Multi Degrees of Freedom Forceps for Ultrasonically Activated Device using Ultrasonic Motor

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Abstract

We have developed multi degrees of freedom forceps which has one degree of bending and one degree of tip rotation freedom for small USAD. Especially, we developed a ultrasonic motor for rotation mechanism, which has various merits of small size and high-torque. For actuation mechanism, we selected cylinder-type ultrasonic motor. Bulk piezoelectric zirconate titanate (PZT) cylinder was used as a stator transducer. Inner diameter and outer diameter of the actuator was 13 mm and 14 mm and length was 25mm. In rotation property evaluation experiment, we confirmed that the actuator has sufficient rotation speed and holding torque. From positioning experiment, we have achieved smooth approach to the brood vessel model using the mechanism.

Keywords: Ultrasonic Motor, Forceps Manipulator, Ultrasonically Activated Device

1. Introduction

Ultrasonically Activated Device (USAD) is widely used in laparoscopic surgery. In USAD, the tip blade vibrate ultrasonically and it appears to offer the mix of coagulation and cutting. By using it, surgeons do not have to suture small vessels, smooth operation is achieved [1][2]. However, because the current USAD has a linear shape, it makes surgeon to use the device from undesirable approach that might cause complications in surgery. By adding the multi degrees of freedom to the forceps, surgeon can approach to the target from desired direction and it causes safe and smooth operation.

To achieve this, we have developed small USAD to be mounted on the tip of instruments and bending forceps manipulator to control it. Small USAD does not need to transfer vibration through any long straight metal rod[3]. So it is compact enough to be arranged on the tip of the instrument and can generate satisfactory large power to incise tissue.

Bending forceps manipulator has two degrees of bending freedom using wire mechanism[4]. However, wire is easily broken and DC motors which are located on the back of the instruments are heavy. Also, especially rotation mechanism of the bending tip is required because it is easy to approach the vessel from the desired direction with the tip-rotation mechanism. But the bending forceps we developed did not have the rotation mechanism.

Ultrasonic motor is counted on the new actuation system for the medical devise because of its characteristics of high-torque and small size[5]. So we decided to use ultrasonic motor instead of DC motor for rotation mechanism. The purpose of this study is to develop a new multi degrees of freedom forceps with...
instrument tip rotation mechanism using ultrasonic motor for small USAD device.

2. Materials and Methods

We designed the actuator to control the small USAD whose diameter and length of small USAD is 12 mm and 57 mm[3]. As actuation mechanism, we selected cylinder-type ultrasonic motor[5]. Bulk piezoelectric zirconate titanate (PZT) cylinder was used as a stator transducer. Electrodes attached on the PZT cylinder was divided in quarters in a circumferential direction. Four radio frequency electrical sources with 90° phase difference were applied to the electrodes. The traveling wave is generated on the end surface by bending motion of the stator transducer which was generated by the r.f. electrical source. The rotor loaded on the end surface of transducer turns around in the indicated direction by the friction force.

Figure 1 shows the structure of ultrasonic motor with USAD. We used cylinder type PZT (C213, Fuji Ceramics Corporation), whose inner diameter and outer diameter of the actuator was 13 mm and 14 mm and length was 25mm. A coil spring was used to add the pre-compression between the stator transducer and the rotor.

We used wire mechanism for bending. Finally, the forceps has one degree of rotation and one degree of bending freedom. Figure 2 shows the photo of the prototype of the multi degrees of forceps with small USAD. Diameter of USAD with ultrasonic motor was 28 mm and length was 83mm.

3. Results

3.1. Stator Transducer Property Experiment

To estimate the properties of vibration, the resonance frequency, vibration mode were measured by monitoring the vibration velocity using a laser Doppler vibrometer (NLV-2500 Polytec Inc.). We measured the relation between the driving frequency and the vibration amplitude. The driving voltage was kept at 40Vp-p.

The result is shown in figure 3. The vibration amplitude was reached a maximum at the resonance frequency, 42.8kHz.

Vibration mode was measured by scanning the laser from the bottom to the top of the side wall of the stator transducer. As a result, the stator transducer had a bending vibration in first-order mode with both end free as expected.

3.2. Rotation Property Evaluation Experiment

Secondly, holding force and rotation speed were measured.

To measure holding force, we fixed the actuator on the material testing machine (EZ Test, Shimazu co. ltd., Japan). A wire was fixed on the rotor and pulled by the material testing machine. Rate of pulling was 5mm/min and we changed precompression condition from 200gf to 600gf. Figure 4 shows the load measured by the material testing machine under the condition of 200gf precompression. We measured peak force as the holding force. The result shows in figure 5. By increasing the precompression, holding force was increased. Then the actuator has enough holding force (500gf) to grasp one-third of human liver by adding 600gf precompression.
Finally, we have measured angular velocity. Under 600gf precompression and applying 110Vp-p power condition, we measured each velocity to rotate 10 degree from 0 to 360 degree. The results shows figure 7. Rotation velocity was inequable and maximum difference was 40 degrees/s. Ultrasonic actuator uses friction mechanism, inequable rotation is often appears. Feedback system using encoders will be solution of this problem.

3.3. Positioning Experiment

Finally, positioning experiment was performed using blood vessel model. Figure 8 shows the picture of the experiment. Tip rotation was smoothly achieved during pushing an activation switch. By bending and rotating the forceps tip, small USAD could easily approach the blood vessel model.

4. Discussion

We developed ultrasonic actuator for rotation mechanism, which has various merits of small size and high-torque. There are several researches about
ultrasonic motor capable of multi-dof actuation for forceps manipulator[7][8]. However, they are not yet competent enough to use for surgery because they has limited output torque, low controllability and difficulty, in fabricating the design. Takemura et. al. proposed a new control scheme for a surgical instrument. However, it is still difficult to achieve the high torque to hold organ. We decided to develop an actuator with simple rotation mechanism and achieved high torque and controllability.

In rotation property evaluation experiment, we confirmed that the actuator has sufficient rotation speed and holding torque. However, the size of actuator and USAD is not small enough to the operation. By optimizing the size of the actuator and re-designing, smaller rotation mechanism can be developed.

Nowadays, several energy devices not only USAD but also bipolar electric scalpel were widely used in laparoscopic surgery. Every device has to approach to the target from the desired direction. Rotation mechanism using a ultrasonic motor is easily applied to such other devices.

Adding more degrees of freedom is very useful for recent minimally invasive surgery such as Single Port Surgery(PS) and NOTES[9]. Also sterilization and electrical safety are very important issue for clinical use. For future work, first we re-design and make the device smaller and study for overcome those issues.

5. Conclusion

We have developed multi degrees of freedom forceps which has one degree of bending and one degree of tip rotation freedom for small USAD. For rotation mechanism, we have developed ultrasonic actuator using cylinder-type bulk PZT. 500gf of holding force and 15rpm of rotational speed which were enough for laparoscopic surgery were achieved with this system. Furthermore, smooth approach to the brood vessel model using the mechanism was achieved.

For future work, we improve the system for smaller size and perform in-vivo experiments to confirm its applicability for clinical treatment.

Acknowledgements

This study is partly supported by JSPS(22700507)

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