# Active Forceps for Endoscopic Surgery

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**Abstract:** Endoscopic surgery has recently been adopted in various surgical operations. Forceps stuck through trocars into the abdominal or chest cavity, dissects and grasps internal organs. Due to their fixed shapes, the current forceps limit the skill of surgeons. We have worked on the development of active forceps adoping shape-memory-alloy pipes and coaxicially assembling them. In this paper, we show several models that we prototyped to find out the functional conditions of SMA pipes and their material. A 3DOF active forceps is also introduced, which posesses 6DOF inside the body being manipulated by the AESOP manipulator. A master-slave robot system is developed using it.

## 1. Introduction

Laparoscopic surgery has shown a rapid and wide expansion as a minimary invasive therapy. Straight shaped equipments, however, limit the surgeons' maneuvers in particular behind complicated spots behind organs. In order to unload the surgeons' load due to the above, we have continued our research since 1993 focussing on the development of actively bending yet stiff forceps employing Ti-Ni shape memory alloy pipes [1][2]. In this paper, we show several models that we prototyped to find out the functional conditions of SMA pipes and their material. A 3DOF active forceps is also introduced, which posesses 6DOF inside the body being manipulated by the AESOP manipulator. A master-slave robot system is developed using it.

## 2. The Active Forceps: Prototype D

### 2.1. Structure

The current prototype consists of a co-axially assembled SMA-pipe pair and a drain pipe as seen in **Fig.1**. The pipes are prepared as follows:

**PIPE1** Ti-Ni-Cu alloy is adopted since it has an advantage of low yield stress at the Martensite phase. The $A_f$ and $M_f$ temperatures ($T_{Af}$, $T_{Mf}$) are designed such that $T_{opL} < T_{Mf} < T_{Af} < T_{opH}$, where $T_{opL}$ and $T_{opH}$ are the lower and higher bound of the operational temperature. A circular shape is memorized by heat treatment.

**PIPE2** Ti-Ni alloy is used with the $M_s$ temperature ($T_{Ms}$) lower than $T_{opL}$. Since a straight shape is memorized, this pipe maintains straight and stiff at the range of the operational temperature.

