Journal of Bioinformatics and Neuroscience (JBINS), 3 (3): 79-84, December 29, 2017
e-ISSN: 2432-5422, p-ISSN: 2188-8116
Applied Science and Computer Science Publications

Accuracy verification of knife tip positioning with position and orientation estimation of the actual liver for liver surgery support system

Daiki Yano, Masanao Koeda, Mayuko Doi, Kodai Okumoto, Shogo Yoshida, Katsuhiko Onishi, Hiroshi Noborio and Kaoru Watanabe

Abstract: We are developing a surgical support system for liver abdominal surgery to prevent surgical accidents. Our support system can detect proximity of certain body parts and can make a warning when the knife approaches the critical part to be excised, such as large blood vessels. The system has two distance cameras with different features, and these cameras are located above the operating table. One camera measures the liver shape and the other tracks the position of a surgical knife during surgery. In this report, to evaluate the accuracy of the distance between the position of the knife tip and the position of the blood vessels, the position and orientation of the liver were estimated using depth images of mock liver and virtual liver by simulated annealing algorithm, and the distance between the knife tip and the blood vessel in the mock liver was measured. The experimental results showed the maximum average error of the measured distance was 5.76 mm.

Keywords: Surgical Support System; Liver, Accuracy; Positioning

I. INTRODUCTION

Liver surgery is difficult because the liver blood vessel system inside the organ is very complicated. In addition, the liver cannot be completely removed because it has a complex function in the body. Although it is possible to be aware of the position of a blood vessel by diagnosis using magnetic resonance imaging (MRI) or computed tomography (CT) before surgery, it is impossible to know in detail how the internal structure of an organ changes during surgery, based only on the preoperative diagnosis.

In the commercially available medical navigation systems [1-3], it is possible to superimpose and display a computer graphics (CG) image of the surgical tool on the Digital Imaging and Communication in Medicine (DICOM) image of the surgical area taken before surgery. However, this medical navigation system does not consider the deformation of the organ during the surgery; thus, it is necessary to attach a marker near the affected part.

In this report, the accuracy verification of the distance between the position of the knife tip and the position of the blood vessels during estimating the position and orientation of the liver is shown.

II. SURGERY SUPPORT SYSTEM

A. System overview

The overview of our system currently under development is shown in Fig. 1. The tomographic images with DICOM format of the patient's liver are captured using MRI or CT before the surgery. A three-dimensional model of the liver is made from the tomographic images using an open source software 3DSlicer [4]. In this system, during the surgery, the liver and knife positions are measured with two distance cameras located above the operating table. The coordinate transform matrix between these cameras are calculated beforehand using the method described in [5].

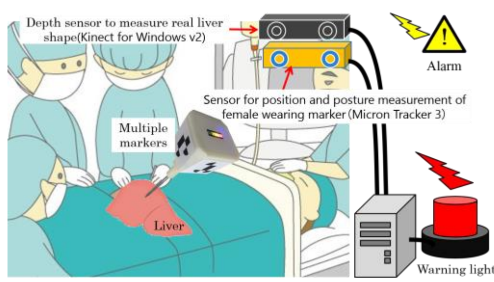


Fig. 1 System overview

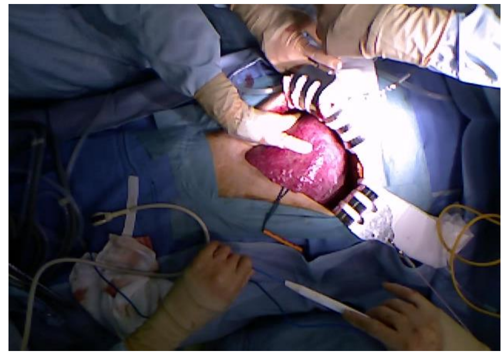
Corresponding Author: Masanao Koeda. Department of Computer Science, Osaka Electro-Communication University, Kiyotaki 1130-70, Shijonawate, Osaka, 575-0063, Japan, TEL: +81-72-876-3317, E-mail: koeda@osakac.ac.jp

