# MEMS 6-AXIS FORCE-TORQUE SENSOR ATTACHED TO THE TIP OF GRASPING FORCEPS FOR IDENTIFICATION OF TUMOR IN THORACOSCOPIC SURGERY

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## ABSTRACT

We developed a MEMS 6-axis force-torque sensor attached to the tip of grasping forceps for identification of tumor in thoracoscopic surgery. To validate the grasping forceps with sensors, the gelatin in which a silicone sphere was embedded was grasped with it and the variations in 3-axis force and 3-axis torque depending on grasping positions were measured. The size of the embedded hard object in a soft material was derived from acquired data of compression forces. It was also indicated that we can get the direction of the object from 2-axis torques.

## INTRODUCTION

Endoscopic surgery is highly expected as a minimally invasive method, because the recuperation period is shorter than that of the open surgery (Table 1). However in this method, it is difficult for surgeons to feel the tumor by palpation, because they have to use the endoscopic instruments including grasping forceps. Especially in the case of surgery for lung cancer, the air was taken away from the lung before the surgery, so the lung itself is deflated and the position of the tumor is almost lost. To solve these problems, research on the grasping forceps with multi-axis force sensors were carried out.

Force sensor integrated surgical forceps for robotic surgery was reported [1]. 2-DOF force sensor was integrated at each tip of their forceps and the sensor characteristics were demonstrated by using a reference force sensor. A laparoscopic grasper with 3-D force measurement capability at the grasping jaw was also reported [2]. The size of the jaw with sensors was approximately 15mm wide by 45mm long by 13mm high. Force sensors at the tip of forceps are always requested to be as small as possible for the practical use. Studies on the measurement of stiffness and viscoelastic properties of the grasped objects by using 3-axis force sensors attached to a grasping forceps were also reported from our group [3, 4].

This paper reports a method to derive the size of hard object embedded in a soft material, which implies a tumor in organ, from acquired data of the MEMS 6-axis force-torque sensor attached to the tip of grasping forceps for thoracoscopic surgery. The size of the tumor like lung cancer is generally estimated by CT (Computed Tomography) scanning before the surgery. If the calculated size by our method is close to the estimated size by CT scanning, we can identify the grasped object by forceps with the tumor itself.

*Table 1: Comparison between the open surgery, the endoscopic surgery without sensors, and that with sensors.*

| | open surgery | endoscopic surgery | |
|---|---|---|---|
| | | w/o sensors | w/ sensors |
| recuperation period | long | short | |
| tactile sensing | by finger | difficult | Easy |
| obtain size & position of tumor | by finger | impossible | possible |

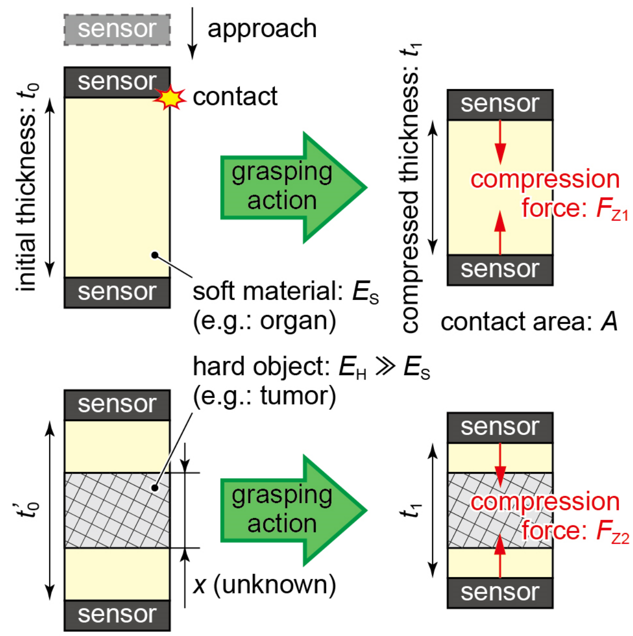


*Figure 1: The principles of our method to calculate the thickness of the hard object in a soft material.*

## PRINCIPLES

Figure 1 shows the principles of our method to calculate the thickness of the hard object in a soft material. In the case of no hard object, initial thickness of the soft material $t_0$ can be determined, because the distance between two tips of the grasping forceps is always measured by using a potentiometer and the contact timing can be known from the output change of the 6-axis force-torque sensor. After grasping actions, compressed thickness $t_1$ becomes a certain value, regardless of whether the hard object is present or not, because the grasping forceps has a ratchet mechanism. Compression force $F_{z1}$ can be measured by the sensor, and the following equation holds:

$$\frac{F_{z1}}{A} = E_s \frac{(t_0 - t_1)}{t_0} \tag{1}$$

where $A$ is the contact area and $E_s$ is Young's modulus of the soft material.

