Master's Thesis
석사학위논문

Usability Evaluation of Wide-Angle Arthroscope and Development of Region of Interest Selection Interface

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Advisor : Professor Jaesung Hong

Co-advisor : Professor Sanghyun Joung

by

Kyunghwa Jung
Department of Robotics Engineering
DGIST

A thesis submitted to the faculty of DGIST in partial fulfillment of the requirements for the degree of Master of Science. The study was conducted in accordance with Code of Research Ethics[1]

07.08.2015

Approved by

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[1] Declaration of Ethical Conduct in Research: I, as a graduate student of KAIST, hereby declare that I have not committed any acts that may damage the credibility of my research. These include, but are not limited to: falsification, thesis written by someone else, distortion of research findings or plagiarism. I affirm that my thesis contains honest conclusions based on my own careful research under the guidance of my thesis advisor.

Usability Evaluation of Wide-Angle Arthroscope and Development of Region of Interest Selection Interface

Kyunghwa Jung

Accepted in partial fulfillment of the requirements for the degree of Master of Science.

05.22.2015

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ABSTRACT

The aim of study is to evaluate the effectiveness of a wide-angle arthroscope by comparison with a conventional arthroscope, and to propose a region of interest (ROI) selection interface which is enable solo surgery without assistants. The usability of wide-angle arthroscope was validated by comparing the scope handling performance between the 150 degree wide-angle arthroscope and 105 degree existing arthroscope when twelve participants with no experience of arthroscopic surgery performed the four shoulder arthroscopic simulation tasks in phantom mode. Four evaluation criteria for assessing the performance were (1) the time taken, (2) total trajectory length scope moved, (3) number of scope handing movements, (4) average acceleration. Experimental results support that the value of evaluation criteria was statistically lower when participants used the wide-angle arthroscope. The ROI selection interface simultaneously shows a wide-angle view and magnified ROI view which is required due to the small size of ROI in the wide-angle arthroscopic view, and an operating surgeon can select the ROI position without any assistants. We propose to use a surgical instrument itself for the selection of ROI position. For that purpose, a camera was affixed to the surgical instrument, and rotational movement of the instrument was analyzed by image processing. AKAZE algorithm was utilized for a feature extraction, and essential matrix acquired from matched features was decomposed into rotation angle. We tested a resolution of ROI selection which satisfied the accuracy up to 48 (6x8) division regions (quantitative assessment) and obtained the surgeon’s feedback that the interface facilitated the solo surgery (qualitative assessment). This study shows a new approach to evaluate the usefulness of wide-angle view in surgical situation using a motion analysis system, and the ROI selection interface is expected to have a great significance for future clinical use of a wide-angle endoscopic system.

Keywords: Wide-Angle Arthroscope, Motion Analysis System, Region of Interest (ROI) Selection Interface

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I. INTRODUCTION

1.1 Demands for wider field-of-view in arthroscopy

As minimally invasive surgery has become popular, the demand for arthroscopic surgery has also increased. The reasons for the enduring popularity of arthroscopic surgery are the small damage sustained by the body and the short recovery time compared to open surgery. Contrary to patient preferences, most surgeons would agree that video-endoscopic surgery (VES) causes more stress and task-related difficulties than open surgery. Berguer et al. demonstrated that performing VES requires significant mental stress and concentration compared to open surgery by measuring tonic skin conductance level (SCL) and electrooculogram (EOG) to monitor the physical and mental fatigue of the surgeons [1]. The most common complications of arthroscopic surgery are an eye-hand coordination problem and indirect way of observing an operative site and manipulating surgical tools, which is due to small field of arthroscopic view [2]. The small field of arthroscopic view (Fig. 1) causes difficulties to identify whole anatomical structure and constrains intuitive perception about the orientation of surgical instruments [3]. These issues lead to the frequent arthroscope maneuvers by a camera assistant, which are not only inconvenient and time-consuming, but the camera assistant and surgeon spend a long time keeping pace with each other. Furthermore, potentially dangerous situations can occur, e.g. when instruments not in sight injure structures in the operative area [4].

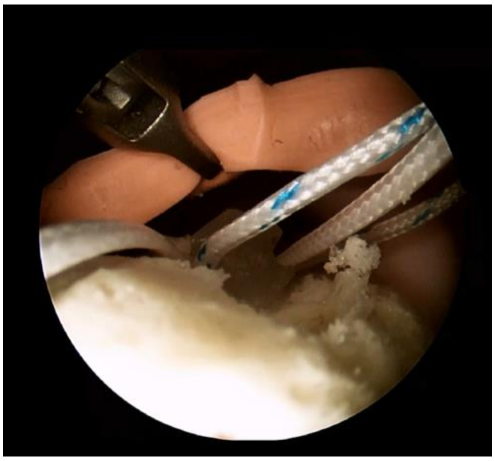

Figure 1. Small field of arthroscopic view in shoulder phantom model.

To overcome the drawbacks caused by the conventional endoscope with a narrow FOV, various studies on a wide FOV endoscope have been conducted. There are two primary approaches: One is to improve the optic system of the existing endoscope, the other is to use additional two or more cameras. Kobayashi et al. [5] and Hong et al. [6] have modified an optical system using prisms, fisheye lens, and movable lens for wider view angles. Tamadazte et al. [7] and Cao et al. [8] have proposed multiple view system by attaching supplementary cameras mounted around the traditional endoscope to obtain a panoramic view of an abdominal structure. According to experimental results of the papers using additional cameras, the time required for a surgeon to perform the task was significantly lower, when participants used multi-camera system compared to a traditional endoscope alone.

1.2 Usability evaluation of wide-angle-arthroscope

Wide-angle endoscope system have been developed by various approaches. However, few attempts have been made at evaluating the usefulness of wide-angle endoscope in an anatomical phantom or cadaveric model. Pellisé et al. [9] and Rex et al. [10] investigated the performance of a wide-angle colonoscope in terms of the detection rate of neoplasia and polyps, and they derived a conclusion that the wide-angle colonoscope could not significantly improve the detection rate compared to a standard colonoscope.

In arthroscopic surgery, there is no study evaluating the usability of wide-angle-arthroscope under anatomical phantom model. Therefore, we derived an idea of novel method for performance evaluation of the wide-angle arthroscope. By utilizing motion analysis system in a laboratory setting, the scope handling performance by a wide-angle scope was compared with 30 degree conventional scope. The motion analysis system assess participants' surgical dexterity when they manipulated the two different arthroscopes respectively to perform arthroscopic surgery tasks. The usefulness of wide-angle arthroscope was validated based on the improved dexterity which could be estimated by the objective four evaluation criteria (the time taken for the tasks, total trajectory length that scope handling hand move, effective movements and average acceleration).

The previous studies [9-10] evaluate the usefulness of wide-angle colonoscope by focusing on task-accuracy which depends on polyp detection rate. However, in this study, the usability of wide-angle arthroscope was assessed by observing the scope handling performance. Evaluation approach is different.

1.3 Region of interest selection interface for wide-angle arthroscope

We have proposed an interface with dual-view for a wide-angle endoscope. Wide-angle endoscopic image for the intuitive perception on the global anatomical structures and pose of surgical instruments in the patient body is obtained by the wide-angle endoscope without additional camera system, and an interested region is magnified by digital zoom for detailed operative view (Fig. 2). The interface was developed considering the property of wide-angle view and arthroscopic surgery situation. The property of wide-angle view is that the size of region of interest (ROI) becomes small in the wide-angle arthroscopic view. Therefore, it is necessary to magnify the ROI view and to select ROI position. The method for selecting ROI within wide-angle arthroscopic view was determined considering the arthroscopy conditions that the operating surgeon holds the surgical instruments in their both hands. A method of selecting the ROI without releasing the surgical tool can be embodied by manipulating the surgical instrument itself as a surgical mouse for positioning the ROI at desired location. For controlling the ROI through the movement of surgical instrument, a web camera was affixed to the surgical instrument, and web-cam image was processed to calculate the movement change of the instrument.