The liver surface shape data (hereinafter abbreviated as actual liver) are obtained from a distance camera. In the current support system, we use Microsoft Kinect for Windows v2 for measuring the shape of the liver. Fig. 2 shows an example of RGB and depth image of a real liver during surgery. The stereo lithography (STL) polygon model of the patient liver is generated from DICOM (hereinafter abbreviated as virtual liver) and the depth image in virtual space is obtained from Z buffer data. Using both depth images, the position and orientation of the actual liver are estimated using simulated annealing method [6].

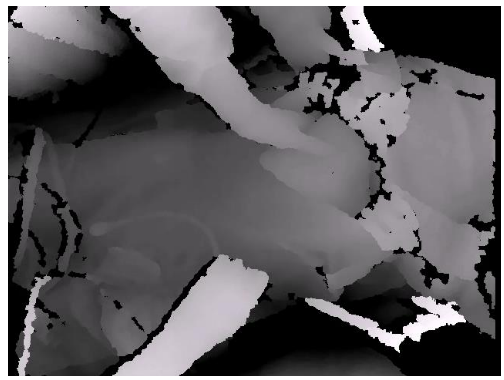
The knife tip position is estimated from the specific markers attached to the top of the knife. Prior to surgery, the relative vectors from each marker to the tip of the knife are calibrated. In the current support system, we utilize MicronTracker3 (model H3-60) [7] to measure the position and orientation of the markers. The detail of calibration and estimation procedure is described in [8].

By merging all the acquired information, the distance between the knife tip and the certain body parts is calculated and the proximity of the knife to the critical parts is determined. The process flow of our system is illustrated in Fig. 3.

In this paper, we evaluated the accuracy of the estimated knife tip position while estimating the position and orientation of the actual liver with a blood vessel.



(a) RGB image



(b) Depth image

Fig. 2 Snapshot images of real liver captured by Kinect during liver abdominal surgery

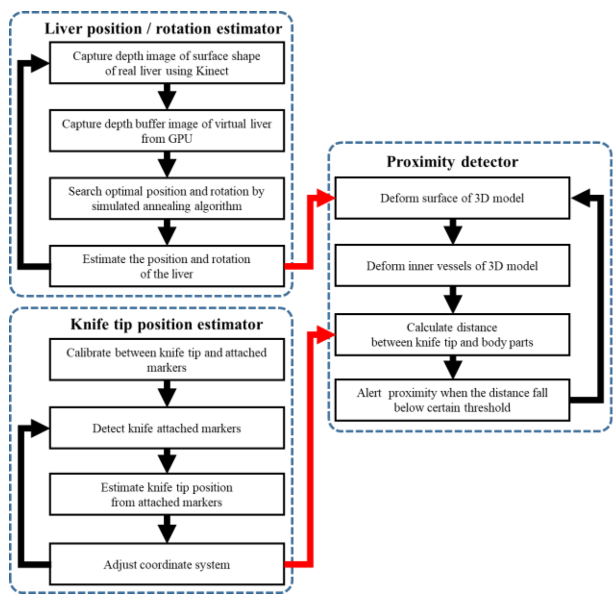


Fig. 3 Process flow

B. **Estimation algorithm of Position and orientation of the actual liver**

The position and orientation of the actual liver are estimated by moving the virtual liver in the virtual space. The virtual liver is translated and rotated so that the coincidence rate r of the depth images of virtual and the actual liver becomes maximally using the simulated annealing method. The r is defined as

$$r = N_{match} / N_{total} \quad (1)$$

where N_{total} is the number of pixels for which the depth value exists in both depth images (hereinafter abbreviated as effective pixel number) and N_{match} is the number of pixels for which the effective pixel difference is within the specified threshold. A conceptual diagram of the coincidence rate is shown in Fig. 4.

