DEVELOPMENT OF AN ACTIVE FLEXIBLE CABLE DRIVEN BY CILIARY VIBRATION MECHANISM

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Abstract:
A proposed new actuation mechanism realizes active or semi-active mobility for flexible long cables such as fiberscopes and scope cameras. A ciliary vibration mechanism was developed and the availability of this mechanism was examined using some prototypes. Driving characteristics of the active cables were confirmed through experiments. Finally, the actuation mechanism was applied for an advanced scope camera that can reduce friction with obstacles and avoid stuck or tangled cables.

Keywords: Active cables, Ciliary vibration mechanism, Rescue robot, Scope camera

Introduction

A proposed new actuation mechanism realizes active or semi-active mobility for flexible long cables. Active actuation of flexible cables is important in many situations. An example is a scope camera for search and rescue in urban disasters. When the scope camera is inserted into narrow and circuitous spaces (Fig. 1), it is difficult to insert it by pushing it from behind because of its flexibility. In such a case, by getting active mobility, it is expected that the scope camera itself can help humans insert it into a narrow space without sacrificing its advantageous flexibility. In other non-rescue cases, a cable having active mobility does not limit a mobile robot's capability. Such a mechanism would be useful as a main driving mechanism for robots such as a pipe-crawling or pipe-inspection robot.

Ciliary vibration mechanisms[1][2] were focused and examined, for the following two advantages:

- those having distributed driving force;
- those that can be easily installed in existing cables.

Our study develops and controls flexible long cables using a ciliary vibration mechanism and analyzes this driving mechanism.

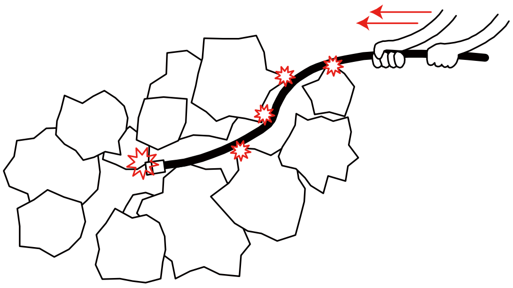

Fig. 1: *Insert scope camera into rubble*

Ciliary vibration mechanism

Trial models of active cables with ciliary vibration mechanisms have been produced and its mobility mechanisms have been estimated. The ciliary vibration mechanism has plastic or metal thin wires called cilia and achieve driving power through cilia vibration. As the cilia are angled and planted, by adding vibration to the cables, a body can move forward through a falling-down and standing-up motion. Changing the angle of planted cilia can control the object's velocity and climbing ability.

This ciliary vibration mechanism was applied to cable. The cable is covered with cilia all around (Fig. 2). Therefore, it is expected to have the following characteristics:

- it has distributive mobility throughout its body;
- it can generate driving forces in all directions around its body;
- it enables attachment to flexible cables;
- it is effective in avoiding cable sticking or tangling;
- it is a comparatively simple mechanism.

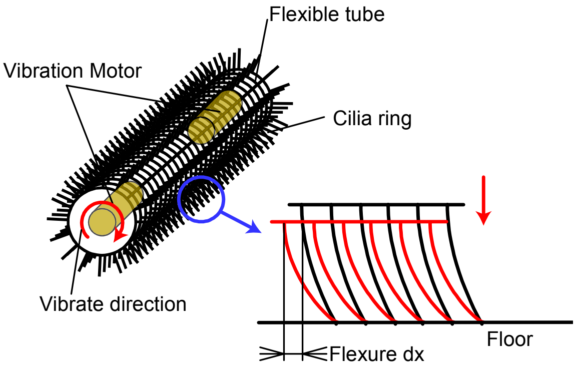

Fig. 2: *Model of ciliary vibration mechanism*

Prototypes with ciliary vibration mechanism

First Prototype

A prototype (Fig. 3) with ciliary vibration mechanism was produced to examine the capability of this mechanism[1]. The dimensions of a first prototype were 73 mm diameter, 230 mm length, 160 mm length of cilia part and 1 kg weight. Cilia made of brass (0.15 mm diameter, 13 mm length) were attached around a flexible tube of 34 mm diameter. The cilia were angled at about 80 degrees from the tube center. Two vibration motors were located in the body.

The first prototype could drive on flat ground without humans' pushing. It could move on the hard running surface, such as wood, concrete and acrylic board. The maximum speed was 130 mm/s and the maximum gradability was 10 degrees. In addition, it could go into narrow space whose size was 3 mm smaller than its diameter.

However, the weight and the large diameter were problems in the first prototype. In addition, the variation of cilia's bending was large and cilia were irregular.