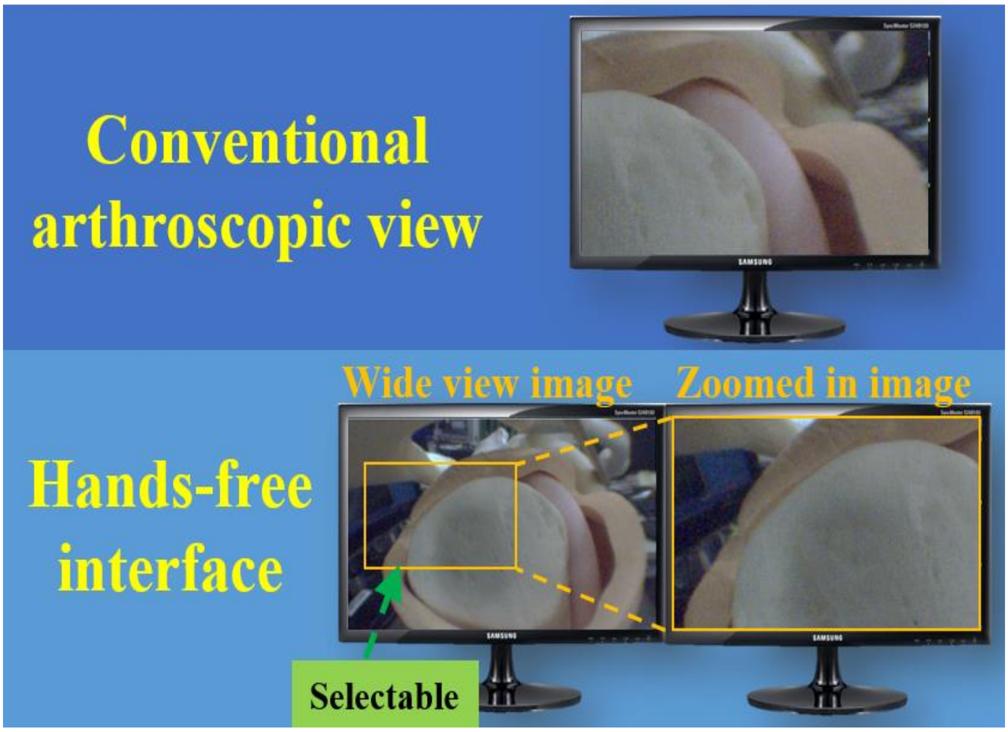

Figure 2. Comparison between conventional arthroscopic view and dual view of hands-free interface.

Movements of surgical instruments are mostly tracked by magnetic or optical tracking systems using their markers in surgical navigation. Cost of magnetic tracker is lower than optical tracker, but accuracy diminishes with distance, while optical tracker has high resolution and accuracy, but it is expensive [11]. Furthermore, line-of-sight should be maintained between the tracker and the sensor markers attached to the instrument. The line-of-sight problem is especially hard to be solved in the operating room with many surgical devices and staffs. Thus, we have proposed to attach a camera on the surgical tool to estimate the tool's pose change (Fig. 3). This method can reduce the line-of-sight problem and enable to select the ROI in real time through image processing steps. The camera attached to the surgical instrument can be regarded as the tracker and the features extracted from camera images can be regarded as the sensor marker.

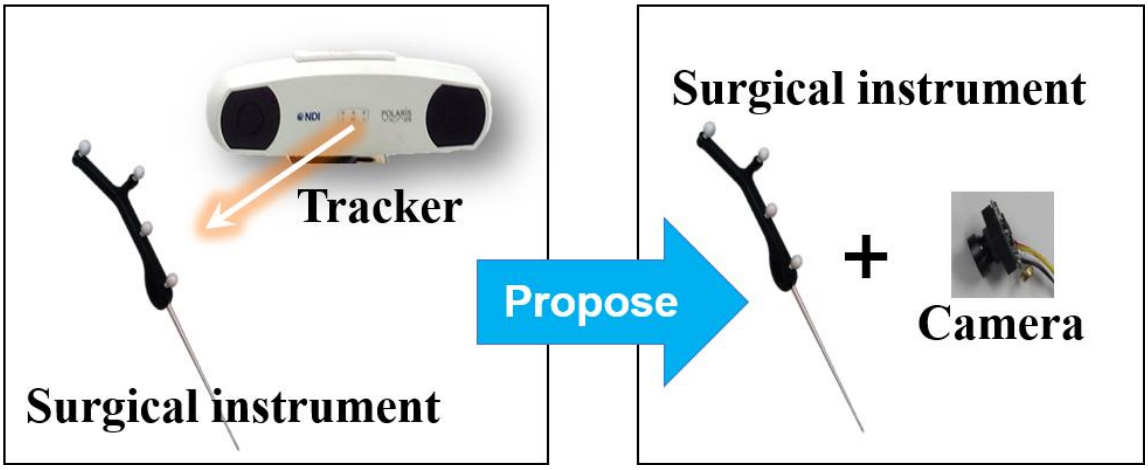

Figure 3. Pose estimation methods of the surgical instrument.

II. Usability evaluation of wide-angle arthroscope

2.1 Wide-angle and conventional arthroscopes

MGB Endoscopy Company provided a new prototype wide-angle arthroscope with 150 degree angle of view. The wide-angle arthroscope include an HD CMOS sensor with 1280 $\times$ 720 pixels resolution and wide-angle lens. Angle of the view of conventional 30 degree arthroscope (HD4300; ConMed Linvatec) is 105 degree and the camera resolution is 1920 $\times$ 1080 pixel (Fig. 4). Both systems delivered arthroscopic images to full-HD monitors respectively and two monitors were placed on the experimental table. Figure 5 indicates different field of view between conventional scope and wide-angle scope. A drawback of the MGB's prototype is pinkish image due to light source which does not spread out as 150 degree viewing angle.

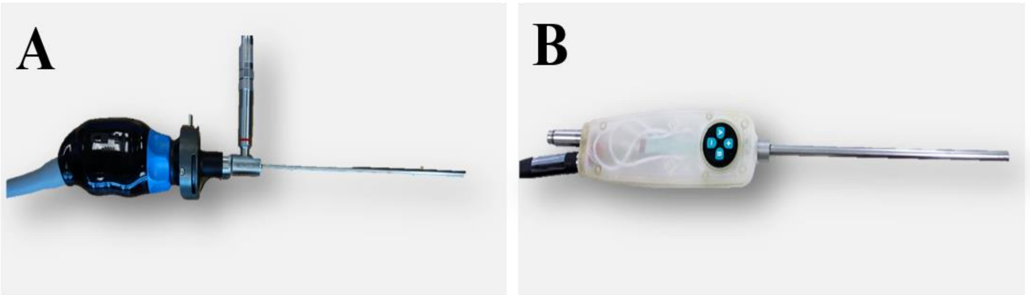

Figure 4. Two arthroscopes for comparison experiment. (A) Conventional 30 degree arthroscope, (B) Wide-angle arthroscope using wide-angle lens

2.2 Subject and simulation tasks

Twelve fourth-year medical students in ASAN Medical Center were enrolled in this experiments. The participants used both wide-angle arthroscope and conventional 30 degree arthroscope to compare their usefulness, and scopes were held by left hand of all participants. We divided participants into A and B groups. Six people in the A group used the wide-angle scope first, then the 30 degree conventional scope, whereas the other six people in the B group used the conventional scope first, then the wide-angle scope to avoid any learning effect from manipulation of a prior scope system.

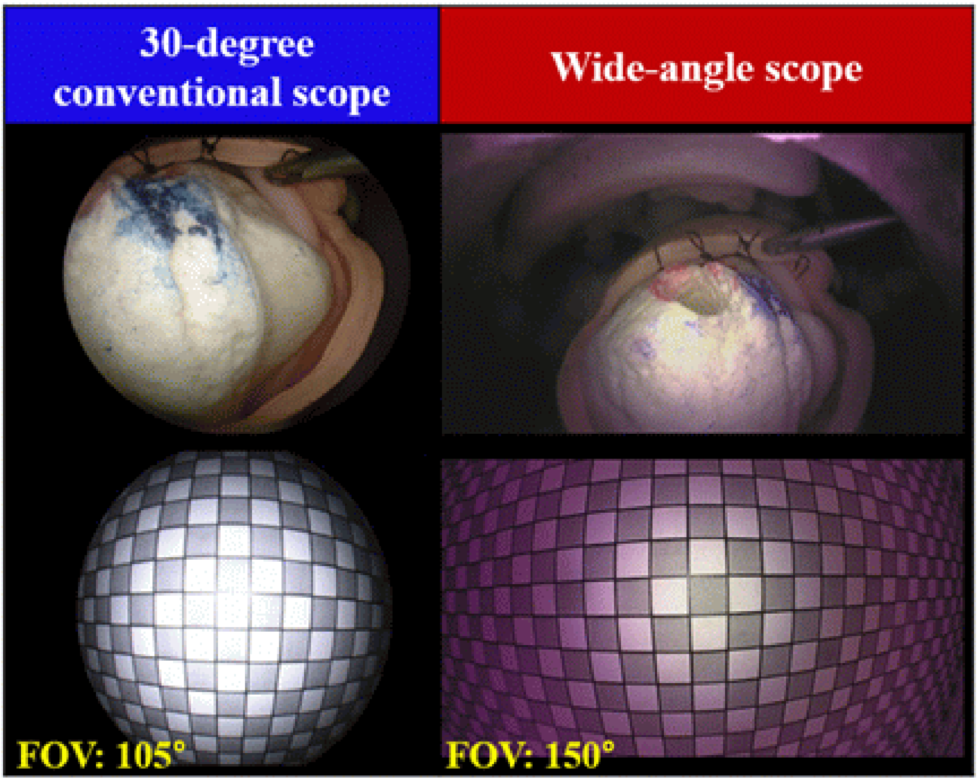

Figure 5. Different field of view between conventional arthroscope and wide-angle arthroscope

Before the experiments, participants watched an instructional video regarding simulation tasks. In addition to the video, an anatomical structure of shoulder phantom model (Arthrex, Naples, FL, USA) was explained, and participants employed arthroscope personally to be familiar with tasks and manipulation of arthroscope. Detailed prior education was required because all participants had no experience in endoscopic surgery.