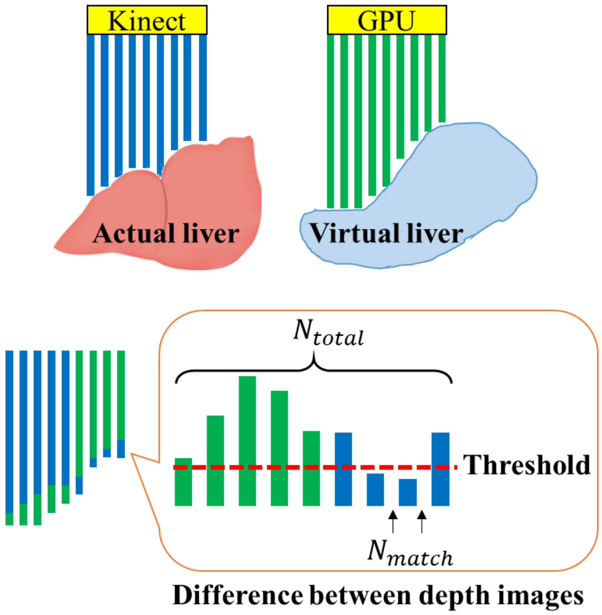


Fig. 4 Definition of coincidence rate

III. EXPERIMENT

In order to confirm the positional accuracy in the proposed system, the position and orientation of the actual liver were estimated using both depth images in real time, and the distance from the knife tip to the blood vessel in the mock liver was measured.

A. Experimental equipment

We created a mock knife to verify measurement error of the knife tip position. The mock knife had an iron needle of φ 6 [mm] and length 130 [mm] inserted into a box. The box was molded using a 3D printer. Four markers of 50 [mm] × 50 [mm] was attached to the four sides of the box. The mock knife used in the experiment is shown in Fig. 5.

The appearance of the mock liver used in the experiment is shown in Fig. 6. It is difficult to calculate the distance from the tip of the mock knife to the blood vessel using real raw liver. For this reason, we created the mock liver and used it as the actual liver. The mock liver was a cube with a length of 145.0 [mm] made with milk agar, with a hole imitating a mock blood vessel with a diameter of 25.0 [mm] at the center. The STL model of the mock liver shown in Fig. 7 was manually created and used as the virtual liver.