**PIPE3** This pipe is made of tefron and used for returning path of water circulation.

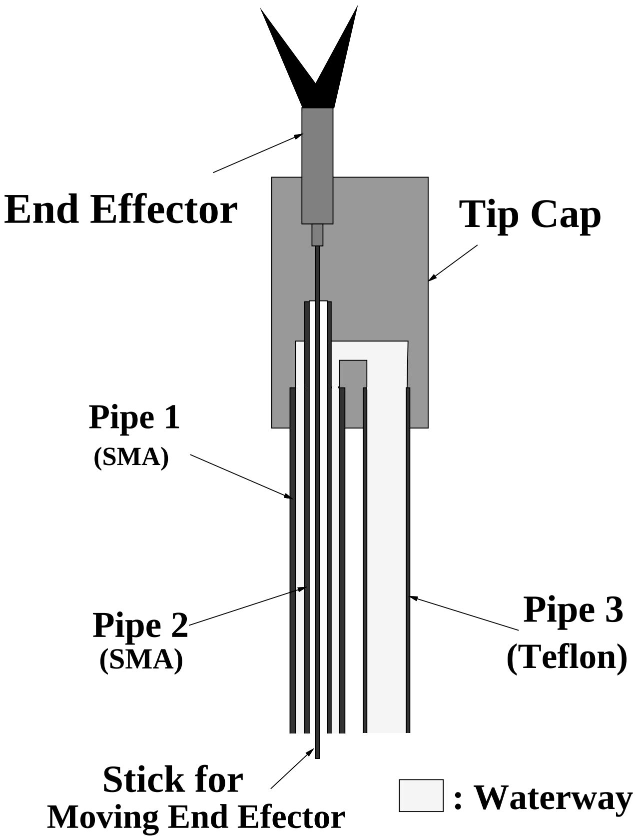


**Fig. 1**. Structure of SMA Active Forceps

The shape of the forceps changes according to the temperature of water circulation as follows: At the higher temperature, the returning force of PIPE1 to recover the circular shape and the elastic force of PIPE2 to keep the straight shape find an equilibrium point at a circular shape that has a larger radius than that of the PIPE1's memory. On the contrary, at the lower temperature, PIPE1 behaves like a plastic material with rather low yield stress. The elastic force of PIPE2 dominates and deternines the shape of the forceps almost straight.

The temperature of water circulation is controlled by mixing prepared hot and cold water.

### 2.2. Performance

In this section, the performance of the prototype introduced in the previous section is to be described.

**Fig.2** shows the photos of the stretched and bent shapes. The minimum bent angle of the stretched shape was 18.0 degree, while the maximum bent angle of the bent shape was 63.6 degrees.

The response from the minimum bent angle to the maximun one took 9.6 sec, among which 3.9 sec was used for sending water from the pump to the forceps. Figure 3 shows the graph of time-response. The pumping pressure was rather low due to the limited performance of pump and the low-pressure connection of water tubes. Although it is anticipated that the improvement of pumping system will significantly lower the response time, to achieve a few seconds response time there needs a fundamental development for the new water circulation system.

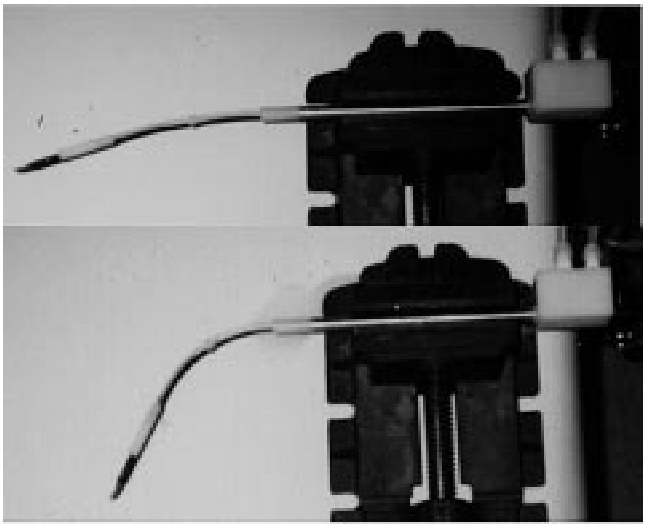

**Fig. 2**. Prototype of Active Forceps in Stretching and Bending State

## 3. Other Prototypes

### 3.1. Prototype A

The prototype A was developed in 1994 using three SMA pipes as shown in Fig.4. The dimensions were chosen as Table **??**. Figure 5 is a photo of the prototype A. Since the outer diameter was fairly large, the maximun strain limited the curvature radius.

### 3.2. Prototype B

In order to get shrap bending, we chose to use pipes with smaller diameters. The stiffness was not sacrificed since the length of the SMA pipes were now one third of the prototype A (30 cm). The prototype used double pipes, while the prototype A used triple pipe structure.