Through several pilot tests, total four simulation tasks were determined by taking into account surgical dexterity of participants and similarity to real arthroscopic surgery (Fig. 6). First task is touching-

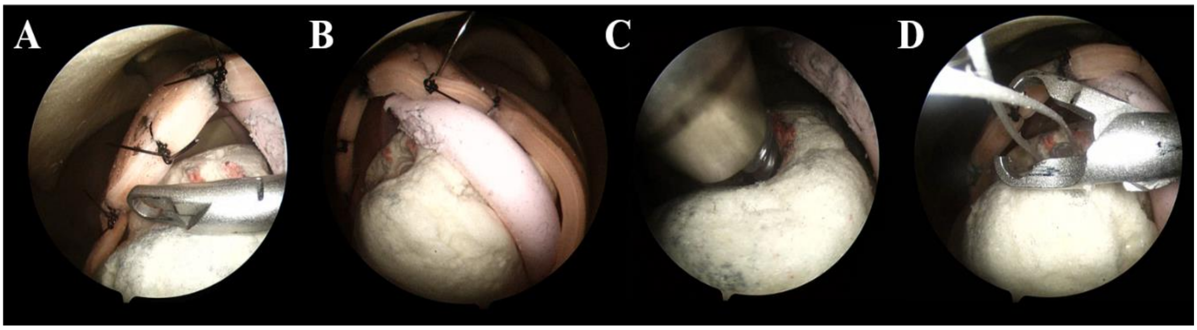

Figure 6. Four simulation tasks of shoulder arthroscopy. (A) Touching five sutures, (B) Inserting a spinal needle, (C) Inserting an anchor in the predefined position, (D) Pulling the sutures out using surgical grasper.

five suture points twice with a surgical grasper. The sutures were placed along the rotator cuff of the phantom model. Second task is sticking a spinal needle in the rotator cuff and bicipital groove, and third task is anchoring on the greater tuberosity which is pre-punched to insert an anchor without any assistance. Last task is changing the position of suture from lateral to anterior portal by pulling the suture using the grasper. All tasks were performed by participants' right hand and their left hand manipulated the scopes.

2.3 Experimental setting

The position of eight motion capture cameras (Prime41; Natural Point, Inc., Corvalis, OR, USA) was adjusted to accommodate the space required for every hands motion of participants during performing tasks (Fig. 7). Three optical marker sensors were affixed on both dorsum of hands and the shoulder phantom model, and the sensors' data were updated every 0.00833 seconds. Among three objects to be tracked, left hand of participants was an interested target in our study because the arthroscopes were dealt with by left hand to acquire the operative view. A right hand manipulated a surgical instrument. Both hands were laid on the table before and after phantom experiment (Fig.8).

Utilizing the motion analysis system, 3D position data of the optical markers were recorded and three evaluation criteria (total path length, average acceleration and the number of left movements) were calculated by a customized Matlab program (R2012b; MathWorks, Torrance, CA, USA). The total path length means distance that the scope handling hand traveled during the tasks. The acceleration of scope-hand over 1.3 cm/s^2 which was set by average value of all participants' handling data was assumed as the number of effective scope movements.

2.4 Statistical Analysis

The OriginPro software (ver.9; OriginLab Corp., Northampton, MA, USA) was exploited for statistical analysis. Time, total path length, the number of movements and average acceleration data were normally distributed. Thus, p-value was calculated by paired-sample t-test and the value below 0.05 indicate statistical significance.

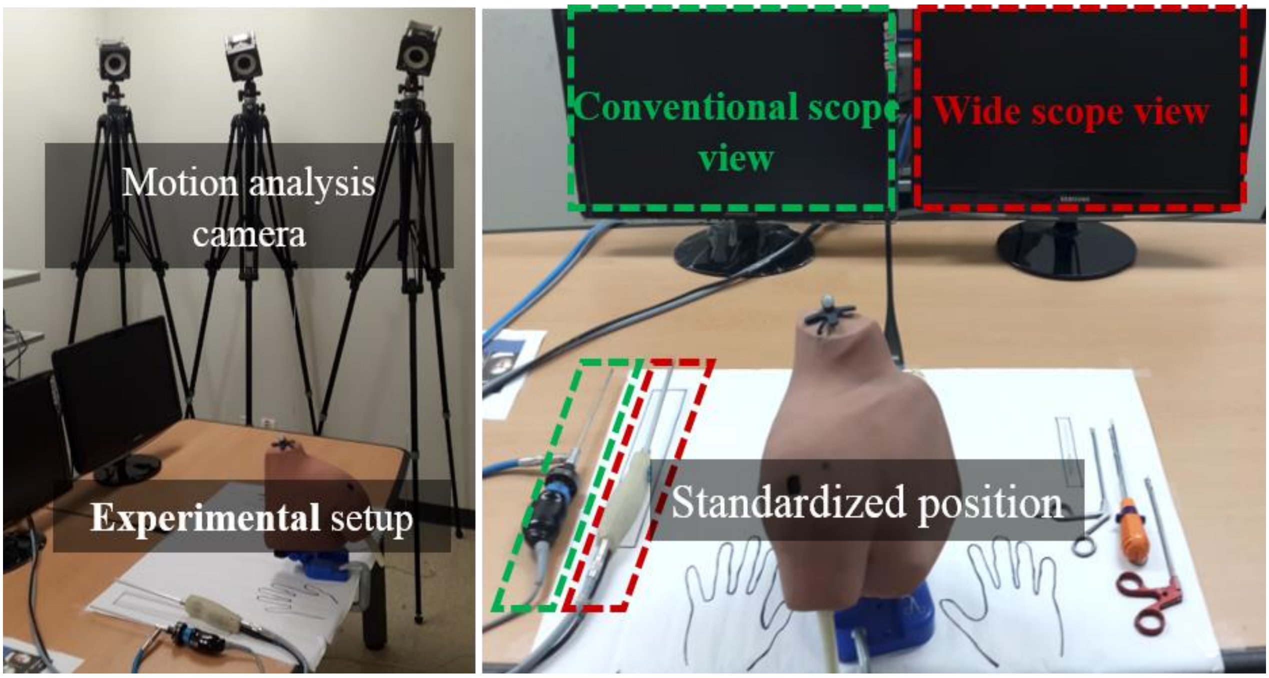

Figure 7. Experimental setting for motion analysis system

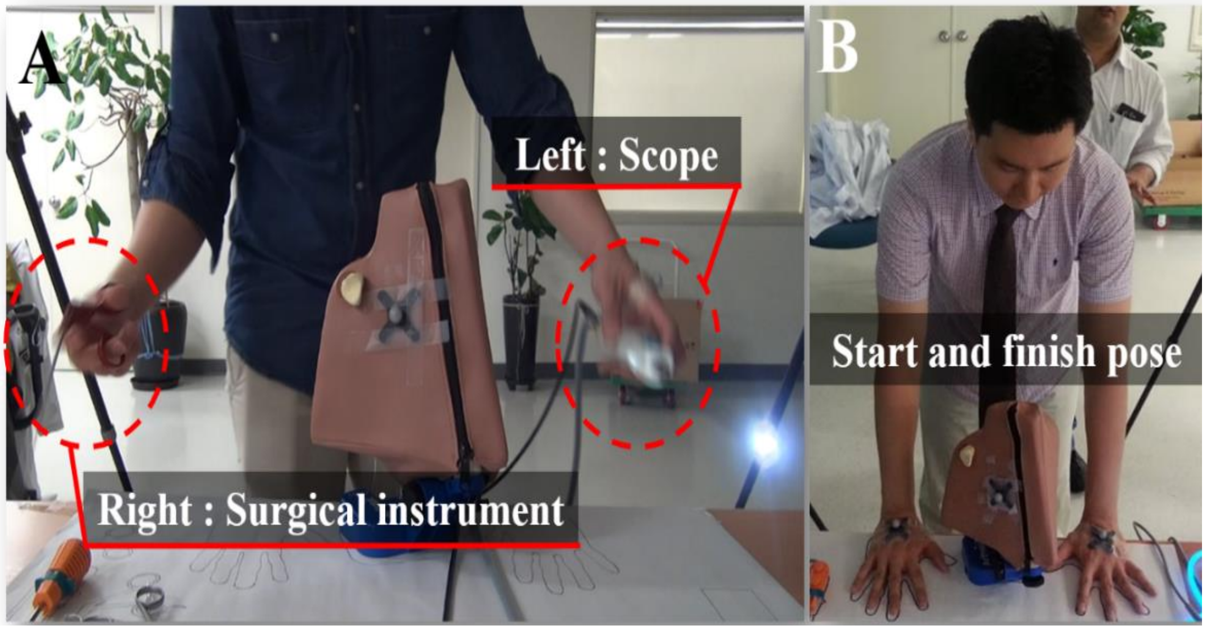

Figure 8. Experimental regulations. (A) Manipulation of scope and surgical instrument was perfomed by left and right hand respectively, (B) Start and finish pose of participants for reducing the bias caused by different hands position

III. ROI Interface for wide-angle arthroscope

3.1 Region-of-interest selection interface

An wide-angle image could provide more information about the operative field space to surgeons than a conventional scope, which is beneficial for understanding the camera position in the patient's body as well as improving hand-eye coordination. However, showing only one wide-angle image is insufficient, because the main image that surgeons generally need during surgery is about the target organ.