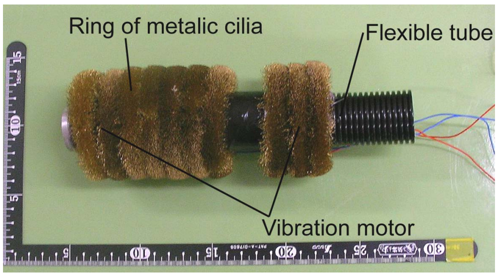

Fig. 3: *First prototype*

Second Prototype

Development of a next prototype (Fig. 4) improved heaviness and large diameter which were problems in the first prototype[2]. The second prototype had cilia made from nylon around a flexible tube and two vibration motors. Using cilia made from nylon and vibration motors that are used conventionally in mobile telephones, size and weight were tried to be reduced. The dimensions of this prototype were 38 mm diameter, 200 mm length and 90 g weight.

In addition, head bending mechanism was installed on the second prototype. It had four memory metals (TOKICorp. BMF) at the head (Fig. 5); its head could be bent by about 30 degrees in four directions. The maximum speed was 40 mm/s on the hard running surfaces, and the maximum gradability was 5 degrees. The reasons of decrease in speed and climbing ability were considered to be following points:

- the lightness of the body;
- the descent of coefficient of friction between cilia's ends and running surface;
- the descent of vibration force.

However, using cilia made from nylon, following advantages were seen; the easiness of setting of cilia's angle; the ability that it drove on comparatively soft surfaces such as cardboard and cloth as well as hard surfaces. In addition, using small vibration motors, the second prototype could achieve miniaturization and reduction in weight.

Fig. 4: *Second prototype*

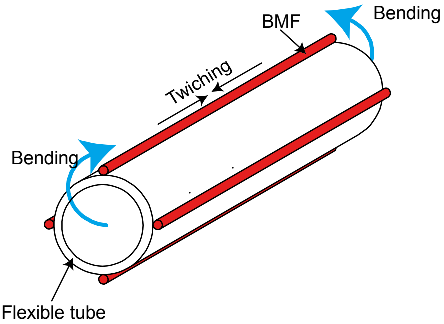

Fig. 5: *Bend in four directions by memory metals*

Estimation of the actuation mechanism

The actuation mechanism can be estimated from video images captured using high-speed video camera (Fig. 6). For falling-down motion (Fig. 6 (I)-(II)), the front edge of a cilium stops on the surface; consequently, the body can move forward. Using a standing-up motion (Fig. 6 (II)-(III)), the front edge of a cilium slips forward on the surface. Consequently, the body can hold its position without moving backward. By repeating this motion, a body moves forward through the use of vertical vibration. It is considered that the strain energy is stored by bending cilia in a falling-down motion and that the body can move forward by using that energy in a standing-up motion.

In addition, through observations obtained by changing the motor's revolution speed, it is apparent that the body has some vibrations aside from those for the motor's vibration. It is confirmed that various patterns of body vibration exist. The reason is considered to be the resonance of the body and the cilia's stick-slip behavior at the contact face.

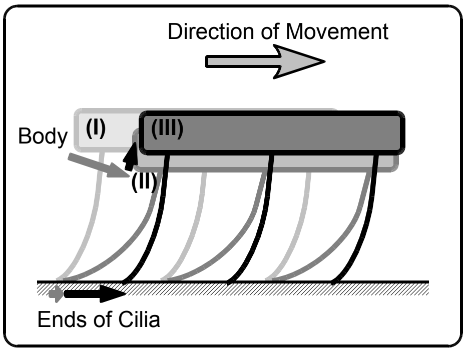

Fig. 6: *Estimation of the actuation mechanism*

Application for an industrial scope camera

Active scope camera

A prototype of an active scope camera was produced (Fig. 7). This ciliary vibration mechanism was attached to a general industrial scope camera. The dimensions of the active scope camera are 30 mm diameter and 5 m in length. It has 18 vibration motors (8 mm diameter, 5.1 mm thickness, 1.25 g weight, 2 G vibration force, FMIU-004; Fujikura Shoji Co. Ltd.), which are located in pairs at ca. 40 cm intervals. The attached cilia (0.01 mm diameter, 10 mm length, made from nylon) are angled at about 80 degrees from the camera center.

The active scope camera has four memory metals (TOKI Corp. BMF) at the head; its head can be bent by about 40 degrees in four directions. Bright LED lights are located beside the camera.

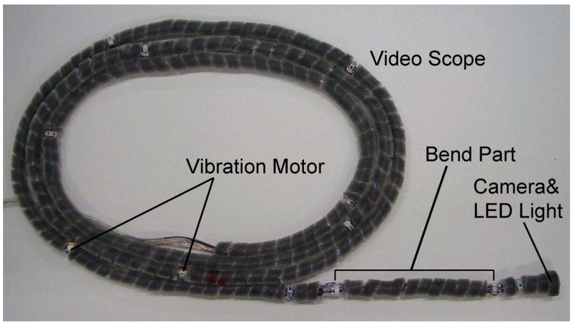

Fig. 7: *Prototype of the active scope camera*

Performance evaluation

First, the basic mobile performance was estimated. The active scope camera was located between V-formation surfaces with length of 2 m. The active scope camera was driven in this situation. Two experiments were made: 1) changing the running surface, and 2) changing the angle of inclination.