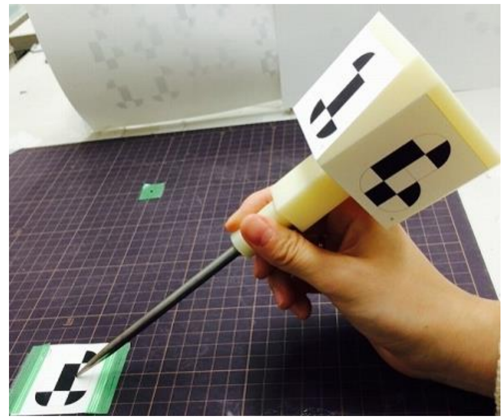


Fig. 5 Mock knife

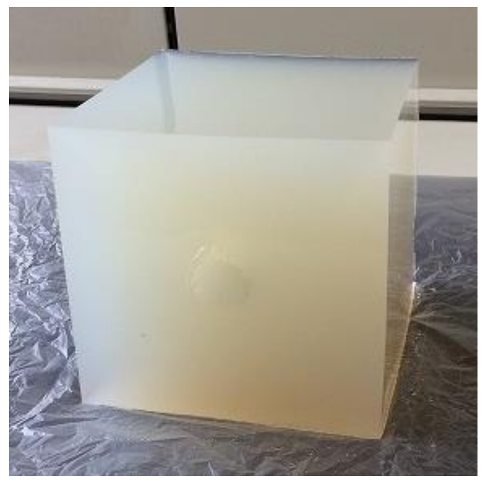


Fig. 6 Mock liver with mock blood vessel

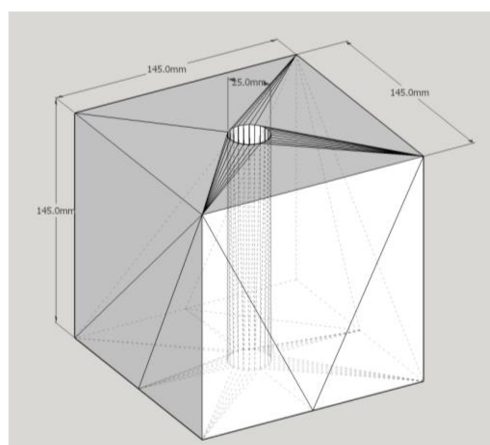


Fig. 7 STL model of mock liver with blood vessel

A. Experimental method

In order to match the coordinate systems between the two distance cameras, the calibration matrix **M** was measured by the method described in [5].

$$\mathbf{M} = \begin{pmatrix} 1.011 \times 10^{-3} & -1.083 \times 10^{-3} & 2.540 \times 10^{-5} & 2.253 \times 10^{-2} \\ -8.874 \times 10^{-6} & 9.581 \times 10^{-4} & 3.033 \times 10^{-4} & -2.355 \times 10^{-1} \\ -1.263 \times 10^{-5} & -3.400 \times 10^{-4} & 9.533 \times 10^{-4} & -1.927 \times 10^{-1} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (2)$$

Using the matrix M, the position of the tip of the knife was estimated.

The distance was measured when the knife tip was contacted with the mock blood vessel of the surface of the mock liver at four points, the upper, lower, left, and right points. The measurement point A, B, C and D in the experiment are shown in Fig. 8.

In the experiment, the search termination time used in of simulated annealing algorithm was set 500 [ms]. The threshold value used difference of depth images was set 10 [mm]. The region of interest (ROI) of the depth image was set around the actual liver to calculate the coincidence rate *r* stably. The snapshots of operation screen of the developed software are shown in Fig. 9.

IV. EXPERIMENTAL RESULTS

Fig. 10, 11, 12 and 13 show the shortest distance between the blood vessel and the estimated knife tip position in 100 [frame] at the measurement point A, B, C and D respectively. In this experiment, the distance should be zero because the knife tip was contacted with the mock blood vessel during measurement. However, certain errors are confirmed in each measurement point.

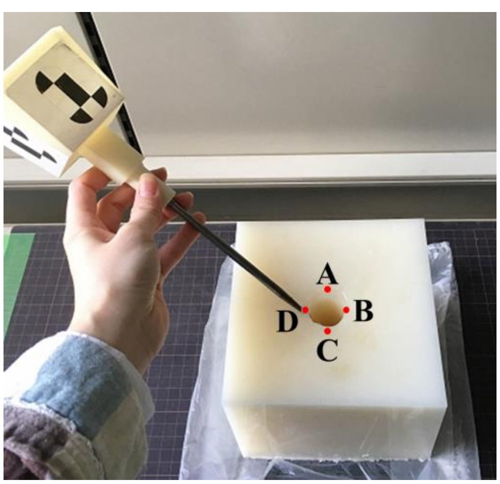
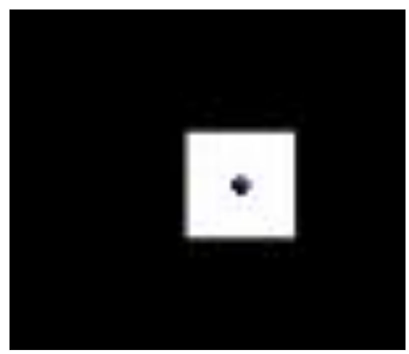