We propose an interface in which both the wide-angle image and the region of interest image are displayed simultaneously. Region of interest (ROI) is magnified by digital zoom function and is selected in the wide image by handling the surgical instrument itself. The magnified ROI endoscopic view can be used when surgeons focus on specific anatomy in detail (Fig. 9).

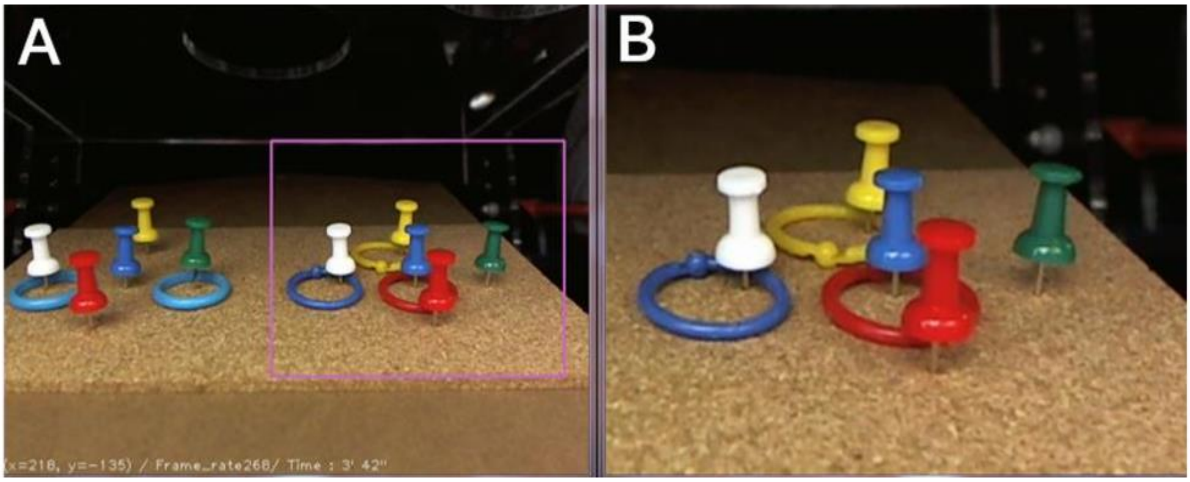

Figure 9. Region of interest selection interface with dual view during carring the colorful rings on both sides. (A) Wide-angle image, (B) Magnified image by digital zoom (×2) for details.

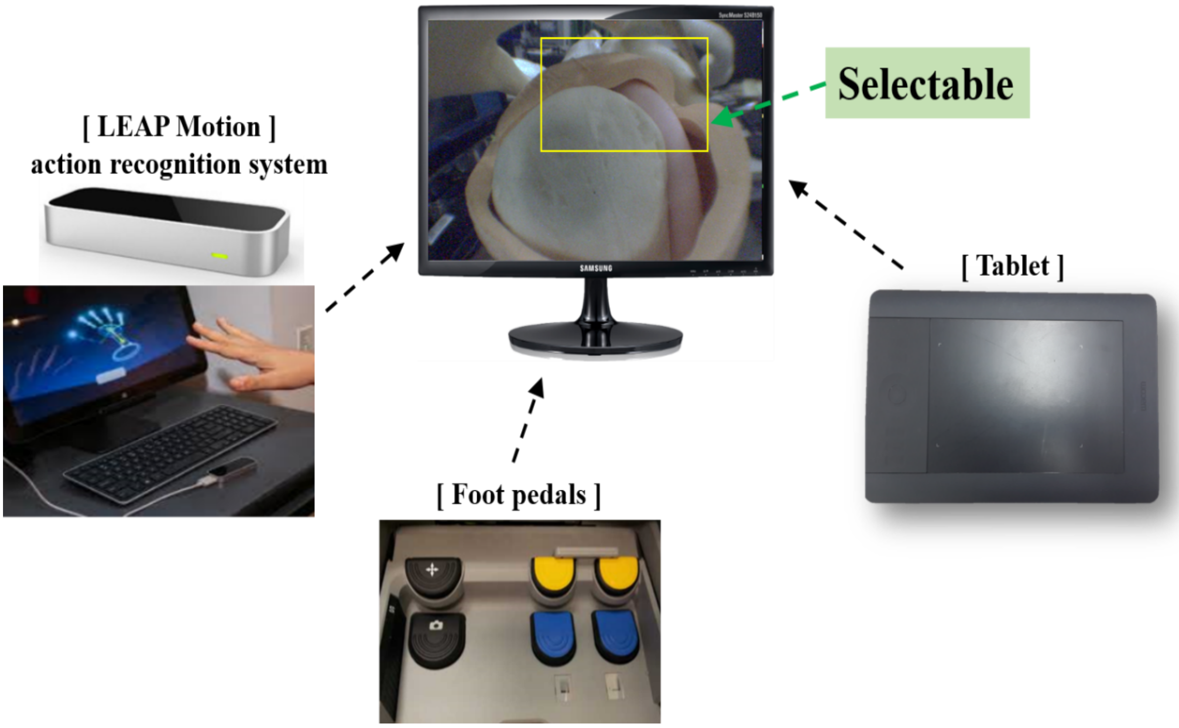

Figure 10. Various interface devices for selecting the region of interest

Several devices have been taken into account for selecting an ROI within a wide-angle image (Fig. 10). At first, mouse touch pad and foot pedal were used to control the position of ROI. Mouse touch pad and foot pedal require direct contact to operate the devices. Direct contact has good accuracy in terms of positioning the ROI square on the operator’s desired point. However, additional hands behavior or assistant is required to use the mouse touch pad. In terms of foot pedals, other foot pedals already have been utilized to turn on the surgical electrocautery and to circulate the water in the body.

Secondly, I considered using motion recognition systems such as 'leap motion' (Leap Motion, Inc., San Francisco, USA) because the motion recognition system does not require direct contact for operation, being a great advantage in terms of clinical use. However, it is difficult to discriminate the intended gesture and unintended gesture. Furthermore, surgeons have to release a surgical instrument out of their hands to operate the motion recognition system.

In this regard, I propose a method that a surgeon manipulate the surgical instrument itself to change the position of ROI without releasing the surgical tool. For that purpose, surgical instrument should be utilized as a surgical mouse, and tracking a pose of the tool is necessary. We affixed a camera perpendicularly to the direction of surgical tool, from which the images will be processed to identify the rotational movement of the tool. A hand switch was used to discriminate ROI selection motion and surgical motion (Fig. 11).

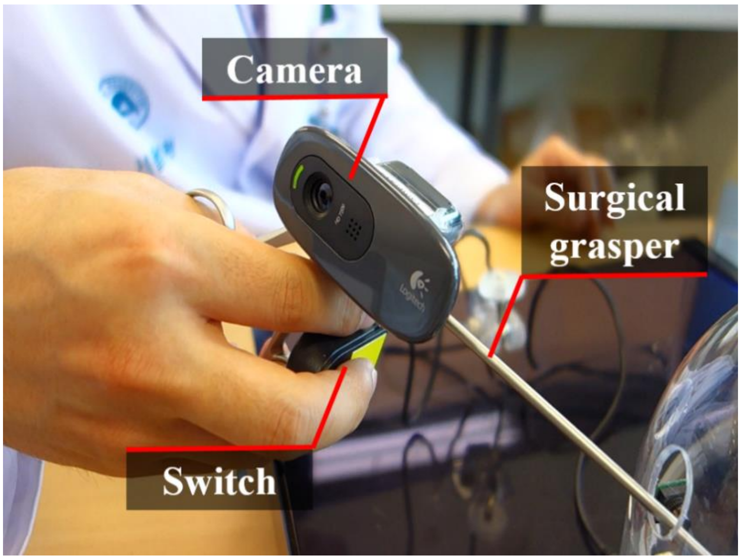

Figure11. Surgical grasper with a camera and switch attached for ROI selection.

