screw-like mechanism, it can support both compressive and tensile loads, enabling the generation of lifting forces when applied to this robot.

(4) **Capability to remain stationary without power consumption**

The ETA's feeding mechanism, like a feed screw, has been experimentally confirmed to be non-backdrivable. This means that even when the robot is suspended from the environment, the ETA will not extend or contract under its own weight without supplying power to the motor, enabling the robot to remain in place without power consumption.

(5) **Capability to supply power and pneumatics to the arm tip**

Because the helically grooved flexible conduit is originally a protective component for wiring and tubing, the ETA can route cables and hoses internally. This enables the transfer of power, electrical signals, and compressed air between the base and tip of the ETA, allowing power sources and control

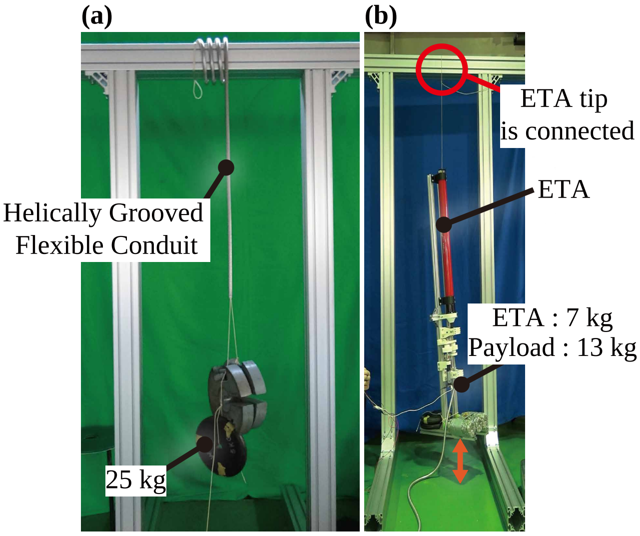

Fig. 3: Lifting experiment. (a) Conduit can support 25 kg without plastic deformation. (b) ETA can lift 20 kg.

units to be consolidated in the body. Consequently, tip weight can be reduced.

IV. PERFORMANCE EVALUATION OF THE ELASTIC TELESCOPIC ARM

In previous studies, extension and contraction tests of the ETA have been conducted under compressive loads, but not under tensile loads. To verify whether contraction is possible when a tensile load is applied to the arm, we experimentally determined the maximum weight that a single arm can lift. The experimental setup is shown in Fig. 3.

When a tensile force is applied to the ETA, the force is borne by the helically grooved flexible conduit. Therefore, we first measured the maximum weight that the conduit (SA-11N, HAGITEC CO., LTD.) could support without plastic deformation (Fig. 3(a)). The upper end of the conduit was fixed at the top, and a weight was suspended from the lower end to apply a tensile load. Plastic deformation of the conduit was evaluated by checking whether it could still mesh with the nut of the feeding mechanism. The experiment was carried out by incrementally adding 5 kgf weights from 5 kgf to 25 kgf. As a result, even with a 25 kgf weight, no significant plastic deformation was observed, and the conduit could be engaged with the driving nut for extension and contraction.

Next, we performed an experiment in which the ETA was extended, the tip was fixed upward, and the arm was contracted to lift its own body (Fig. 3(b)). The ETA used in this experiment had a mass of 7.0 kg. The motor used (MM-26EH, NIPPOU DENKI Co., Ltd.) was for an electric driver. Gear ratio of the motor was 31.5:1. In this experiment, the supply voltage to the motor was 12 V, and the maximum current was 2.5 A.

The results showed that without payload, the arm could lift its own weight at an estimated speed of 20 mm/s. When weights were added in 5 kgf increments, the arm ultimately succeeded in lifting a total of 20 kg (including its own mass) at an estimated speed of 10 mm/s. Based on these results, we can estimate the upper limit of mass for a robot moving using multiple ETAs. For example, a robot equipped with four ETA units must have a total mass of 80 kg or less.

