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Snake Robot Gripper Module for Search and Rescue in Narrow Spaces

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Abstract:

This research introduces a novel gripper module particularly made to enable serpentine rescue robots in confined spaces with efficiency. Three main aspects are introduced by the gripper module: (1) Fingers that can be accommodated internally within the body; (2) Three fingers that can grip items with uneven surfaces firmly could be trident grippers. (3) The incorporation of a camera-equipped fingertip to improve visibility in tight locations. A novel three-finger, eight-degree-of-freedom gripper module is suggested in order to accomplish these capabilities in a small, light design. The gripper module's joint arrangement departs from standard designs to maximize its usefulness for activities in small places. The grasper module's effectiveness in carrying out rescue operations in collapsed situations is demonstrated by its integration into a prototype snake-shaped robot.

***Keywords*—Search and Rescue Robots, Grippers and Other End-Effectors, Mechanism Design, Snake-like robot.**

Introduction

Snake-like robots, introduced by Hirose [1], have attracted considerable interest owing to their versatility across different terrains and scenarios. One notable application is their use in operations within collapsed structures, illustrated in Fig. 1. For example, a team of researchers at Carnegie Mellon University (CMU) employed a 16-module. The compact diameter of the CMU snake robot allows it to traverse narrow passages and maneuver through various terrains such as rubble heaps and stairs. However, its functionality is limited by the presence of a single camera positioned on its head, lacking supplementary sensors or grippers for survivor detection and assistance. Tanaka introduced a featuring grabber capable of omnidirectional manipulation, including object grasping and valve rotation [6], [7]. While the T2 Snake robot demonstrates adept object handling, it lacks the ability to attach sensors to its gripper and its size impedes movement in confined spaces. To effectively execute search and rescue missions, snake-like robots necessitate additional functionalities (Fig. 2).

Firstly, the ability to independently move its "eyes" to survey surroundings without altering its body position is essential.

Figure 1. Visualization robot utilized in search and rescue missions

Robotic grippers have undergone extensive research, resulting in the development of 2-finger [8]-[11] and 3-finger grippers [12]-[16], commonly featuring adaptive mechanisms and under-actuated designs. While these grippers find applications in various industrial settings due to their simplicity, they lack protection for the fingers from external elements and hinder the integration of fingertip cameras for narrow space exploration. Anthropomorphic robotic hands [17]-[23], with their high dexterity and versatility, closely mimic human hand kinematics but face challenges in compact actuator integration. Soft grippers [24]-[29], employing compliant materials, offer flexibility in grasping complex shapes but suffer from durability limitations and require intricate control systems.

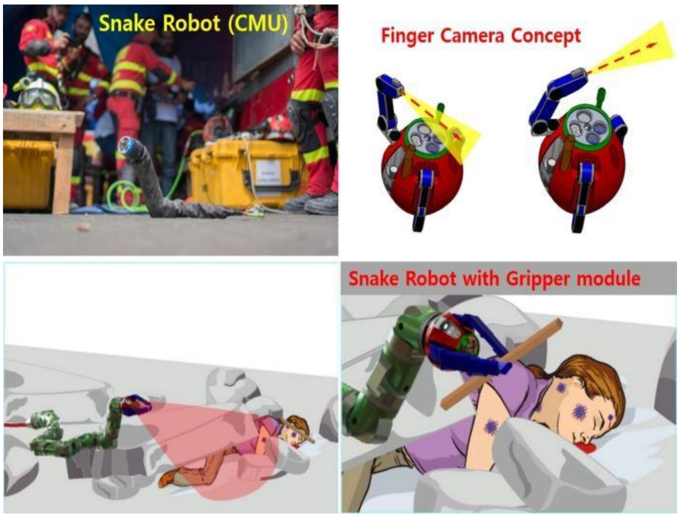

Fig. 2. Functional diagram

The described grippers are incompatible with snake robots due to their excessive size, weight, and absence of fingertip cameras. Gripper modules tailored for snake robots must prioritize compactness and versatility to navigate narrow passages efficiently.