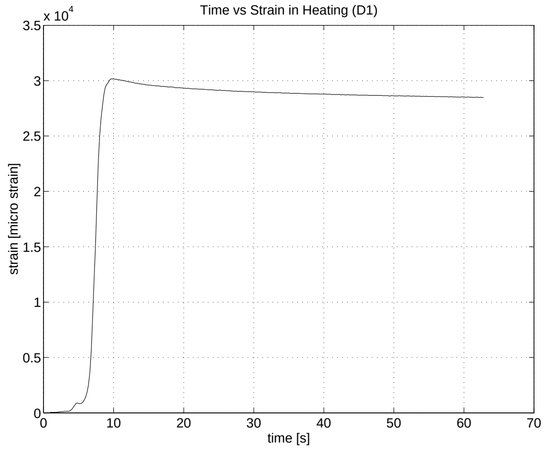


**Fig. 3**. Step Responce of Prototype

| | |
|---|---|
| Pipe1(SMA2) | $\phi$7.3 ~ $\phi$7.0 [mm] ($t$=0.15 [mm]) |
| Pipe2(SMA1) | $\phi$5.2 ~ $\phi$4.2 [mm] ($t$=0.5 [mm]) |
| Pipe3(SMA2) | $\phi$2.3 ~ $\phi$2.0 [mm] ($t$=0.15 [mm]) |
| Length | 298 [mm] |

**Table 1**. Dimensions of SMA pipes: external and internal diameters, and thickness

The structure is shown in Fig.6. The dimensions of several different designs are in Table 2.

Figure 7 show the results of bending experiments.

The large bending angle was attained by adopting diffrent material for the outer pipe, which contains a little Cu in Ti-Ni alloy. This combination provided lower yield stress.

The prototype D in the previous section adopted the same materials. The effect of having a drain tefron pipe was not significant as seen in Fig. 8.

## 4. Master-Slave Surgical Robot

We have developed a master-slave surgical robot system incorporating the active forceps developed in the previous section. Figures 9 and 10 show the master device whose 3D location and orientation is mesured by a Polhemus sensor. The handle is made of Pilling's handle.

The developed slave robot is shown in Fig.11

The forceps has three degrees of freedom, of which one is of SMA pipes and the other two are motor-driven as seen in Fig.12.

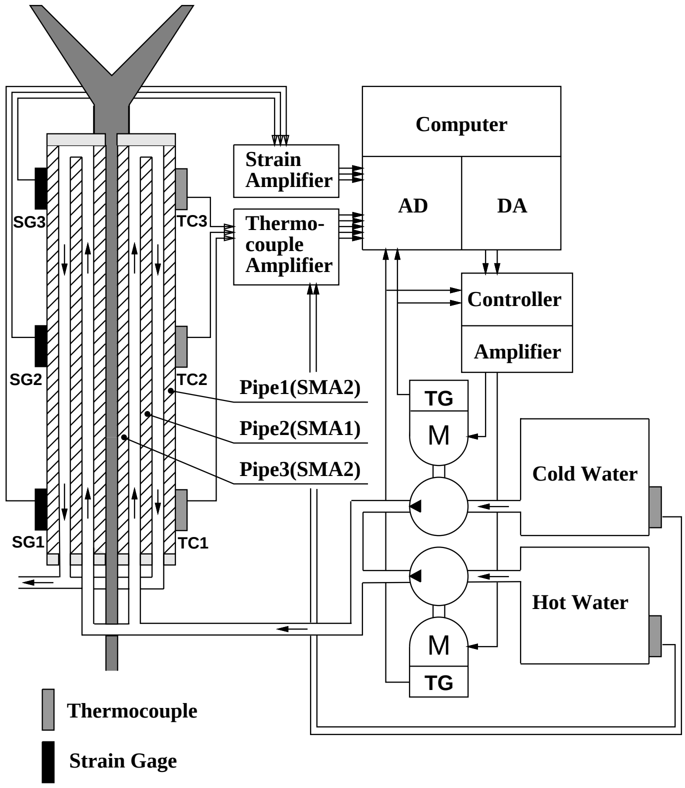


**Fig. 4**. System configuration of SMA active forceps

## 5. Conclusion

We have developed an actively bending yet stiff forceps for laparoscopic surgery. Use of Ti-Ni-Cu and Ti-Ni alloy was useful to make the effective bending angle large (from 18.0 to 63.6 degrees). The response time of current prototype was 9.6 sec. The improvement of pumping system will shorten the time. For the significant improvement of response time, however, we will need a fundamental new development of water circulation system. A master-slave surgical robot system is proposed and developed using a 3DOF active forceps.