V. STAIR-CLIMBING EXPERIMENT USING A FOUR-WHEEL-DRIVE ROBOT EQUIPPED WITH AN ETA

A. *Experimental Overview*

A proof-of-concept experiment was conducted to evaluate the feasibility of using an ETA as a means of locomotion by connecting the robot to the environment via the arm. While the proposed robot is intended to use multiple ETAs for aerial mobility, as a first step toward verifying the principle, this experiment aimed to determine whether a single ETA could improve the rough-terrain traversability of a four-wheel-drive robot.

For wheeled robots, climbing steps can be difficult. Step heights greater than the wheel radius are generally impassable unless sufficient friction exists between the wheel and the step to lift the robot, and climbing such steps carries the risk of tipping over or slipping due to loss of balance. In this experiment, an ETA was mounted on a four-wheel-drive robot, and the gripper at the arm's tip was used to grasp environmental structures while climbing steps, in order to verify whether the integration of the ETA. Although prior studies have attempted to mount an ETA on a wheeled robot for rough terrain traversal [8], they required additional tether winding devices and did not sufficiently address the release of the end-effector after fixation.

B. *Prototype*

The robot built for this experiment is shown in Fig. 4. It consists of a four-wheel-drive base and an ETA. The four-wheel-drive base used was “HELIOS-IV” [9], which has a movable table that travels along a track composed of arcs and straight segments. Movement of the table along the arc section changes its inclination. In this study, the ETA was mounted on the table, and its pitch angle was controlled by adjusting the table's tilt. The arm section of the ETA used a cable guide made of glass fiber reinforced plastic (GFRP) (DRF-10000L, DENSAN). The arm was equipped at the rear with a reel mechanism for storing the helically grooved flexible conduit, and at the tip with a gripper. The gripper used was a vine-like, power soft gripper [10], which is pneumatically actuated. By routing pneumatic tubing inside the helically grooved flexible conduit used for arm extension and contraction, the gripper at the arm tip could be operated from the base side.

C. *Vine-like, Power Soft Gripper*

When the proposed robot moves on rough terrain, the shape of the object to be gripped is not always clearly defined. Therefore, the gripper must be highly adaptable to different shapes. In this experiment, we used a soft gripper called Vine-like, Power Soft Gripper [10]. This gripper wraps around an object in a spiral shape and grips it using the friction between the gripper and the object. Based on Euler's

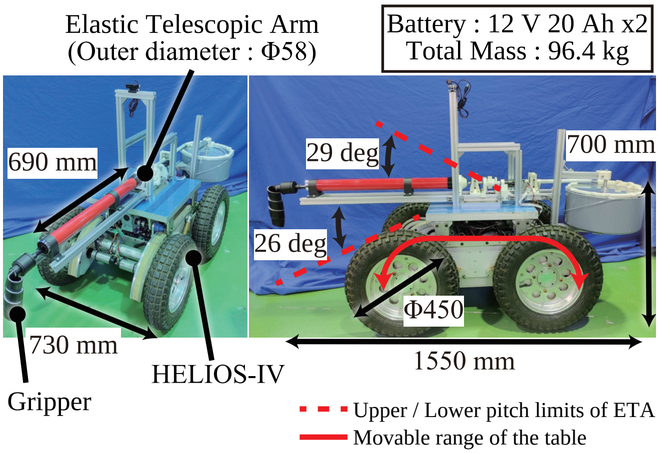

Fig. 4: Prototype of four-wheel drive robot "HELIOS-IV" with the Elastic Telescopic Arm.

