A Miniature Manipulator for Integration in a Self-Propelling Endoscope

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Summary. This paper presents a miniature robotic manipulator that will be integrated into a self-propelling endoscope. The endoscope is meant to inspect and intervene in the human colon through which it moves by inch worm motion. The manipulator is used to orient camera and tools and has two bending degrees-of-freedom (± 40°). It consists of two modules driven by an electromagnetic motor with worm gear reduction. Each module is 12 mm in diameter and 20 mm long. The total arm with integrated camera is 40 mm long. Also a miniaturised version has been built, having a diameter of 8.5 mm and one degree-of-freedom.

Keywords: colonoscopy, inch worm, microrobotics

Introduction

Classic colonoscopes (endoscopes for inspection and intervention in the colon) are semi-flexible tubes which are inserted into the colon by pushing. As the colon is very elastic and contains multiple sharp bends, it requires a skilled surgeon to perform the insertion and the procedure is often painful for the patient. Furthermore, it is not always possible to inspect the whole colon.

As an alternative, a self-propelling endoscope is under development which moves through the colon by inchworm locomotion. As shown in figure 1, it consists of a propulsion unit, a miniature robotic arm, and a tail. The propulsion unit consists of two suction clamps connected by expansion bellows. For more information on the propulsion unit is referred to Dario et al. [1]. The tail connects the endoscope to the outer world and contains electrical wiring, pneumatic tubes, tool channel, flushing channel, and illumination fibres.

This paper describes the design of the miniature manipulator which is placed at the front of the endoscopic system and which is used to orient and position the tools and camera. Manipulation of the tools requires a manipulator with high force output. Therefore, previous manipulators were based on shape memory alloy (SMA) actuation or hydraulic actuation. Examples of SMA manipulators are described in [2,3,4,5]. Problems occurring with SMAs are the slow response, the difficulty to control them and the heat losses causing the system’s temperature to rise above the safety limit.

Examples of hydraulic manipulators are found in [6,7,8,9]. In [6], the manipulator consists of an elastomer multi-lumen tube of which each chamber can be pressurised individually. Differences in pressure cause the tube to bend. One problem associated with this manipulator is its low stiffness. Higher stiffness can be obtained with the miniature parallel manipulator described in [7,8,9]. It consists of a Stewart platform driven by three hydraulic pistons. A disadvantage for all hydraulic manipulators is that they cannot be directly driven electrically, but require a hydraulic circuit, and that the hydraulic tubes

![Fig. 1: Self-propelling robotic endoscope.](image-url)
increase the diameter and stiffness of the tail. Integration of valves in the manipulator or propulsion unit of the endoscope could reduce the number of hydraulic tubes, but this significantly increases the complexity of the device.

The manipulator presented in this paper is based on electromagnetic motors. These are much easier to control than SMA or hydraulic actuators and can be powered by thin, flexible electrical wires.

A previous design [8,9] is based on a Stewart platform with three degrees-of-freedom. It has three telescopic legs, each driven by an electromagnetic motor with spindle. Its main drawback is its size: 15 mm in diameter and 45 mm long in its shortest state. A more compact manipulator is obtained with the design presented in the following paragraph.

**Manipulator design**

The new manipulator design is based on a serial combination of two modules with one rotational degree-of-freedom. The design of a single module is shown in figure 2. The module is 12 mm in diameter and 20 mm long, and can rotate 40 degrees to both sides. The module is driven by a miniature gearmotor through a worm gear reduction.

The motor is an RMB SMOOVY brushless DC motor (SHH30002), 3 mm in diameter and 7 mm long. According to the data sheets it generates a maximum continuous torque of 25 µNm and runs at a maximum speed of 100 000 rpm. The motor is supplied with a planetary reduction of 1:25. The input speed of the reduction is limited to 30 000 rpm. The output speed is therefore maximally 1200 rpm. Due to an efficiency of 80 % of the reduction, the maximal output torque of the motor-reduction combination should be 0.5 mNm. However, measurements show that the real motor torque is about 0.2 mNm, about 40% of the value specified in the data sheets. It is not yet clear what causes this difference.

The torque is further increased by the worm gear reduction having a gear ratio of 1:28, which brings the total reduction to 1:700. The maximal rotational speed of the module is thus 260 degrees/s. The worm gear offers also a compact way to change the orientation of the rotation axis.

A large hole runs through the module to pass the tool channel, camera wiring, illumination fibres, and flushing channel.

**Prototype**

Figure 3 shows a prototype of a single module. Both parts of the body are from stainless steel and produced by wire-electro-discharge-machining. The worm, also from stainless steel, is a cylinder with standard M2.5 screw thread. The worm gear is from bronze and is also produced by wire-electro-discharge-machining.

The module moves smoothly and can be easily controlled. Measurements show that the prototype generates torques up to 1.1 mNm. This means that the efficiency of the worm gear is 20 %.

**Integration in the endoscope**

The manipulator requires two degrees-of-freedom, such that two modules have to be put in series. Four different configurations are possible, but the configuration shown in figure 4 is the most optimal. Advantageous is that the camera is integrated into the front module while the other module is for a large part integrated into the front clamp of the endoscope. Therefore, the arm extends only 40 mm at the front of the propulsion module. The front module is longer than the second module because of the length of the camera integrated in it. A smaller camera could reduce the arm’s length to 30 mm.

Another advantage of the chosen configuration is that both rotation axes are located close to each other such that the manipulator characteristics in both directions are nearly identical.

The manipulator should be hermetically sealed to protect the motor, gears, and bearings against electrical short circuits and dirt. Rubber bellows can be used for that purpose.
Miniaturised manipulator

The manipulator described above can be further miniaturised. Figure 5 shows the design of an 8.5 mm diameter manipulator working on the same principle and having mainly the same construction. As a reference, the outer diameter of the ‘large’ module is displayed too. The main difference is the eccentric placement of the shaft. As can be seen in figure 5, this allows a smaller diameter for the same size and placement of the motor and worm gear. Another consequence is that the stroke is not equal to both sides: 60º when rotated to the left and 45º when rotated to the right.

Another difference is the replacement of the ball bearings by plain bearings in order to save space. Tests showed no significant influence on the module’s characteristics.

Due to the reduced diameter, also the space left for cables and tool channels is reduced. In the current design sufficient space is left for a 3 mm diameter cable or channel.

The same motor and planetary reduction are used as for the ‘large’ module. The worm is reduced in size, from 2.5 mm to 2 mm in diameter. The worm gear reduction has a ratio of 1:33, which gives a total reduction of 1:825.

An 8.5 mm camera has been placed at the front of the miniaturised manipulator. Figure 6 shows the prototype in both its extreme positions. Figure 7 shows a close-up of the internal mechanism with a view on the worm, worm gear, and camera cable. The total length of the manipulator is 45 mm and is mainly determined by the length of the camera. The driving module itself (as shown in figure 5) is only 21 mm long. A smaller camera is under development and can significantly reduce the size of the manipulator.

Also this manipulator should be sealed with rubber bellows.
Conclusion and future work

The presented designs result in compact manipulators which move smoothly and are easy to control. The current output torque is rather low. Future work includes improvement of the efficiency, the use of a planetary reduction with higher gear ratio (1:125), and the addition of a position sensor for closed loop control. Finally, the manipulator has to be sealed with rubber bellows and integrated into the endoscope.

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References