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Position sensing for surgical robots using Time-of-Flight sensor

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Abstract

Since the spread of COVID - 19 worldwide, information and communication technology has been accelerating in the medical field. It is easy to switch to online medical interviews, but it is difficult to go online for biological examinations and surgical procedures. Therefore, there is an increasing demand for automatic handling of living organisms in the medical and bioengineering fields. Although surgical robots, such as the da Vinci, reduces labor, it is necessary to accurately measure the position and posture of organs and blood vessels for complete automation, and such technology has not been applied to surgical robots. There are methods for creating a three-dimensional model of an organ by measuring it beforehand using magnetic resonance imaging or computed tomography, and to reflect the information during surgery by using augmented reality and other methods. However, there is currently no technology for automatically determining the position of organs and blood vessels in real time during surgery. To automate the grasping motion of a forceps-type manipulator used with surgical robots, we applied a time-of-flight, ToF, sensor to obtain the position and orientation of a blood vessel. We developed a method for detecting blood vessels from the points measured using a ToF sensor and estimating their thicknesses and directions. We evaluated the effectiveness of our method in an experiment involving a simulated blood vessel. This work was supported by JSPS KAKENHI Grant Number 19K04308.

Keywords: Sensor, Robot, Positioning, Information

1. Intoroduction

Due to the spread of coronaviruses in recent years, there is a shortage of medical personnel to prevent infection, which may lead to the collapse of medical care. Also, There is a risk of healthcare workers becoming infected by direct contact with an affected person. In underpopulated areas, the number of medical personnel is small in relation to the population, and there is a serious shortage of doctors. For this reason, many surgeries have to be postponed to prevent infection. To address these problems, tele-surgery is becoming increasingly important because of its ability to reduce contact with patients and the expected division of labor for more difficult operations. However, most surgical assistive manipulators in use have less freedom of movement than conventional open surgery, and the field of view is fixed. In addition, the number of doctors who can perform surgery using such manipulators is limited because of the lack of tactile sensation and the need for skilled personnel. There are methods for creatong a three-dimensional (3D) model of an organ by measuring it beforehand, such as using magnetic resonance imaging (MRI) or computed tomography (CT) [1, 2]. However, there have been no methods for automatically determining the position of organs and blood vessels in real time during surgery.

A blood vessel is a relatively small object to be operated on and can be grasped automatically using a surgical assistant manipulator by measuring it with a ToF sensor beforehand [3] and obtaining the position and orientation of the target organ by acquiring 3D information of the operative field. We previously developed force-sensing micro forceps [4-6] to enable autonomous grasping motion.For this study, we developed a method for detecting the position of blood vessels, etc. and obtaining information to determine whether a manipulator can grasp them using a time-of-flight (ToF) sensor in surgery. This makes it possible to simplify and automate robotic surgery. We evaluated the effectiveness of this method using a simulated blood vessel.

2. ToF sensor

An overview of the proposed method is shown in Figure 1. In endoscopic surgery with a surgical manipulator, a vessel to be grasped is measured using a ToF sensor, and the grasping is presented to the operator surgeon by obtaining the relative position and orientation with the forceps. The ToF sensor measures distance by irradiating an object with infrared light and measuring the time it takes for the reflected light to return to the sensor. However, this takes up a large amount of space and a long time to show the surgeon the positional relationship around the affected area because they are alternately operated and imaged. Howver, a compact ToF sensor can be inserted into the body like an endoscope, which enables simultaneous measurement and operation. Our method of measuring position and posture involves using the M-estimator sample consensus (MSAC) algorithm [7] for the point cloud data obtained from ToF measurement. This algorithm approximates the point cloud data of the artery as a series of columns and obtains the position of the center of gravity, direction of the central axis, and diameter of the column.