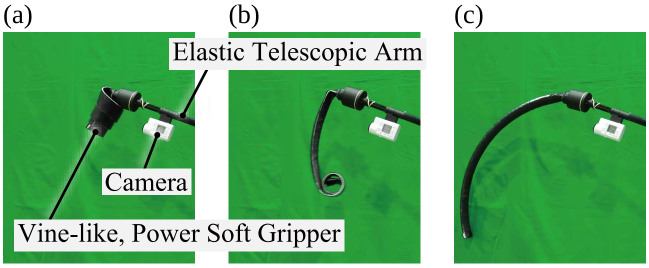

Fig. 5: Movement of Power Soft Gripper. (a) Contraction. (b) During extension. (c) Extension.

belt theory, the carrying capacity increases significantly as the winding angle of the gripper around the object increases. Additionally, since gripping is achieved through friction, it does not consume energy to maintain the gripping posture. It has been confirmed that these two grippers can lift 1660N [10]. The gripper is capable of being released even while holding a heavy object. However, because it expands from its base when opening, more space is required for releasing than for grasping.

This gripper consists of a spiral-shaped constant-force spring inserted into a hose, with a rubber sheet adhered to it. The gripper operates as shown in Fig. 5. In the initial state, the gripper is wound in a spiral shape by the constant-force spring (Fig. 5(a)). When air pressure is applied to the hose , the gripper extends from the base side (Fig. 5(b)) and extends fully by inflating the hose (Fig. 5(c)). After that, when the gripper tip is in contact with the object to be gripped, exhausting the air causes the gripper to unwind from the tip due to the constant-force spring (Fig. 5(b)), gripping the object by wrapping around it (Fig. 5(a)). The application and release of air pressure are manually operated from the base of the ETA.

D. *Experimental Results*

The layout and dimensions of the stairs and pipes used in the experiment are shown in Fig. 6. Two metal pipes were attached to the wall at the landing of the stairs; the upper pipe was used as the grasping target for the arm.

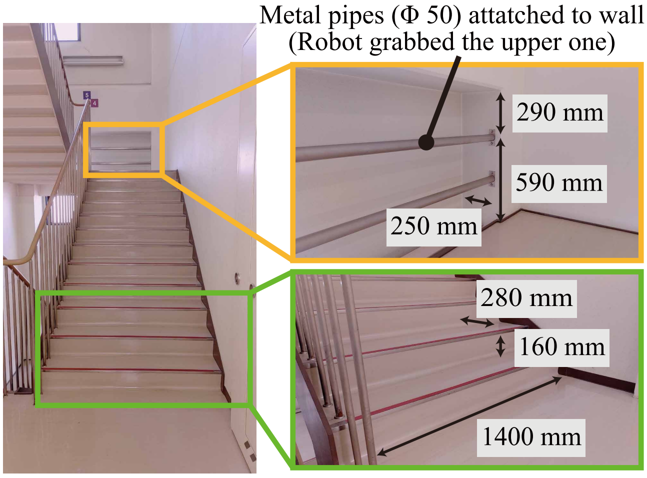

Fig. 6: Stairs and pipes gripped by the robot.

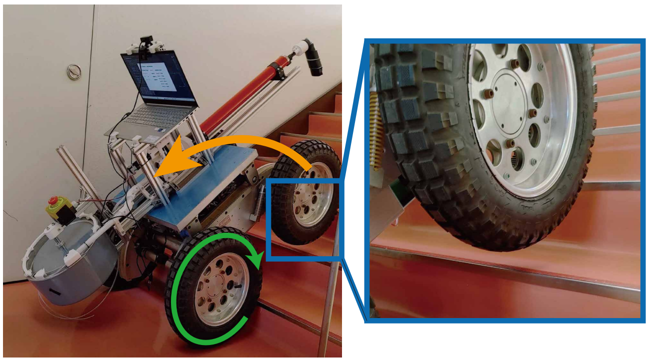

Fig. 7: Experiment of climbing stairs without using ETA. The front wheels were lifted off the ground due to the torque from the spinning rear wheels.