When the hard object is present in the soft material, initial thickness $t_0'$, compressed thickness $t_1$, and compression force $F_{z2}$ can be also measured. If the Young's modulus of the hard object $E_h$ is high enough to ignore the deformation, the following equation holds:

$$\frac{F_{z2}}{A} = E_s \frac{(t_0' - t_1)}{(t_0' - x)} \tag{2}$$

where $x$ is unknown thickness of the hard object. From these two equations, $x$ is expressed as follows:

$$x = t_0' - \frac{F_{z1} t_0 (t_0' - t_1)}{F_{z2} (t_0 - t_1)} \tag{3}$$

## MATERIALS

The design, fabrication process, and calibration method of the 6-axis force-torque sensor built on the preceding research [5]. The area of the sensor chip, 1.25mm square in size as shown in Figure 2(a), was reduced by 60 percent. The

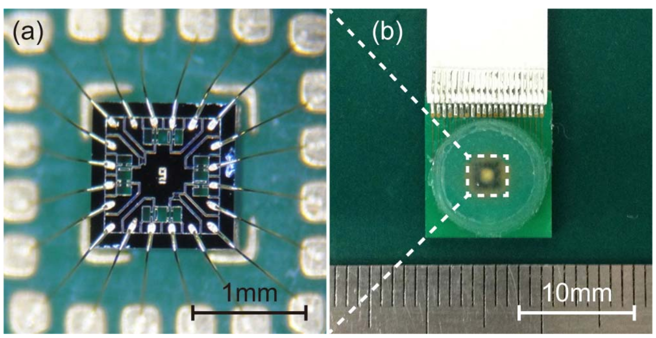


*Figure 2: Photos of (a) the sensor chip and (b) 6-axis force-torque sensor embedded in a silicone rubber.*

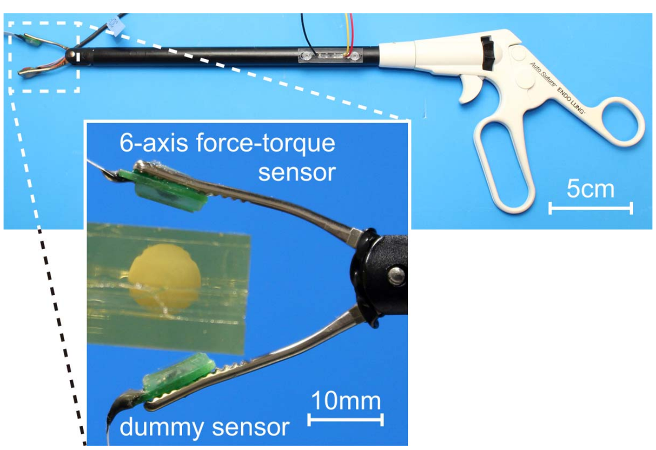


*Figure 3: A photo of the grasping forceps and a close-up of tips with sensors.*

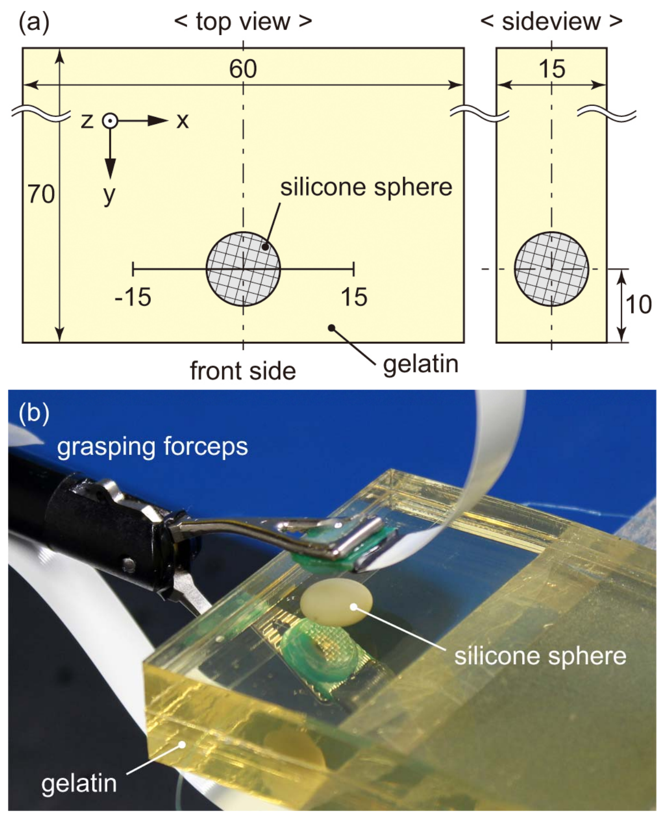


*Figure 4: (a) A schematic of the gelatin sample. (b) A photo of the experimental setup.*

sensor chip bonded on the substrate was embedded in a silicone rubber whose diameter and thickness were 10mm and 2mm, respectively (Figure 2(b)).