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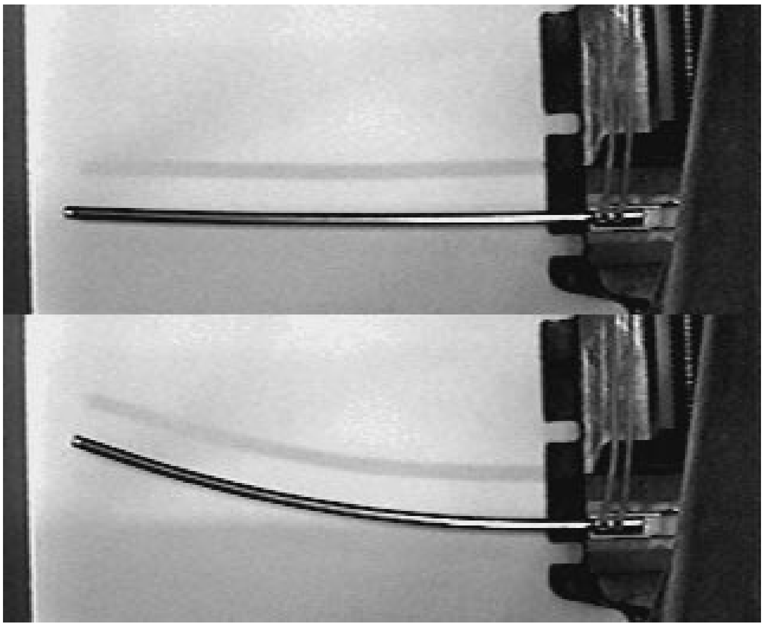

**Fig. 5.** The active forceps in stretching and bending states

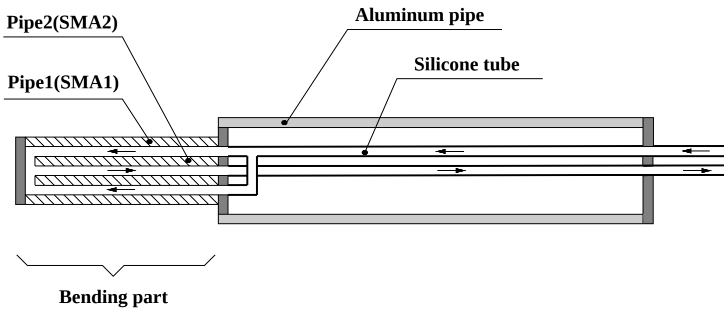


**Fig. 6.** Structure of SMA active forceps B

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**Table 2.** Sizes and memorizing angle of SMA pipes using at prototype B3–6 ($D_1$:external diameter,$D_2$:internal diameter,$t$:thickness, $\theta$:memorizing bending angle)

| | | Pipe1 | Pipe2 | Length[mm] |
|---|---|---|---|---|
| B3 | $D_1[mm]$ | 3.825 | 2.28 | 100 |
| | $D_2[mm]$ | 3.33 | 1.49 | |
| | $t[mm]$ | 0.25 | 0.40 | |
| | $\theta[\,^\circ\,]$ | 47 | 0 | |
| B4 | $D_1[mm]$ | 3.825 | 2.48 | 100 |
| | $D_2[mm]$ | 3.33 | 1.69 | |
| | $t[mm]$ | 0.25 | 0.40 | |
| | $\theta[\,^\circ\,]$ | 47 | 0 | |
| B5 | $D_1[mm]$ | 3.825 | 2.69 | 100 |
| | $D_2[mm]$ | 3.33 | 1.88 | |
| | $t[mm]$ | 0.25 | 0.40 | |
| | $\theta[\,^\circ\,]$ | 47 | 0 | |
| B6 | $D_1[mm]$ | 3.825 | 2.69 | 100 |
| | $D_2[mm]$ | 3.33 | 1.88 | |
| | $t[mm]$ | 0.25 | 0.40 | |
| | $\theta[\,^\circ\,]$ | 101 | 0 | |