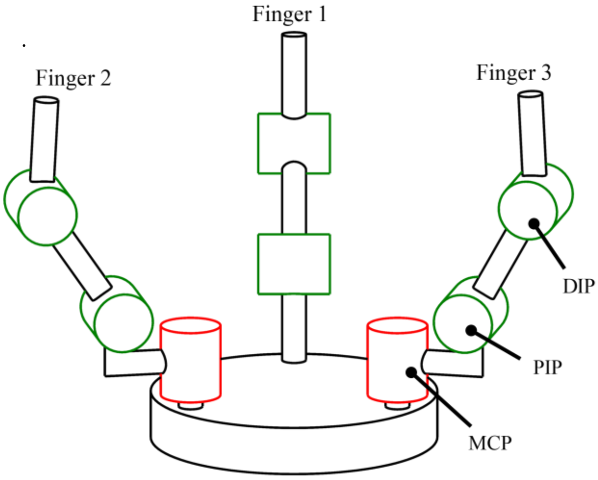

Fig. 3. Conceptual depiction Flex Grip module

It introduces a specialized optimized for snake robots to execute a missions within confined environments. The proposed module enables manipulation of small objects and efficient exploration utilizing a fingertip camera, eliminating the need for extensive body movement. Moreover, the retractable fingers enhance mobility in narrow spaces, crucial for USAR operations. Significantly, one of the module's fingers incorporates a camera on its fingertip, streamlining the search process. The finger joints employ a pan-tilt structure, enabling three-dimensional exploration using the fingertip camera. Manufactured with dimensions of 68mm (diameter) and 106mm (height) radius of 250mm.Integration of the module into a snake robot showcases its effectiveness in conducting rescue tasks in collapsed environments, validated through rigorous experimental trials. The subsequent sections delve into the design considerations, kinematics, mechanical and electronic specifications of the proposed gripper module, followed by comprehensive experimental validation and evaluation results, culminating in conclusive remarks.

I. Dynamic Grip: Kinematic Analysis of the Innovative Gripper Module

The proposed gripper module design considers several key conditions to ensure its effectiveness in search and rescue tasks within narrow spaces. Firstly, stability in grasping and manipulating small objects is prioritized. Secondly, the finger design should not impede the movement of the snake robot when integrated. Lastly, the size should be comparable.

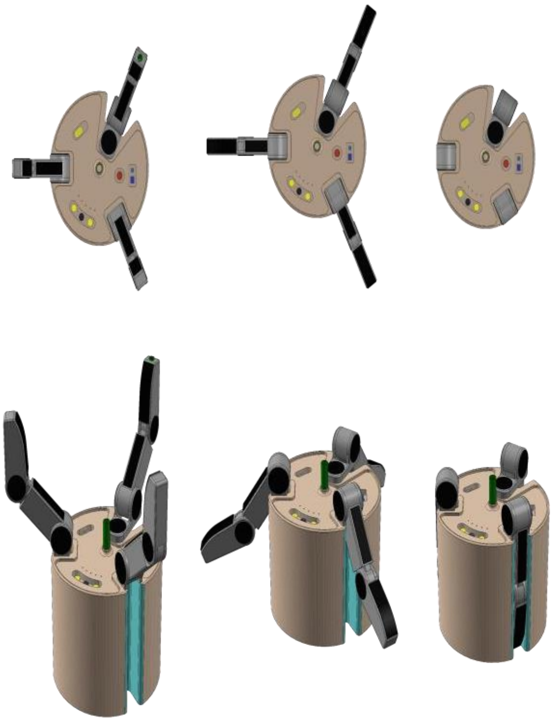

Fig. 4 Finger tucking method

Comprising three fingers, the gripper module facilitates stable grasping and manipulation features pitch–pitch degrees of freedom (DOFs) with proximal and distal interphalangeal (PIP, DIP) joints, while fingers 2 and 3 possess roll–pitch–pitch DOFs with metacarpophalangeal (MCP), PIP, and DIP joints. Without necessitating advanced in-hand manipulation. The pan-tilt configuration of joints in fingers 2 and 3 enables effective searching in narrow spaces. To minimize the gripper module's size, considerations extend beyond sensor count to finger configuration. Accommodating the fingers within the module reduces the outer diameter and eliminates shaded areas for sensors. Fig. 4 demonstrates the folding method