First, an experiment was carried out in which the robot attempted to climb the stairs without using the ETA (Fig.7). Without the ETA, when the rear wheels reached the step, the torque from the rear wheels lifted the robot's front wheels off the ground. Although this might be mitigated by shifting the center of gravity forward using the movable table, the robot's mass of 96.4 kg posed risks of damaging the robot or the building. For safety reasons, the experiment was terminated when the robot nearly tipped over.

Next, a stair-climbing experiment was performed using the ETA (Fig. 8). The procedure was as follows:

1. Place the robot in front of the stairs (Fig. 8(a)).

2. Extend the arm diagonally upward (Fig. 8(b)).

3. After extending the arm to a sufficient length, adjust its extension and angle to grasp the target pipe securely with the gripper (Fig. 8(c)).

4. While adjusting the arm's tilt and extension to avoid excessive bending or tensile forces on the ETA, contract the arm while simultaneously driving the wheels to climb the stairs (Fig. 8(d)(e)(f)).

With the ETA, the robot successfully climbed the stairs without tipping or slipping. Considering that the robot nearly tipped backward without the ETA, the arm contributed not

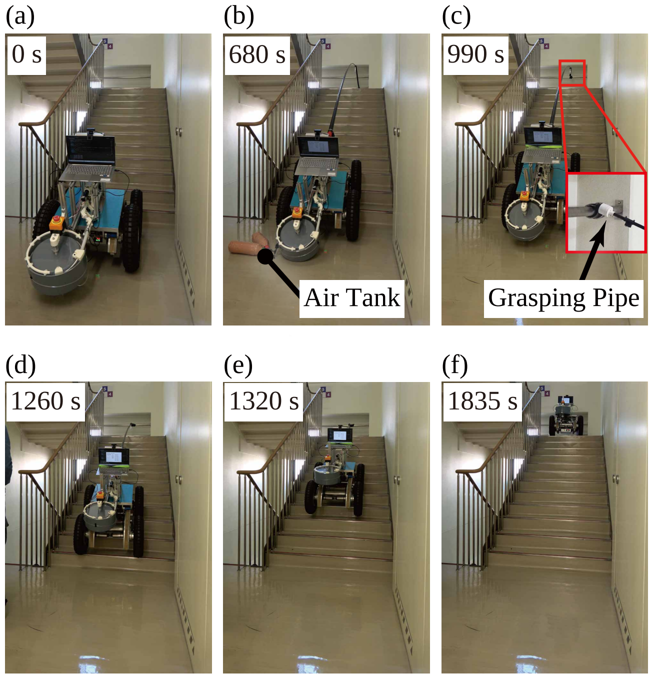

Fig. 8: Experiment of climbing stairs using ETA. (a) Start of the experiment. (b) ETA extension. (c) Grasping a pipe attached to wall. (d)(e) Climbing stairs. (f) Climbing finished.

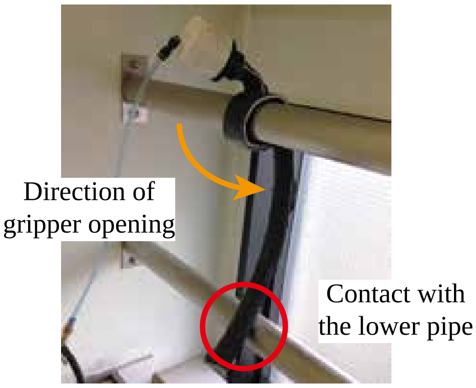

Fig. 9: The release of the gripper was prevented by interference with a pipe located below the grasped object.

only to pulling the robot upward but also to preventing it from overturning. Furthermore, the stair step blocked a direct line-of-sight approach to the target pipe from the HELIOS base. However the flexibility of the ETA allowed the arm to bend around the step and reach the pipe. These results demonstrate the potential effectiveness of the ETA in improving rough-terrain mobility for robots.