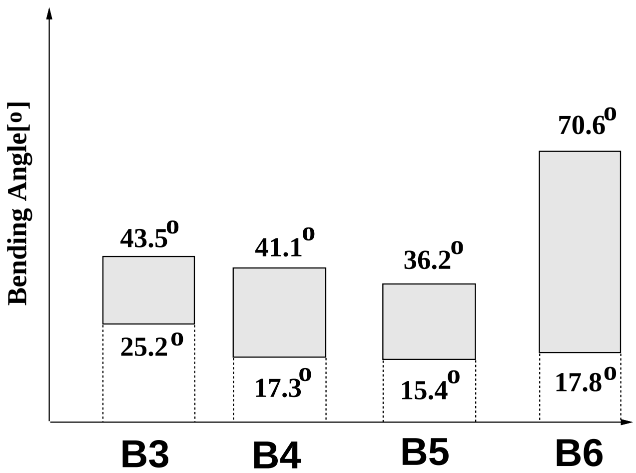


**Fig. 7.** Maximum bending angle and minimum bending angle

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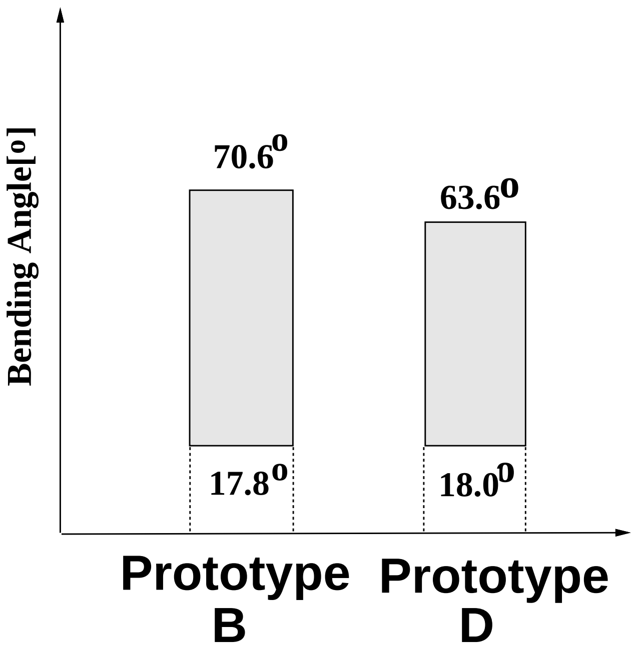