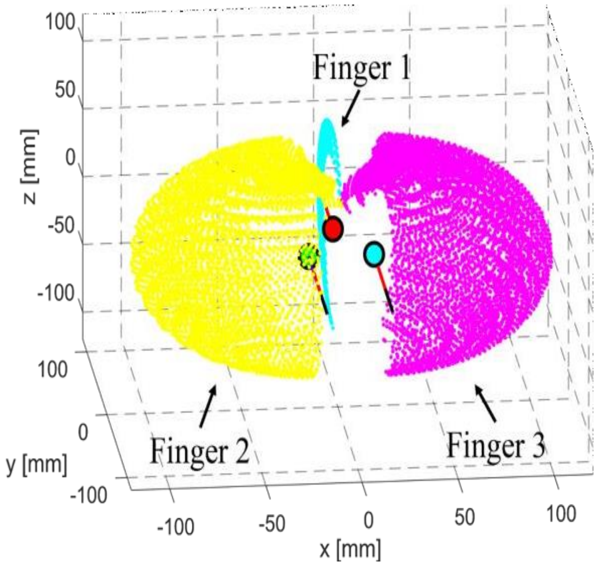

Fig. 5. Workspace.

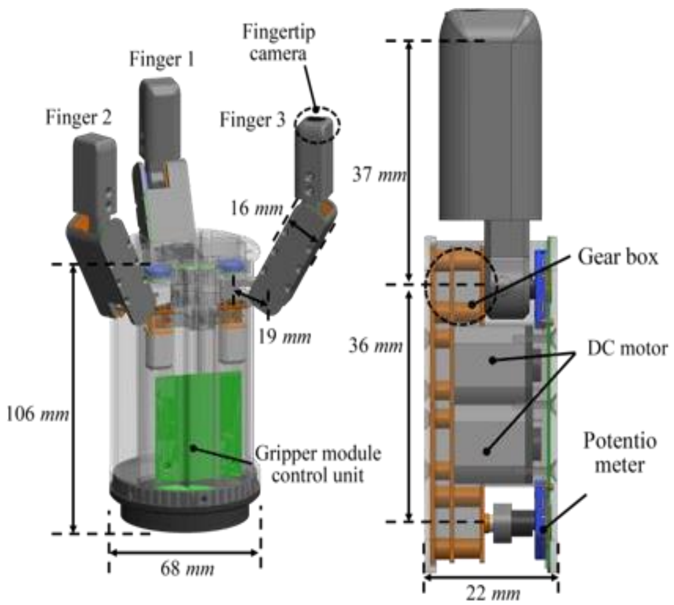

Fig. 6. 3 Dimensional model.

for finger accommodation, enhancing the module's maneuverability and interaction with obstacles. Large degrees of freedom in finger joints and grooves are essential for implementing this accommodation mechanism. Alternative accommodation methods, such as gathering fingers in front of the gripper palm, were considered but deemed complex and prone to sensor shading. It determined based on module size and accommodation mechanism. Finger workspace point clouds, depicted in Fig. 5, validate the manipulability of the claw module. While the overlap area of finger workspaces is relatively small compared to the human hand, it remains adequate for power and pinch grasping tasks. In summary, the proposed gripper module design fulfills critical design conditions, ensuring stability, compatibility with snake robot movement.