3.2 Relation between DOF of a surgical instrument and ROI movement

In case a surgical instrument pass through a portal, the motion of the instrument is determined with four kinds of degrees of freedom (DOF) (Fig. 12). The first DOF regarded forward and backward motion; the second DOR was rotation movement in a longitudinal axis; the third DOF was left and right motion; and the fourth DOF was up and down motion. The third and fourth DOFs were matched with ROI movements (up/down, left/right).

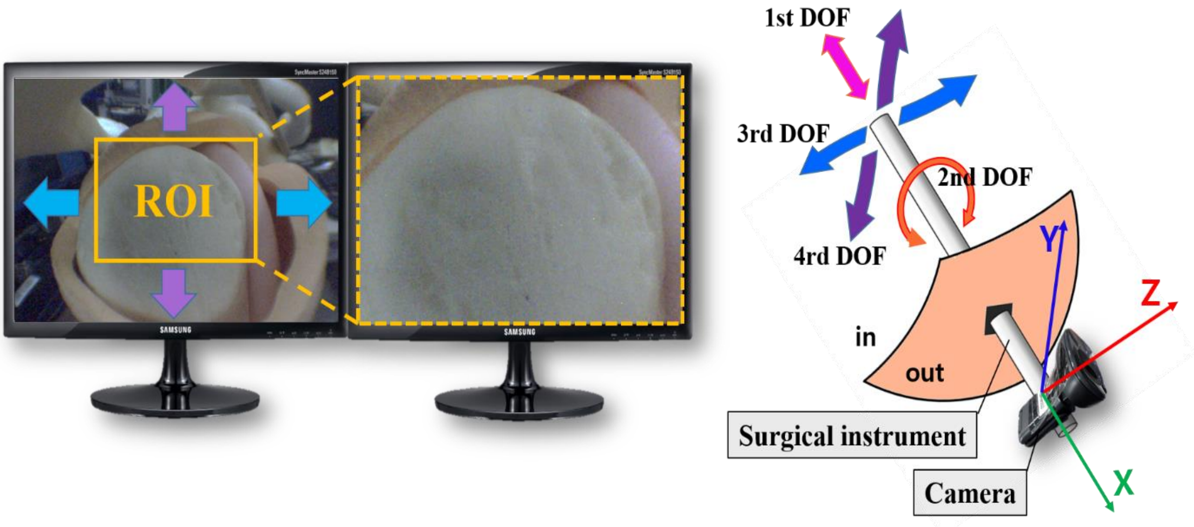

Figure 12. Relation between the DOF of surgical instrument pass through a portal, camera coordinates, and ROI movements.

We determined the relation between the surgical instrument and the camera in formula 1. From the relation, when the tool was moved along the direction of the third DOF, the camera was rotated in the Y-axis. As the camera rotated in the Y-axis, the ROI moved to the left-right side. When the tool was moved along the direction of the fourth DOR, the camera was rotated in the Z-aixs. As the camera rotated in the Z-axis, the ROI moved up/-down. The ROI movements could be controlled by using the rotation angle.

$$\text{1st DOF} \perp \text{Z axis} \quad \& \quad \text{1st DOF} \,/\!/\, \text{X axis} \tag{1}$$

The position of the camera could be determined from four settings by considering how many features could be extracted from each background (Fig. 13).

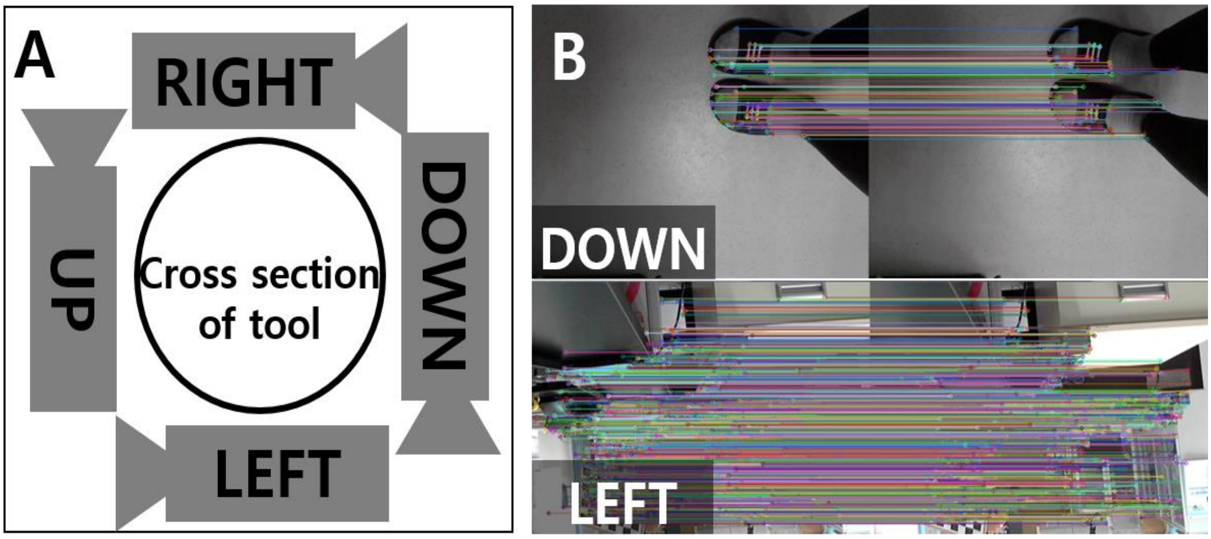

Figure 13. Four initial poses between the tool and camera for the better feature extraction (A)Four relative camera position with surgical tool, (B) Feature matches images at dwon and left position.

3.3 Feature extraction and matching algorithm

The motion of the instrument with a camera attached was estimated by matching the features of two consecutive scene frames. The estimation accuracy of the tool movement depended on the image processing capacity, such as feature extraction, feature matching, and fundamental matrix calculation. In particular, because we used the pure scene images without specific vision markers or pattern images, acquiring the features from the background image was an essential step.

There have been a variety of algorithm studies in terms of feature detection and description. Among the algorithms, the most popular multiscale feature detection and description algorithms are the Scale Invarianat Feature Transform (SIFT) [12] and the Speeded Up Robust Features (SURF) [13]. Both SIFT and SURF approaches and the many related algorithms use Gaussian derivatives as smoothing kernels for building a Gaussian scale space. However, the Gaussian scale space does not preserve the meaningful boundary information of objects in the scene images and both fine edges and noise became blurred at every scale level. Loss of the fine boundary data in the significant scene images bring the repeatability, distinctiveness and robustness of algorithms to be reduce. In this paper, the features were extracted using the Accelerated-KAZE (A-KAZE) algorithm which exhibits a good performance and fast multiscale feature detection and description [14]. KAZE means wind in Japanese.

Wind blow nonlinearly in the typical environments. In the KAZE algorithm [15], the nonlinear image scale space is built by the nonlinear diffusion approach, which exhibits higher repeatability and distinctiveness than previous algorithms based on the Gaussian scale space. The difference of nonlinear scale space compared to the Gaussian scale space is to conserve the essential edge and boundary of the image with noise reduction, which could be achieved by function g. The function g smoothen images at the point where edge data is week and preserve image properties at the high contrast edge point. However, the main defect of KAZE is a computational issue in solving the nonlinear diffusion equation. Accelerated-KAZE (AKZE) could resolve the issue by using Fast Explicit Diffusion (FED) which builds a nonlinear scale space much faster. According to [14], computation time of A-KAZE is faster than SURF, SIFT and KAZE, it is more expensive to compute than BRISK and ORB. The features were matched by considering a nearest neighbor distance ratio approach [Fig. 14]. We set 0.8 as a ratio value [12].

Figure 14. Feature matches in consecutive image frames when a camera affixed to the surgical tool moved.

3.4 Essential matrix decomposition for finding camera rotation angle

We assumed that 3D point P is projected onto a 2D image plane by a pinhole camera model. Scene features in the 2D images plane from a camera attached to the surgical instrument are tracked when the pose of camera are rotated by tool manipulation. Feature tracking means that corresponding feature points in the previous and later images from a camera are matched. Given corresponding features are utilized to estimate the relative camera rotation (Rotation of surgical instrument) on the basis of epipolar geometry. The rotation of the surgical instrument was derived by decomposing the essential matrix which was calculated using the matched feature points and camera intrinsic parameters. Camera intrinsic parameters encompass the focal length, the skew coefficient, and principal point.

The geometry of a stereo vision is depicted in Figure 15. A 3D point P in the world is imaged in two image planes. Each corresponding points projected on both O_l camera image and O_r camera image are related with the fundamental matrix F. The relation between the point pair is called epipolar constraint.