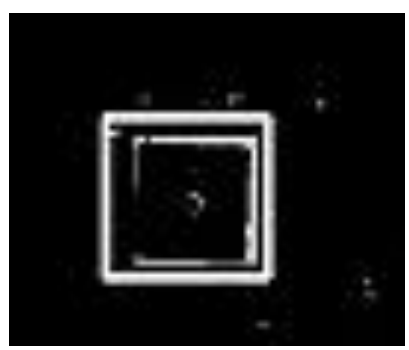
Fig. 8 Measurement points

(a) RGB image captured by Kinect

(b) Depth image of actual liver captured by Kinect



(c) Depth image of virtual liver generated by GPU



(d) Region of interest

Fig. 9 Snapshots of operation screen

The averaged errors of 100 [frame] at each measurement point are shown in Fig. 14 and Table 1. The averaged error was 5.76 [mm] and the maximum error was 11.38 [mm] at the measurement point C.

V. CONCLUSION

We evaluated the distance accuracy when the knife tip was contacted with the mock blood vessel of the surface of the mock liver with estimating position and orientation of mock organ in real time. As a result, the averaged error was 5.76 [mm] and the maximum error was 11.38 [mm] at the measurement point C, which is the near side of the operator.

According to a liver surgeon, blood vessels with a diameter of 5 mm or less could be stopped with an electric scalpel and the estimation error should be less than 5 [mm]. At this time, our system is not meet the requirement yet and needs the accuracy improvement.

In future, we intend to improve the precision of the support system and investigate the effect of soft body deformation of organs during surgery.