In this experiment, we did not release the gripper; therefore, the feasibility of gripper release was examined separately. The results showed that the release was prevented when the gripper contacted a pipe located below the grasped object during opening(Fig. 9). The lower limit of the gripper length is determined by the expected tensile load, while the upper limit is defined by the maximum length that allows the gripper to open and release within the space of the target object. In future work, we will use this criterion to determine the appropriate gripper length for the intended application.

VI. CONCLUSION

In this study, we proposed a novel robot capable of three-dimensional movement in space by employing multiple Elastic Telescopic Arms (ETAs), focusing on its potential as a means of locomotion and its ability to enhance the rough-terrain traversability of mobile robots. To verify their effectiveness, we carried out a contraction experiment under tensile load and confirmed that the current ETA can contract under tensile forces of up to 20 kgf. We also carried out a stair-climbing experiment using a four-wheel-drive robot equipped with an ETA, achieving successful traversal of stairs that were otherwise difficult to climb without the arm. These results demonstrate the usefulness of ETAs for rough-terrain mobility. Future work will focus on improving ETA performance, including increasing payload capacity and extension range, toward the realization of the proposed quasi-static, spatially mobile robot.

REFERENCES

[1] H. Arisumi, “Casting manipulation,” *Journal of the Robotics Society of Japan*, vol. 41, no. 10, pp. 854 – 857, 2023 (in Japanese).

[2] H. Nakamoto, F. E. Fukushima, and S. Hirose, “Research on hyper-tether no.12 development of launching and anchoring gripper,” *The Proceedings of JSME annual Conference on Robotics and Mechatronics*, p. 77, 2002 (in Japanese).

[3] N. Asano, H. Nakamoto, T. Hagiwara, and S. Hirose, “Tethered detachable hook for the spiderman locomotion (design of the hook and its launching winch),” in *Field and Service Robotics*, A. Howard, K. Iagnemma, and A. Kelly, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 25–34.

[4] S. gon Roh, B. Allan, R. Marshall, S. Kerr, D. Killen, and S. Hirose, “Development of tethered detachable hook iv for robot locomotion in extremely rough environments(robotics for hazardous fields),” *The Proceedings of JSME annual Conference on Robotics and Mechatronics (Robomec)*, vol. 2011, pp. 1A2–Q03, 2011 (in Japanese).

[5] S. Inoue, K. Kawaharazuka, T. Suzuki, S. Yuzaki, K. Okada, and M. Inaba, “Cubix: Portable wire-driven parallel robot connecting to and utilizing the environment,” in *2024 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, oct 2024, pp. 1296–1301.

[6] Y. Fujitsuka, R. Kiyohara, T. Nagai, H. Takahashi, H. Kikura, and G. Endo, “Elastic telescopic arm extension/contraction mechanism using a helically grooved flexible conduit,” in *2025 IEEE/SICE International Symposium on System Integration (SII)*, 2025, pp. 96–102.

[7] K. Tsukahara, T. Aruga, G. Endo, T. Shiga, R. Matsumura, H. Konishi, and M. Sato, “Study on elastic telescopic arm -realization of 5 m vertical extension with 5 kg payload-,” *The Proceedings of Annual Conference of the Robotics Society of Japan*, pp. 2P1–01, 2025 (in Japanese).

[8] T. Nagai, A. Ogawa, H. Nabae, K. Suzumori, and G. Endo, “Rough terrain traveling method using an elastic telescopic arm and a tether,” in *2022 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)*, 2022, pp. 22–28.

[9] S. Hirose, E. Fukushima, R. Damoto, and H. Nakamoto, “Design of terrain adaptive versatile crawler vehicle helios-vi,” in *Proceedings 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems*, vol. 3, 2001, pp. 1540–1545.

[10] H. Kodama, T. Ide, F. Yunhao, H. Nabae, and K. Suzumori, “Vine-like, power soft gripper based on euler’s belt theory,” *IEEE Robotics and Automation Letters*, vol. 9, no. 4, pp. 3108–3115, 2024.