**Fig. 8**. Maximum bending angle and minimum bending angle of B6 and D1

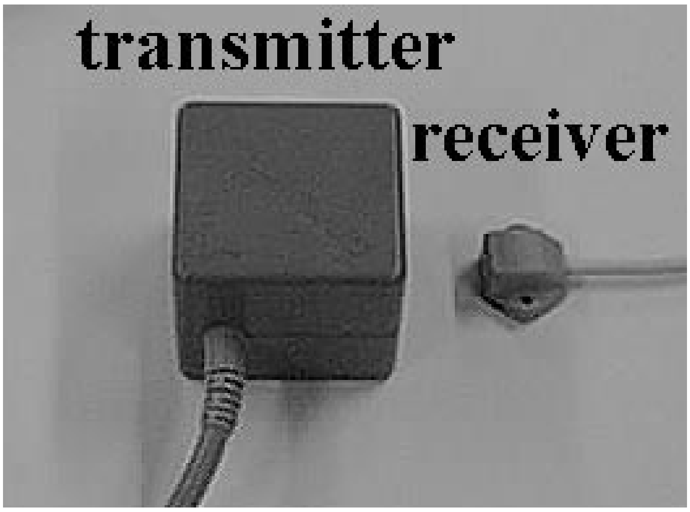


**Fig. 9**. Polhemus sensor

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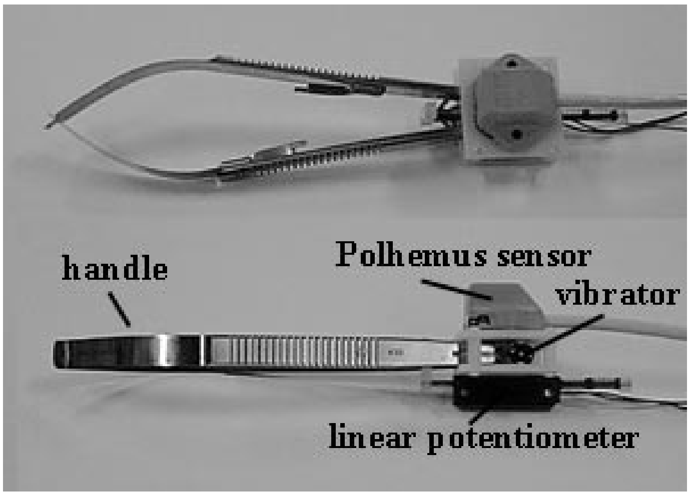


**Fig. 10**. The master device : Pilling's handle and a Polhemus sensor

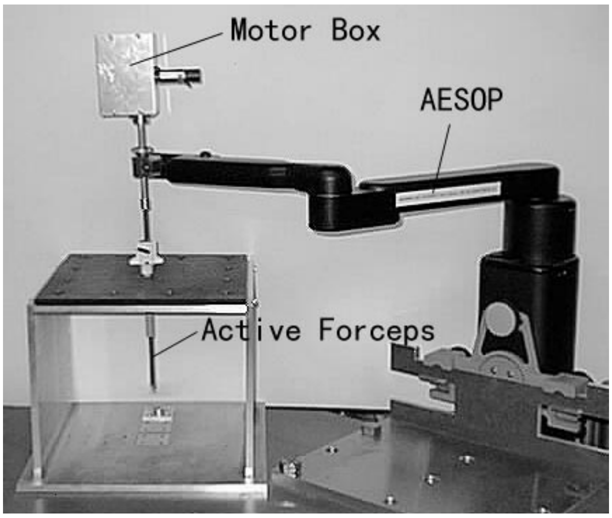


**Fig. 11**. The slave manipulator: an AESOP holding a 3DOF active forceps

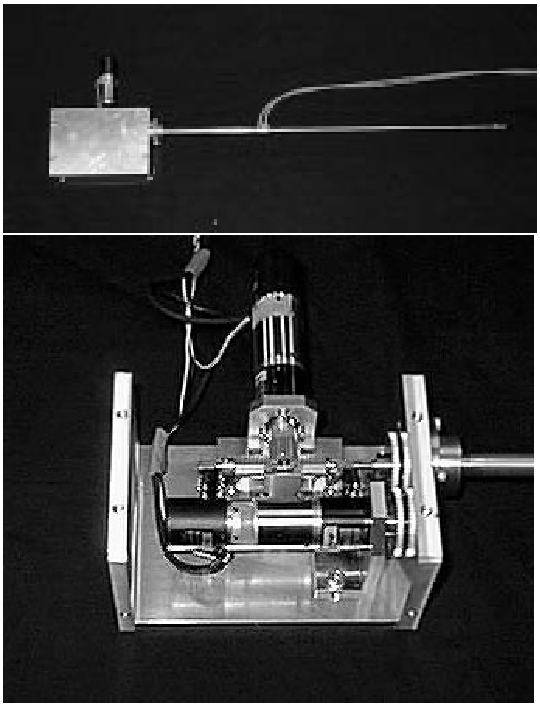

**Fig. 12**. 3DOF active forceps: 1DOF SMA pipes and motor-driven 2DOF