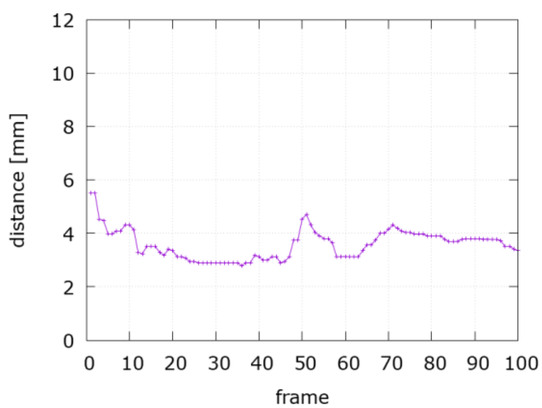


Fig. 10 Measurement result of Position A

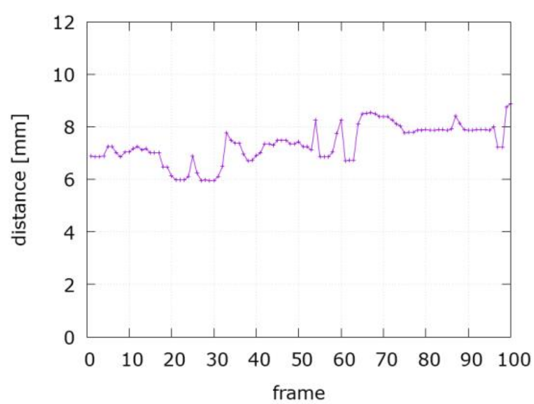


Fig. 11 Measurement result of Position B

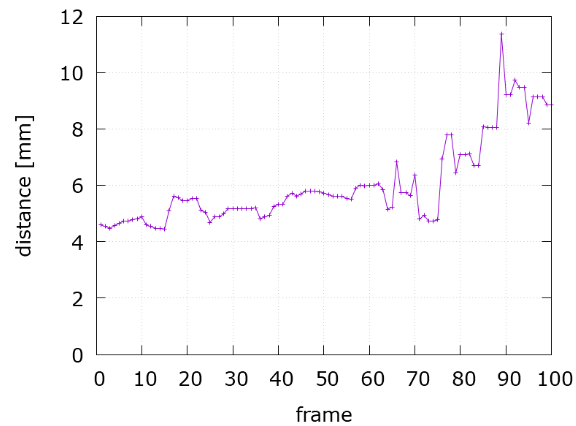


Fig. 12 Measurement result of Position C

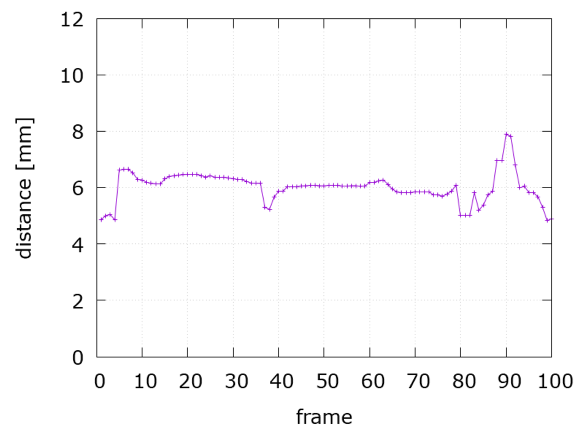


Fig. 13 Measurement result of Position D

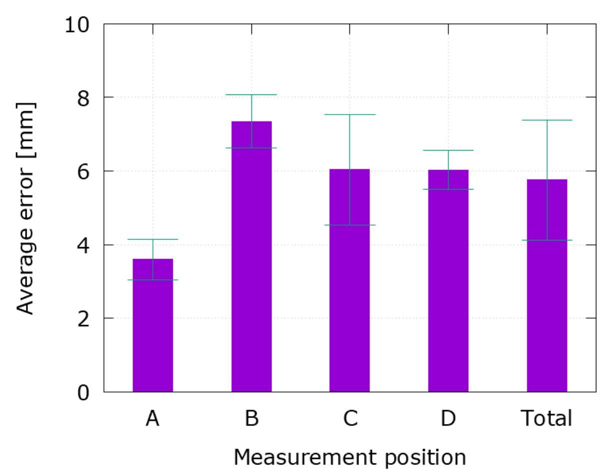


Fig. 14 Average error with standard deviation

Table.1 Estimation error at each measurement point

Measurement Point	Average Error [mm]	Maximum Error [mm]	S.D. [mm]
A	3.60	5.50	0.55
B	7.35	8.88	0.72
C	6.04	11.38	1.51
D	6.03	7.89	0.53
Total	5.76	11.38	1.64

ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number JP26289069.

REFERENCES

[1] Knee Navigation Application - Brainlab: https://www.brainlab.com/en/surgery-products/orthopedic-surgery-products/knee-navigation/

[2] ClaroNav - Dental and ENT Navigation Solutions: http://www.claronav.com/

[3] Surgical Theater - Surgical Navigation Advanced Platform: http://www.surgicaltheater.net/site/products-services/surgical-navigation-advanced-platform-snap

[4] 3D Slicer: https://www.slicer.org/

[5] M. Koeda, A. Tsukushi, H. Noborio, K. Onishi, K. Mizushino, T. Kunii, K. Watanabe, M. Kaibori, K. Matsui, M. Kon: "Depth Camera Calibration and Knife Tip Position Estimation for Liver Surgery Support System", *Springer International Publishing, HCI International 2015 - Posters' Extended Abstracts, Communications in Computer and Information Science*, Vol. 528, DOI: 10.1007/978-3-319-21380-4_84, pp: 496-502, 2015.

[6] K. Watanabe, S. Yoshida, D. Yano, M. Koeda, and H. Noborio: "A New Organ-Following Algorithm Based on Depth-Depth Matching and Simulated Annealing, and Its Experimental Evaluation", *Springer International Publishing, Design, User Experience, and Usability: Designing Pleasurable Experiences, Part II, Lecture Notes in Computer Science 10289*, DOI: 10.1007/978-3-319-58637-3_47, pp: 594-607, 2017.

[7] ClaroNav - MicronTracker: http://www.claronav.com/microntracker/

[8] M. Doi, D. Yano, M. Koeda, H. Noborio, K. Onishi, M. Kayaki, K. Mizushino, K. Matsui and M. Kaibori: "Knife Tip Position Estimation Using Multiple Markers for Liver Surgery Support", *In Proceedings of The 2015 JSME/RMD International Conference on Advanced Mechatronics*, pp: 74-75, 2015.