III. DESIGN OF PROPOSED MODULE

It aims to facilitate mounting on a snake robot operating within narrow spaces, for performing tasks. To meet these requirements, the gripper module's diameter should be under 70mm, and its length should not exceed 150mm.. The gripper module is expected to be compact, lightweight, and robust, with minimal exposure of components to withstand harsh environments encountered during deployment. the actuators, optimizing internal space usage. Geared DC motors, specifically the GM12F for MCP joint and GM12L for PIP and DIP joints, are employed due to their compact size and light weight. The GM12F motor measures 12mm (width), 10mm (thickness), and 35mm (height), while the GM12L motor measures 24mm (width), 10mm (thickness), and 19mm (height).

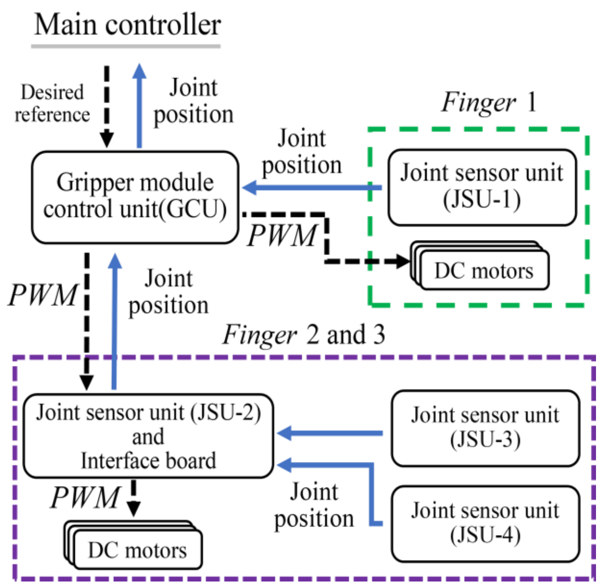

Fig. 7. System diagram

III. EXPERIMENTAL VALIDATION

The effectiveness was assessed through a comprehensive series of experiments, focusing on its accommodation, grasping force, grasping capability.

A. Mode Changing

Sequential testing of these modes was conducted to verify seamless transitions between functionalities. Furthermore, the, highlighting its efficacy in facilitating the snake robot's navigation through tiny places.

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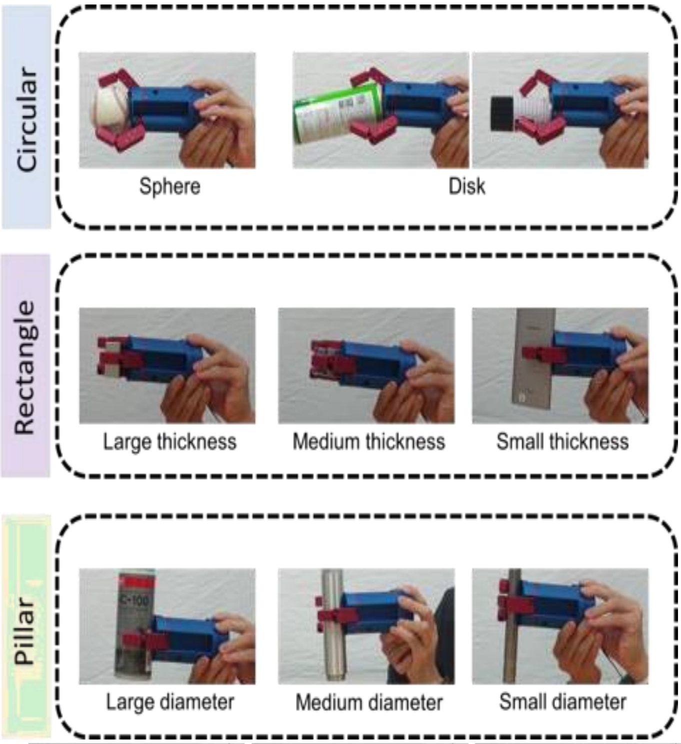
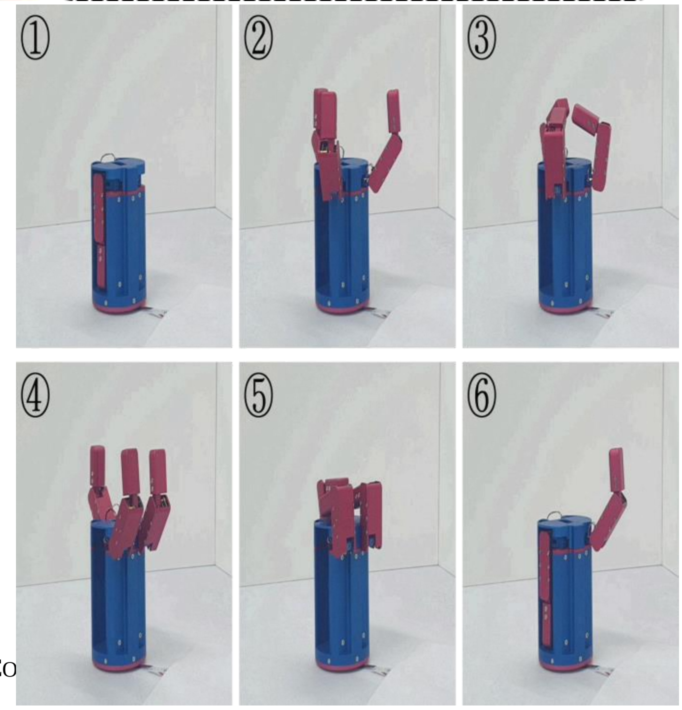
B. Grasping Force Test
A critical aspect of the gripper module's functionality is its grasping force, essential for manipulating objects in narrow spaces. The maximum grasping force was measured using a load cell, as shown in Fig. 10. Experimental results indicated a peak grasping force exceeding expectations, confirming the gripper module's robust performance. However, to ensure stability, the maximum payload capacity was determined as 2.48kgf.





