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Snake Robot Gripper Module for Search and Rescue in Narrow Spaces

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Abstract—This letter presents a gripper module for a snake-like robot to perform search and rescue tasks in a narrow space. The proposed gripper module has three features: (1) It can accommo- date the fingers inside its body. (2) It has three fingers that can grip objects with irregular surfaces stably. (3) One of the fingers is equipped with a camera on the fingertip to search in a narrow space. To implement the above features in a small, light, and compact gripper module, we propose a novel design of a gripper module with three fingers and eight degrees of freedom. The joint configuration of the proposed gripper is unique compared with a general-type gripper. A prototype of the proposed gripper module has been integrated into a snake-like robot to demonstrate its capability of performing rescue tasks in a collapsed environment. The three fea- tures of the proposed gripper module are experimentally verified: it is light (0.4 kg), small (less than 68 mm in diameter), and powerful (grasping force = 2.48kgf).

Index Terms—Search and rescue robots, grippers and other end- effectors, mechanism design, snake-like robot.

INTRODUCTION

SINCE it was first introduced by Hirose [1], snake-like robots have been extensively investigated because they can be used in various terrains and situations. One of the representative appli- cations of snake-like robots is urban search and rescue (USAR) at collapsed sites, as shown Fig. 1. For example, Carnegie Mellon University (CMU) researchers deployed a snake-like robot composed of 16 modules to search for trapped survivors in a collapsed apartment building [2]–[4]. The CMU snake robot can access narrow spaces because it has a really small diameter.

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can traverse a wide range of terrains, including open flat \regions, piles of rubble, and stairs [5]. The CMU snake robot, however, has only one camera on its head, and there were no other sensors or grippers to detect or help survivors.

The T^2 Snake-3 robot with a soft gripper was introduced by Tanaka [6], [7]. It has an omnidirectional soft gripper to grip an object or to rotate a valve. The T^2 Snake robot shows excellent object handling performance; however, sensors cannot be attached to the gripper, and the size of the robot is big to move in a narrow space.

To effectively perform search and rescue tasks, two additional functions are required simultaneously for a snake-like robot (Fig. 2). First, a snake robot should be able to move its eyes and look in all directions without moving its body, and second, the snake robot should be able to remove small objects, such as collapsed debris, in narrow spaces. A smart and powerful gripper module for snake robots is required to performs search and rescue tasks in a narrow space.

Robotic grippers have been extensively studied in recent years. 2-finger grippers [8]–[11] and 3-finger grippers [12]–[16] have been developed to grasp objects. An adaptive mechanism is applied to the finger link in these grippers, and most grippers have an under-actuated mechanism that drives a large number of joints using a small number of actuators. They are used in various industrial fields because they are structurally simple. However, the fingers are exposed to external environments. Additionally, it is impossible to perform a search task using a fingertip camera in a narrow space because of the under-actuated mechanism. There is a limit to reducing the size of these grippers because they have a complex link structure. Anthropomorphic robotic hands have been developed to mimic human hands as closely as possible in terms of

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kinematics, beyond the ability of simple grippers.

In addition, sufficient power grasping and pinch grasping can be achieved using two MCP joints. One of the fingers is equipped with a camera on the fingertip for convenient searching to perform search and rescue tasks. The finger joint of the gripper module has a pan-tilt structure; thus, it can point to a three-dimensional space and search a narrow space using the fingertip camera. The diameter and height of the manufactured gripper module are 68 mm and 106 mm, respectively, and it is designed to perform USAR tasks in a narrow space with a diameter of 100 mm and a radius of curvature of 250 mm. The proposed module is integrated into a snake robot to show its capability of performing rescue tasks in a collapsed envi- ronment. The accommodation mechanism, stable grasping, and improved searching of the gripper module are confirmed through experiments.

1. LITERATURE SURVEY

The purpose of a literature review is to gain an understanding of the existing research and debates relevant to a particular topic or area of study, and to present that knowledge in the form of a writtenreport. Following are the IEEE papers referred
The history of surgical endoscopes dates back to the 1990s when the first robotic system AESOP was introduced by computer motion
The evolved versionZEUS reflected the former's multifunctional features, including dictation and tactile feedback.
When coupled withvisual and light sources, provides bimanual control and operation of therobot arms.
This robot include itshigh tensile strength with limited access tocurved pathways, as well as its single-portentrance.
The researchers present a frameworkis to compute climbing motions of three limbed robot inreal vertical natural terrain.
The framework ofclimbing robots handles motion constraints, complicated robotgeometries