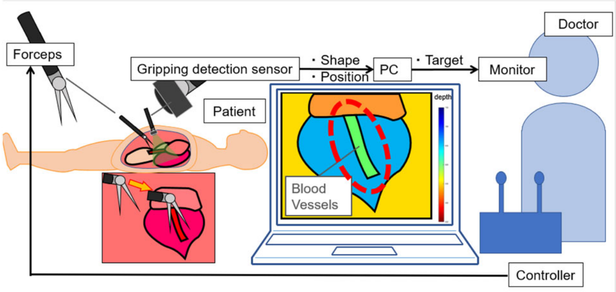


Figure 1. Concept of proposed method

3. ToF Sensing for body of organism

Because a body of an organism is an optically highly scattered object, a ToF sensor may incorrectly measure distance. This is because once the incident light enters the body it is scattered, and the time until the light is received is shifted or the waveform is changed. The degree of scattering tends to vary depending on the transparency of the object. We first investigated the correlation between object transparency and measurement error. The transmittance of each sample (four parts of a chicken with varying transparency (20 steps), as shown in Fig. 2) and its position were measured using a ToF sensor to compare the errors. Using an optical microscope, which can illuminate the sample from underneath, a sample was photographed and the luminance averages of the photographed images were calculated. The ToF sensor was a Basler ToF camera (tof640-20gm_850nm - Basler Time-of-Flight). The average luminance was calculated from the averaged distance of 100 images taken at a distance of 500 mm from the surface of the specimen. A piece of cardboard with an opaque surface was measured in the same manner and taken as the true value of the measured distance. The samples were mixed with a fixed amount of alumina powder in potato starch water, and the transmittance was varied by changing the ratio of the powder.

The relationship between light transmission and measurement error is shown in Figure 3. The error decreased as it approached full opacity. As the error decreased, it approached full transparency. We found a correlation between transmissivity and measurement error and that the error differed depending on the part of the chicken. Therefore, it is possible that the difference in measurement error can be used to determine the difference in the characteristics of biological tissues by treating them as characteristics of the organism caused by the amount of light transmission.

4. Blood-vessel detection

Our method is used to approximate the vessel to be grasped as a cylinder and present the position of the center of gravity, axial direction, and diameter of the cylinder. The cylinder approximation is done by applying noise processing and the MSAC algorithm [7] to the point cloud data measured with the

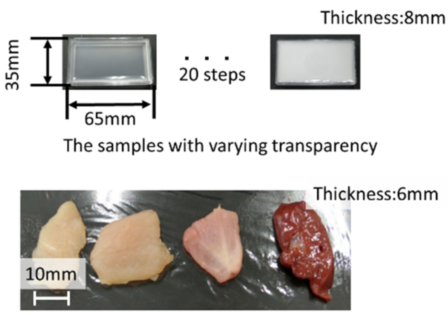
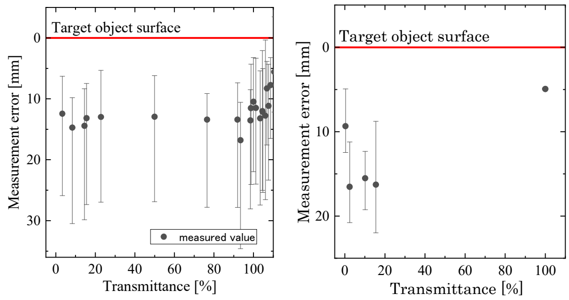


Figure 2. Experimental samples (organs with opaque acrylic)



(a) Alumina **(b)** Body parts

Figure 3. Differences in measurement error with changing transparency

ToF sensor. In our experiment, the distance to the object was 100 mm, and the measurement target was a white cable with diameters of 2.3, 4.0, 5.3, and 12.3 mm, under the assumption that these are common vessel sizes. The experimental environment is shown in Figure 4. Note that the evaluation was based on the absolute error of the center position, angular error of the central axis, and absolute error of the radius value, which were averaged over 100 approximations to a cylinder. The detection results are shown in Figure 5. In a cable that mimics a blood vessel, the approximation as a cylinder was possible.

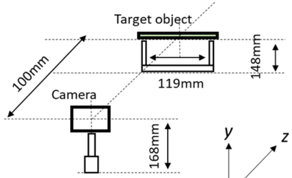


Figure 4. Experimental environment

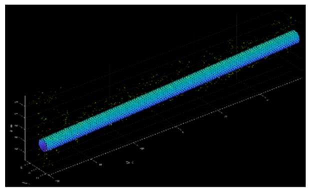


Figure 5. Results from experiment involving detection of simulated blood vessel

5. Conclusion

We developed a method for detecting blood vessels from the points measured using a ToF sensor and estimating their thicknesses and directions. We conducted an experiment in which we applied a ToF sensor to obtain the position and orientation of a blood vessel for grasping motion of a forceps-type manipulator used in surgical robots. We were able to grasp a simulated vessel by estimating its position and thickness and the direction of its extension from the ToF sensor. We clarified the relationship between light transmittance and measurement error in the ToF sensor and suggested the possibility of treating the error as a characteritic of living organisms since the error differs in different parts of the same organism.

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