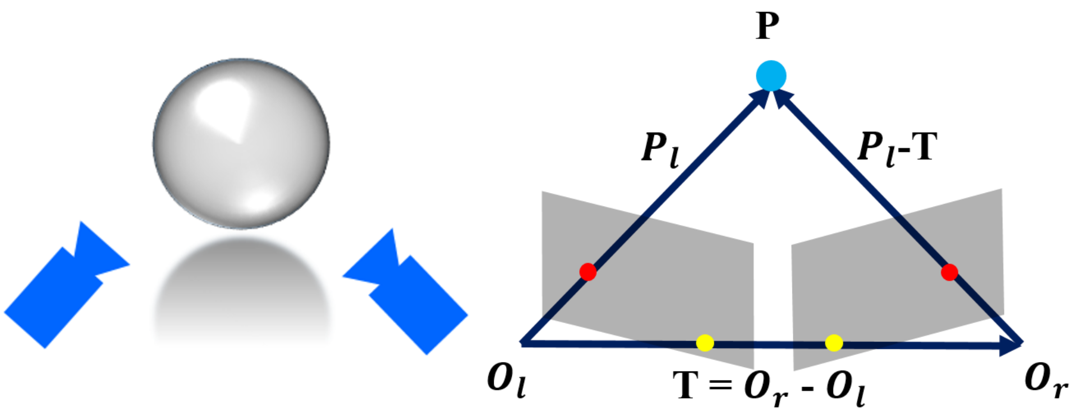

Figure 15. Epipolar geometry when the camera moved from $\boldsymbol{O_l}$ to $\boldsymbol{O_r}$.

The equation (formula 2) of the epipolar plane is given by the following coplanarity condition, and formula 3 can be written when the P_r = R(P_l - T). By expressing cross product as a 3x3 skew symmetric matrix, we can have formula 4 and Essential matrix (E in the formula 5). Finally, rotation (R in the formula 7) is determined by a singular value decomposition (SVD) of E. The scale of ROI movement was set by multiplying the constant with the rotation angle. Our interface system was programed using C++ and OpenCV 3.0 library beta version.

$$(P_l - \mathrm{T})^T (T \times P_l) = 0 \ = 0 \tag{2}$$

$$(R^T P_r)^T (T \times P_l) = 0 \ = 0 \tag{3}$$

$$P_r{}^T R[t]_\times P_l = 0 \;=0,\;\; [t]_\times = R\begin{bmatrix} 0 & -T_z & T_y \\ T_z & 0 & -T_x \\ -T_y & T_x & 0 \end{bmatrix} \tag{4}$$

$$\mathrm{E} = R[t]_\times \tag{5}$$

$$E = U\Sigma V^T \tag{6}$$

$$R = UW^{-1}V^T \;\;,\; \mathrm{W} = \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} with\ W^{-1} = W^T \tag{7}$$

3.5 ROI selection experiment

3.5.1 Resolution test of ROI selection

In order to assess the resolution of the ROI selection, we prepared three kinds of images (640×480 pixels) with different sizes of colorful squares with a black background (Fig. 16). The square was regarded as a ROI. Every 4 seconds, one colorful ROI was randomly shown at different position within the black background image. Success was counted when the square was selected by instrument control within 4 seconds in 20 attempts. The experiment was repeated five times in each resolution (12, 25, and 48 ROIs).

Figure 16. Three resolution tests: 12 (3× **4**) ROIs, 25 (5× **5**) ROIs, and 48 (6× **8**) ROIs

3.5.2 Phantom test

We qualitatively tested the ROI selection interface using a shoulder phantom model. A surgeon completed two tasks. The first task involved placing the dot point within multi-size circle of five groups with controlling the ROI position from first-group to fifth-group (Fig. 16). Second task is to retrieve four blue sutures among eight sutures through other portal using a grasper (Fig. 17). In the first task, ROI position was changed when surgeon put a dot on the piece of paper from first-group to fifth-group sequentially and in the second task, when the surgeon wanted to distinguish the tangled sutures due to a cannula, ROI was dealt with.

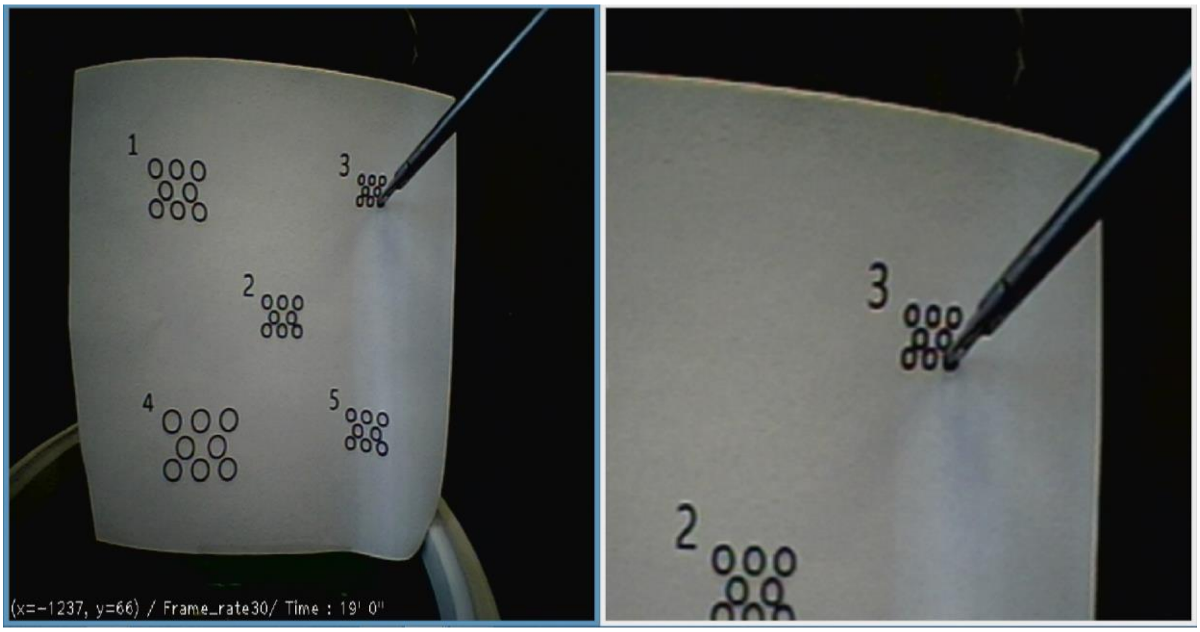

Figure 17. Interface phantom test: placing a point in the eight small circles.

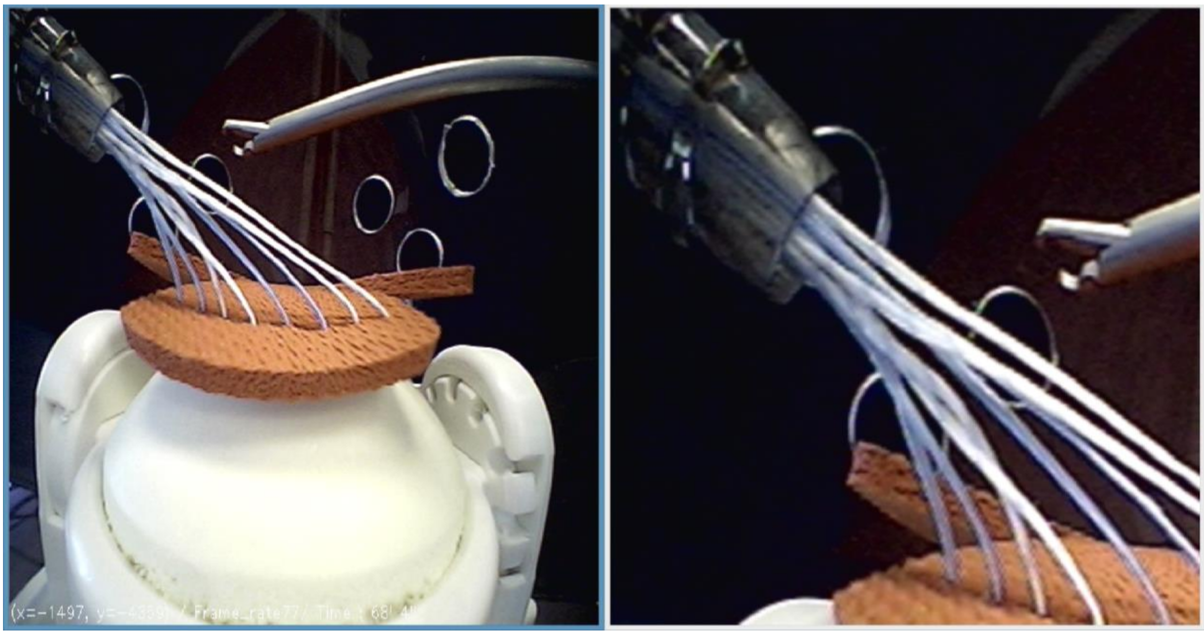

Figure 18. Interface phantom test: pulling the blue sutures out through other portal using a grasper.