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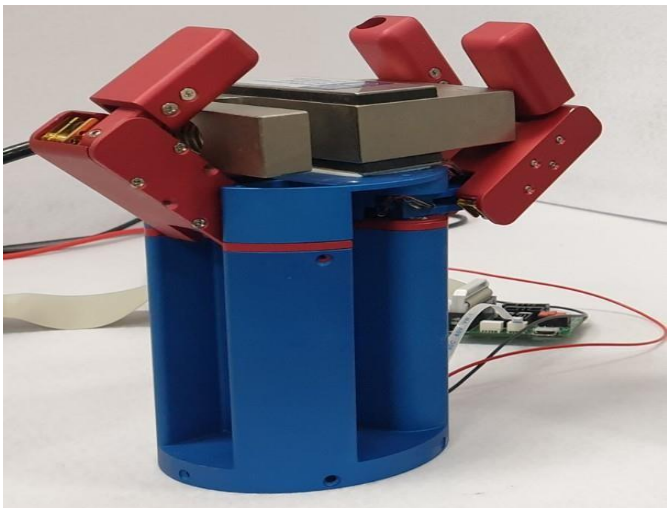
C. Grasping Pose Test
Experiments were conducted to assess the gripper module's ability to grasp various objects, including circular, rectangular, and pillar-shaped debris. Further demonstrated the module's effectiveness in securely gripping objects of different shapes, validating its suitability for USAR missions.



D. Integration into Snake Robot
The integration of the framework into the snake robot system was seamless, serving as its head module. It depicts the snake robot's operations with the gripper module, demonstrating its adaptability in traversing environments and eliminating obstacles.

In summary, experimental validation affirms the robust performance and versatility of the prototype, ensuring its effectiveness in search and rescue missions within confined spaces.

This research presents an original gripper module design aimed at enhancing the urban search and rescue (USAR) capabilities of a snake-like robot within confined spaces. Comprising three fingers, the proposed gripper module enables stable gripping. Additionally, it incorporates a mechanism to internally house the fingers, enhancing the snake robot's mobility in narrow environments. Furthermore, the integration of a fingertip camera provides versatile directional vision. Consequently, the proposed gripper module stands out for its compact, lightweight, and efficient nature.

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