Results of experiments are shown in Fig. 8 and Fig. 9. The active scope camera achieves high performance on a wood surface. Because wood is plentiful in rubble spaces in which scope cameras are used, this result can illustrate the effectiveness of this active scope camera. In addition, this scope camera was believed to be incapable of driving on expanded polystyrene because of its softness and asperity, but it was able to run on expanded polystyrene at a low speed. The maximum gradability was 11.5 degrees; it showed higher climbing ability than previous prototypes (about 5 degrees)[2].

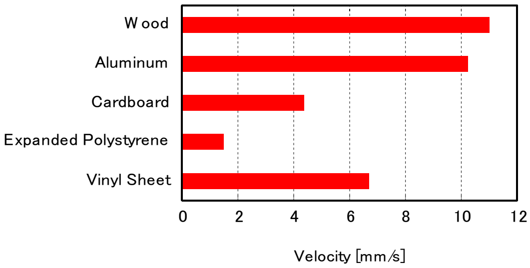

Fig. 8: *Experimental results of velocity change: running on floor material*

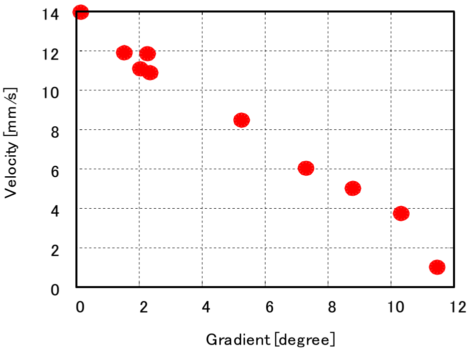

Fig. 9: *Experimental results of velocity change: angled slope*

Next, to evaluate the ability of escaping from a stuck situation, friction forces was measured by pulling the cable in the supposed stuck situation and located three obstacles. In Fig. 10 set d= ϕ 5 cm and a=40 cm, static friction forces and dynamic friction forces were measured while changing distance b from 0 to 35 cm at 5 cm intervals. Static friction forces were forces at which the body began to move; dynamic friction forces required the force of tension to pull at a constant velocity of 3.3 cm /s.

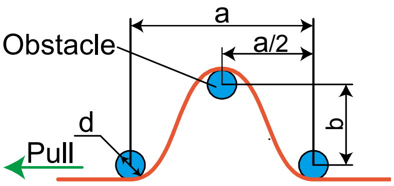

Fig. 10: *Measurement of the pull friction. The active scope cable is set along the obstacles and pulled.*

Static friction forces and dynamic friction forces are shown in Fig. 11 and Fig. 12 changing length b. In the case of adding vibration compared to using a cable alone, the static and dynamic forces are reduced greatly in spite of an enlarged diameter. Especially regarding static friction forces, forces are reduced in the case of adding vibrations compared with no vibration. From this tendency, it is considered that application of this mechanism is available because the scope camera repeats stopping and motion.

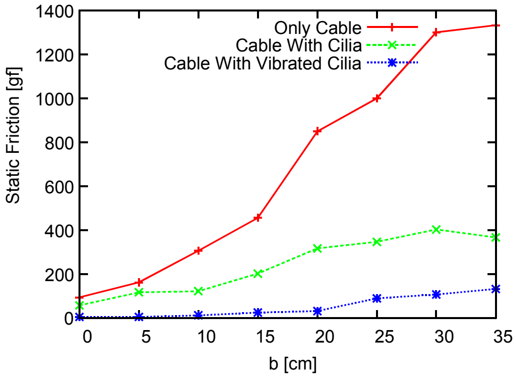

Fig. 11: *Results of static friction experiments*

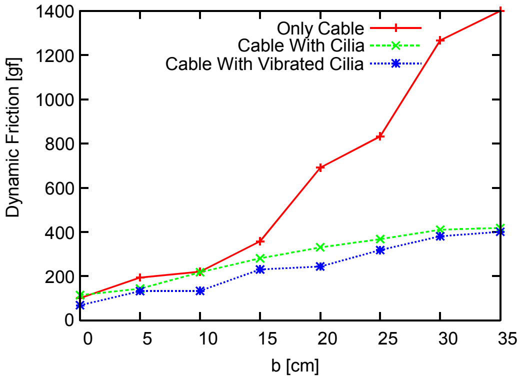

Fig. 12: *Results of dynamic friction experiments*

Merely attaching cilia without vibration reduces the cable friction greatly because the contact between the scope camera and surface becomes a point contact as a result of the cilia; furthermore, repulsive forces are generated by the bending of the cilia. The stick-slip behavior occurred only with a cable, but the attached cilia reduced this behavior.

Conclusion

Our study develops and controls flexible long cables using a ciliary vibration mechanism and analyzes this driving mechanism. Ciliary vibration mechanisms were examined through developed prototypes.

Furthermore, by experiments using the developed advanced scope camera, it was confirmed that friction forces were greatly reduced by attaching the ciliary vibration mechanism. For that purpose, attaching this mechanism was effective.

Acknowledgments

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