IV. RESULTS

4.1 Comparison of work performance between 30 degree conventional arthroscope and wide-angle arthroscope

We found that four variables (the time taken for task, total path length of scope handling hand, the number of scope hand movements and average acceleration) were lower when participants used the wide-angle arthroscope than an existing 30 degree arthroscope (Table 1). Total path length and the number of movements were decreased by 32% and 45% respectively in case of wide-angle arthroscope. The reduction of the average acceleration was highest, which is 53% decreases. We statistically verified that wide-angle scope could improve the surgical skills of surgeons by p-value of three variables ($P < 0.005$, paired-sample t-test). However, there was no statistical significance in terms of the time variable ($p = 0.249$) in spite of 13% average reduction (Fig. 18). In the qualitative evaluation, every participant answered that enlarged arthroscopic view is useful to handle the tool and scope.

Table 1. Differences in motion analysis performance between conventional and wide-angle arthroscope.

Variable	Conventional Arthroscope (n = 12)	Wide-angle Arthroscope (n = 12)	P Value
Time (sec)	66.31 ± 28.64	57.86 ± 16.77	.249
Path length (cm)	52.77 ± 38.15	36.12 ± 21.66	< .05
Number of movements	1640.08 ± 1035.87	896.42 ± 581.03	< .05
Average acceleration (cm/s^2)	2.63 ± 1.34	1.23 ± 0.59	< .05

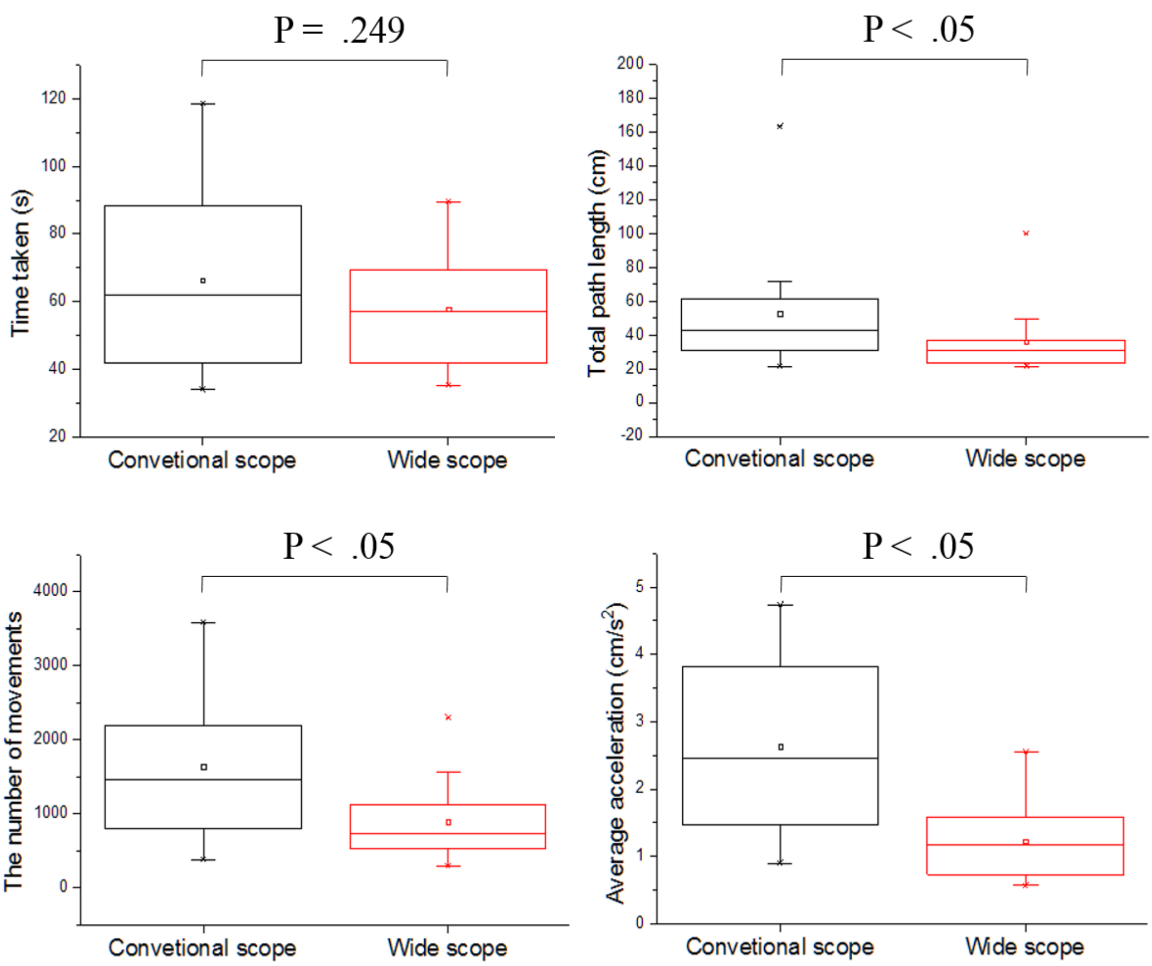

Figure 19. Comparison of conventional arthroscopy and wide-angle arthroscopy

4.2 Resolution test of ROI selection and phantom test

In the resolution test, when the number of ROIs was twelve, the success rate was perfect, and as the number increased, the success rate became lower. Standard deviations of 25 ROIs and 48 ROIs accounted for less than 5.5 % (Table 2).

Table 2. Resolution test of ROI selection.

Number of ROIs	Success rate
12	100 ± 0.00 %
25	93 ± 5.10 %
48	85 ± 5.47 %

In the phantom test, the qualitative assessment of ROI selection interface was implemented by a surgeon who manipulated the interface. The surgeon manipulated both the conventional arthroscope and the ROI selection interface during performing the tasks. The strength of the ROI selection interface was that one-hand task was possible and there was no collision between the scope and surgical.

V. DISCUSSTION AND CONCLUSION

This study firstly revealed that wide-angle arthroscope significantly improves the scope handling performance of participants in the shoulder arthroscopy in phantom mode. Except for the time taken for performing the tasks, the other three evaluation criteria (the total path length, the number of movements and average acceleration of movement manipulating arthroscope) had lower value, when the participants used wide-angle arthroscope. The total path length was reduced by 32% (170 mm), the effective scope handling movements and the average acceleration was decreased by 45% (744 movements) and by 54% (1cm/s^2). Although the time taken for the tasks was also decreased by 13% (8 seconds), the time difference was not significant (P=.249, paired-sample t-test).

Evaluating the performance of wide-angle arthroscope using motion analysis system is a novelty method because previous researches focused on the task accuracy such as polyp detection rate and time taken [9-10]. Assessing the generic operative skill of the surgeons have been attempted using an Objective Structured Assessment of Technical Skill (OSATS) scores [16] or results of motion analysis system such as total path length hands traveled, the number of endoscope handling, and task completion time [17]. Experienced surgeons recorded lower path length, the number of endoscope handling, and the time-consumed for the tasks than untried surgeons. The idea was that when the participants utilized different arthroscopes, by comparing the validated criteria which have been utilized in the surgical skill evaluation, we can figure out which system is helpful in growing the skill level (reducing the criteria values). This experiment was performed in the shoulder phantom model about four simulation tasks, it is not assure that the result of this study can be satisfied with real arthroscopic surgery. However, we determined the four tasks considering the similarity to the real shoulder arthroscopic surgery. Thus, we expect analogous outcomes in the arthroscopic surgery.

After effectiveness verification of wide-angle scope, we have developed a region of interest selection interface showing dual view for wide-angle arthroscope. In the resolution test for ROI selection, success rates of 12 ROIs was 100%, in case of 25 ROIs and 48 ROIs, success rate recorded 95% and 85% respectively. Although the success rates of 25 ROIs and 48 ROIs are not perfect, we expect that the resolution of 12 ROIs is sufficient for the view selection. In the results of phantom test using the interface, the first strength is that one surgeon can control the surgical image without other assistants, which means solo surgery is possible. When the participant performed the phantom tasks, he used only one hand. The second strength is reducing the collision ratio between the scope and surgical tool because a wide-angle arthroscope can show a wider arthroscopic image, although the wide-angle scope is placed farther than a conventional arthroscope.

For a laparoscopic surgery, Yamauchi et al. [18] developed a dual-view endoscope which consists of a 120-degree-wide view and a zoomed view by an image shift. By the image shift mechanism, the resolution of zoomed view is equal to that of wide-view. However, the diameter of endoscope is 40 mm by 50 mm, and the region of interest was selected by controlling the operation switch attached to a handle of a forceps. We have proposed the method to position the ROI at a desired point by handling the surgical instrument intuitively. For that purpose, most important information is the movement of surgical instrument by surgeons' order.