METHODOLOGY

It should be possible to mount the proposed gripper module on a snake robot that moves in a narrow space with a diameter of 100 mm and a radius of curvature of 250 mm to perform USAR tasks. To satisfy these conditions, the diameter of a snake robot module should be less than 70 mm, and the length of a module should be less than 150 mm. In addition, the head module of a snake-like robot should also satisfy the limiting conditions. The gripper module should be small, light, and powerful; besides, the exposure of components, such as the actuator's gear, sensors, and control boards, should be minimized because we will deploy the snake-like robot in a harsh environment. The sensor or finger structure should not protrude outside the module. Fig. 6 shows the 3D model of the proposed gripper module. The outer diameter of the gripper module is 68 mm, and its height is 106 mm including the length of the fingers. The width, thickness,and height of the fingers are 22 mm, 16 mm, and 85 mm, respectively. There are three grooves on the gripper module to accommodate the fingers. The two MCP joint actuators are arranged vertically considering the space required to accommodate the fingers. In this arrangement, a separate gear is not required to change the power transmission direction. This structure enables the actuator to be placed outside to utilize the internal space. The PIP and DIP joints of all fingers have the same structure, and the actuators of the PIP and DIP joints are placed on the PIP link to provide space for installing sensors, such as a camera,on the fingertip. The gripper module uses a small and light commercial geared DC motor. The GM12F motor is used for the MCP joint. It has a small size, with a width, thickness, height of 12 mm, 10 mm, and 35 mm, respectively. The GM12 L motor is used for the PIP and DIP joints. Its width, thickness, and height are 24 mm, 10 mm, and 19 mm, respectively. The weight of the DC motor is approximately 10 g, the rated torque is 147mNm, and the stall torque is 343mNm. The control board is arranged in the internal space of the gripper module. Embedded boards are developed to reduce the size of the gripper module. These includea control board for driving and controlling the module and a sensing board for measuring the position of joints. Fig. 7 shows the block diagram of communication flow between the electronic components of the gripper module and main controller. The gripper module control unit (GCU) communicates with the main controller computer via RS232. It collects the position data measured at each joint through a joint sensor unit (JSU) and transmits it to the main controller. In addition, it performs position control for each joint through PID control. The JSU is built into finger 1, and it directly transmits the position data of the PIP and DIP joints to the GCU. In the case of fingers 2 and 3, the position data of the DIP and PIP joints are transmitted to the GCU through JSU-2, which acts as an interface board and acquires the position data of theMCP joint. Fig. 8 shows the GCU, JSU & I/F, and JSU board of the gripper module. The main control unit (MCU) of the GCU (Fig. 8(a)) is STM32F446, and the size of the GCU is 40 mm×45 mm. The GCU is mounted on the module body, and it controls the gripper with a control cycle of 1 ms. JSU-2 (Fig. 8(b)) is mounted on the palm of the module.

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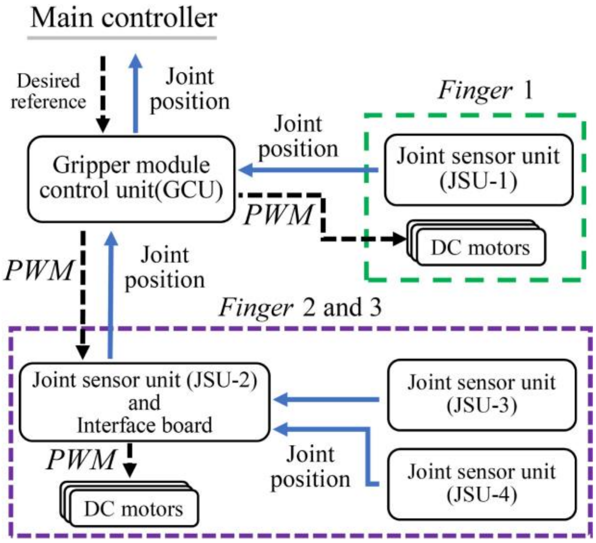

Block diagram of Gripper module

Applications

Snake robot gripper modules can be highly beneficial for search and rescue operations in narrow spaces. The unique design and capabilities of these modules enable them to access confined areas that are difficult to reach by humans or traditional robots.

Urban search and rescue: In disaster scenarios such as collapsed buildings or urban areas affected by natural disasters, snake robot grippers can navigate through tight spaces, debris, and rubble to search for survivors. They can reach areas where human rescuers may face difficulty, increasing the chances of locating and rescuing trapped individuals.

Confined spaces exploration: Snake robot grippers can explore and inspect confined spaces like underground tunnels, pipelines, or industrial machinery. These modules can traverse through narrow passages, reach remote corners, and perform visual inspections or collect data in hazardous environments, minimizing the risk to human operators.

Caves and mines exploration: Snake robots equipped with gripper modules can navigate through narrow cave systems or mine shafts. They can assist in exploring uncharted areas, locating trapped miners or spelunkers, and providing crucial information to rescue teams.

Military and law enforcement operations: Snake robot gripper modules have potential applications in military and law enforcement scenarios. They can be used for reconnaissance, surveillance, and accessing confined spaces in urban warfare situations, hostage rescues, or counterterrorism operations.

Underwater search and rescue: Snake robots equipped with grippers can be used for underwater search and rescue missions, such as locating submerged vehicles or retrieving objects. Their flexible and maneuverable bodies allow them to navigate through submerged wreckage or narrow underwater passages, assisting divers and improving the efficiency of search operations.

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