The sensor was attached to one tip of grasping forceps and a dummy sensor was to the other tip. A potentiometer was also attached to the shaft of the grasping forceps to measure the distance between two tips. A photo of the grasping forceps using for this research and a close-up of tips with sensors are shown in Figure. 3.

## EXPERIMENTS AND RESULTS

To validate the developed grasping forceps with sensors, the gelatin in which a silicone sphere was embedded was grasped with it. The silicone sphere (durometer hardness: A70) and gelatin (30wt%, Young's modulus: approx. 25kPa) imply the tumor and organ, respectively. Figure 4 shows a schematic of the gelatin sample with 15mm thickness and a photo of experimental setup. The 10mm diameter silicone sphere was positioned at the center of the thickness of gelatin, and 10mm away from the front surface.

The grasping forceps approached from the front side, moved along the x-axis from -15mm to 15mm by 1mm, and pinched the gelatin sample until the distance between two tips became a certain value. Variations in 3-axis force and 3-axis torque depending on grasping positions were shown in Figure 5. As the grasping forceps is near to the sphere, compression force $F_z$ becomes large and peaks at the center

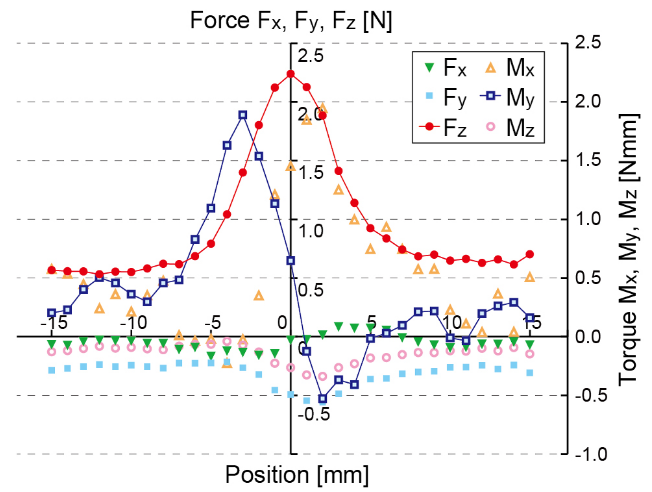


*Figure 5: Variations in 3-axis force and 3-axis torque depending on grasping positions.*

of it. Torque $M_y$ becomes also large, but is inverted after passing the center. It indicates that we can get the direction of the embedded object from 2-axis torques, $M_x$ and $M_y$.

By using the data of $F_z$, the thickness of the embedded object was calculated from the equation (3) as shown in Figure 6(a). As the thickness means the distance between top and bottom profiles, they can be represented as shown in Figure 6(b), considering the vertical symmetry. The diameter of fitting circle between both profiles was 10.9mm.

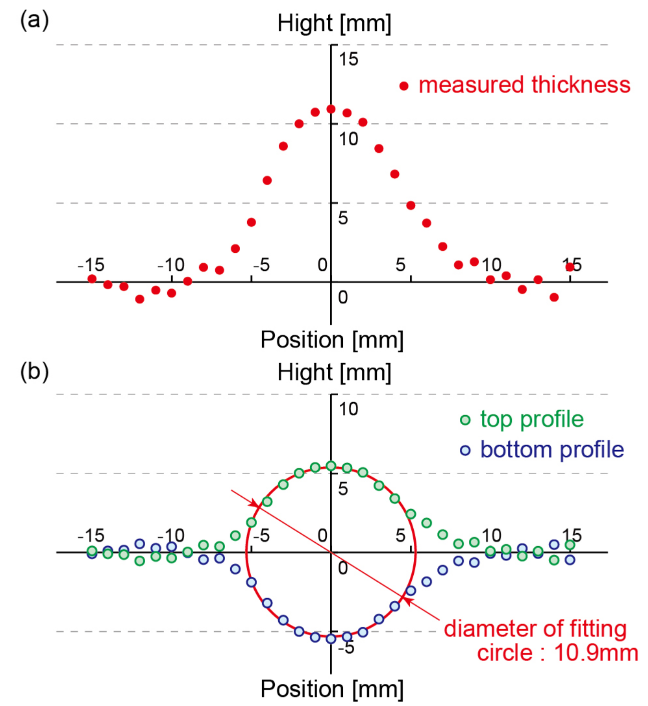


*Figure 6: (a) Measured thickness, (b) calculated top and bottom profiles, and fitting circle.*

# CONCLUSIONS

We proposed and demonstrated a method to derive the size of hard object embedded in a soft material from the compression forces of the MEMS 6-axis force-torque sensor attached to the tip of grasping forceps. It was also indicated that we can get the direction of the object from 2-axis torques. To obtain the position and size information contributes to the identification of the tumor in thoracoscopic surgery.


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