For tracking the 3D position of an object, optical or magnetic trackers have been utilized with sensor markers. The trackers show good accuracy in the navigation surgery. However, limited tracking volume, line-of-sight issues and high costs are disadvantages of the trackers. We have proposed the idea of attaching a camera to the surgical tool to overcome the limitations of existing trackers. The line of sight problem could be reduced as the camera could track the scene features, though the tool had turned in the opposite direction or a new object appear between the camera and background scene such as wall and devices. This method was applied as an ROI selection method for wide-angle endoscope interface for solo surgery.

In future studies, we plan to address the ability to recognize differences between image changes by the camera movement and by object movement within a camera FOV. Further studies are needed to discriminate between the instrument movements and scene changes by movements of people or device because it is an essential step to reduce the line-of-sight problem. This study shows a new approach to evaluate the usefulness of wide-angle view in surgical situation using a motion analysis system, and the ROI selection interface is expected to have a great significance for future clinical use of a wide-angle endoscopic system. This could be one step toward the development of a wide-angle endoscope interface.

References

[1] Berguer, R., Smith, W. D., and Chung, Y. H. "Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery." Surgical endoscopy, 15(10), 2001, pp. 1204-1207.

[2] Wentink, P. B. M. "Eye-hand coordination in laparoscopy-an overview of experiments and supporting aids." Minimally Invasive Therapy & Allied Technologies, 10(3), 2001, pp. 155-162.

[3] Kobayashi, E., Sakuma, I., Konishi, K., Hashizume, M., and Dohi, T. "A robotic wide-angle view endoscope using wedge prisms." Surgical Endoscopy And Other Interventional Techniques, 18(9), 2004, pp. 1396-1398.

[4] Breedveld, P. "Observation, manipulation, and eye-hand coordination problems in minimally invasive surgery." European Conference on Human Decision Making and Manual Control (ed): Proceedings of the 16th European Conference on Human Decision Making and Manual Control, Kassel, 1997, pp. 219-231.

[5] Kobayashi, E., Masamune, K., Sakuma, I., and Dohi, T. "A wide-angle view endoscope system using wedge prisms." In Medical Image Computing and Computer-Assisted Intervention–MICCAI 2000. Springer Berlin Heidelberg, 2000, pp. 661-668.

[6] Hong, W., Wang, J., Qiu, F., Kaufman, A., and Anderson, J. "Colonoscopy simulation." In Medical Imaging, International Society for Optics and Photonics, 2007, pp. 65110R-65110R.

[7] Tamadazte, B., Agustinos, A., Cinquin, P., Fiard, G., and Voros, S. "Multi-view vision system for laparoscopy surgery." International journal of computer assisted radiology and surgery, 10(2), 2015, pp. 195-203.

[8] Cao, A., Darin Ellis, R., Composto, A., Pandya, A. K., and Klein, M. D. "Supplemental wide field-of-view monitor improves performance in surgical telerobotic movement time." The International Journal of Medical Robotics and Computer Assisted Surgery, 2(4), 2006, pp. 364-369.

[9] Pellisé M, Fernández–Esparrach G, Cárdenas A, et al. "Impact of wide-angle, high-definition endoscopy in the diagnosis of colorectal neoplasia: a randomized controlled trial." Gastroenterology, 135(4), 2008, pp. 1062-1068.

[10] Rex DK, Chadalawada V, and Helper DJ. "Wide angle colonoscopy with a prototype instrument: impact on miss rates and efficiency as determined by back-to-back colonoscopies." The American journal of gastroenterology, 98(9), 2003, pp. 2000-2005.

[11] Singh, H., Karar, V., Kumar, N., and Saini, S. S. "Performance Comparison: Optical and Magnetic Head Tracking." International Journal of IT, Engineering and Applied Sciences Research, 2(3), 2013, pp. 27-32.

[12] Lowe, D. G. "Distinctive image features from scale-invariant keypoints." International journal of computer vision, 60(2), 2004, pp. 91-110.

[13] Bay, H., Tuytelaars, T., and Van Gool, L. "Surf: Speeded up robust features." In Computer vision–ECCV 2006, Springer Berlin Heidelberg, 2006, pp. 404-417.

[14] Alcantarilla, P. F., and Solutions, T. "Fast explicit diffusion for accelerated features in nonlinear scale spaces." IEEE Trans. Patt. Anal. Mach. Intell, 34(7), 2011, pp.1281-1298.

[15] Alcantarilla, P. F., Bartoli, A., and Davison, A. J. "KAZE features." In Computer Vision–ECCV 2012, Springer Berlin Heidelberg, 2012, pp. 214-227.

[16] Datta, V., Chang, A., Mackay, S., and Darzi, A. "The relationship between motion analysis and surgical technical assessments." The American journal of surgery, 184(1), 2002, pp. 70-73.

[17] Howells, N. R., Brinsden, M. D., Gill, R. S., Carr, A. J., and Rees, J. L. "Motion analysis: a validated method for showing skill levels in arthroscopy." Arthroscopy: The Journal of Arthroscopic & Related Surgery, 24(3), 2008, pp. 335-342.

[18] Yamauchi, Y., et al. "A dual-view endoscope with image shift." In CARS 2002 Computer Assisted Radiology and Surgery, Springer Berlin Heidelberg, 2002, pp. 183-187.

요 약 문

광각 관절경의 유용성 평가와 관심영역 선택 인터페이스 개발

본 연구에서는 기존 관절경과의 비교를 통하여 광각 관절경의 유용성을 평가하였고, 보조의사의 도움 없이 수술자의 솔로 수술을 실현케 하는 광각 관절경을 위한 관심영역 선택 인터페이스를 제안하였다. 광각 관절경의 유용성은 관절경 수술 경험이 없는 총 12 명의 실험참가자들이 시야각 150 도의 광각 관절경과 시야각 105 도의 기존 관절경을 번갈아 사용하여 어깨 팬텀 모형 환경에서 모의 관절경술을 시행할 때, 움직임 분석 시스템을 사용하여 실험 참가자의 관절경 조작 능숙도 비교를 통해 평가되었다. 능숙도 비교를 위해서 (1) 수술 시간, (2) 관절경 조작의 총 거리, (3) 관절경 조작의 유효횟수, (4) 관절경 조작의 평균 가속도, 총 4 개의 지표를 평가기준으로 삼았다. 비교실험 결과, 광각 관절경을 사용한 경우가 기존 관절경을 사용한 경우보다 관절경 조작 거리, 조작 횟수, 조작의 평균 가속도 값이 더 낮음을 보였고, 통계적으로 유의성을 확인 하였다. 광각 이미지는 넓은 시야를 확보 할 수 있지만, 관심영역의 이미지는 작아지게 된다. 따라서, 광각의 이미지와 관심영역이 두 배 확대된 이미지를 동시에 보여주면서, 관심영역 선택 및 확대 기능을 조수의 도움 없이 수술자가 직접 다룰 수 있는 관심영역 선택 인터페이스를 개발하였다. 이는 수술도구를 양손에 든 의사가 관심영역을 선택하기 위해서, 수술도구를 사용하여 관심영역을 선택하는 방법으로, 수술도구의 방향인지를 위해서 카메라를 부착하여 영상처리를 통해 수술도구의 회전 정보를 얻었다. AKAZE 알고리즘을 사용하여 카메라의 이미지 속에서 특징점들을 추출하였고, 수술도구의 움직임으로 인해 발생하는 연속의 이미지들 속에서 특징점들을 매칭하여 Essential matrix 를 획득하였다. Essential matrix 를 분해하여 카메라의 각도변화를 획득하였으며, 각도에 상수를 곱하여 관심영역의 움직임 정도를 조절하였다. 관심영역 선택의 정밀도 테스트를 통해서 최대 48 개의 분할영역을 선택할 수 있는 정확도를 정량적으로 확인 하였고, 팬텀 실험을 통해서 의사의 피드백(정성적 평가)을 얻었다. 본 연구는 수술시간 비교를 통해서 광각의 효과를 확인해 왔던 이전 연구들과는 달리, 움직임 분석 시스템을 사용하여 사용자들이 광각 관절경과 기존의 관절경을 사용할 때의 움직임을 분석하여 4 개의 평가지표결과를 통해서 광각의 유용성을 확인하였다. 이는 광각 이미지가 수술환경에 미치는 효과를 새로운 접근법으로 확인한 연구다. 또한 관심영역 선택 인터페이스는 광각의 이미지를 수술환경 및 상황에 맞게 사용할 수 있도록 도와주는 시스템으로, 다양한 임상에서 사용될 미래의 광각 내시경 시스템 발전에 중요한 첫 발걸음이 될 것으로 기대된다.