Original Article Clinics in Orthopedic Surgery 2021;13:436-446 • https://doi.org/10.4055/cios20004

Touchless Control of Picture Archiving and Communication System in Operating Room Environment: A Comparative Study of Input Methods

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Background: The advancement of computer information technology would maximize its potential in operating rooms with touchless input devices. A picture archiving and communication system (PACS) was compared with a touchless input device (LMC-GW), relaying to another person to control a mouse through verbal guidance, and directly controlling a mouse.

Methods: Participants (n = 34; mean age, 29.6 years) were prospectively enrolled and given nine scenarios to compare the three methods. Each scenario consisted of eight tasks, which required 6 essential functions of PACS. Time elapsed and measurement values were recorded for objective evaluation, while subjective evaluation was conducted with a questionnaire.

Results: In all 8 tasks, manipulation using the mouse took significantly less time than the other methods (all $p < 0.05$). Study selection, panning, zooming, scrolling, distance measuring, and leg length measurement took significantly less time when LMC-GW was used compared to relaying to another person (all $p < 0.01$), whereas there were no significant differences in time required for measuring the angles and windowing. Although the touchless input device provided higher accessibility and lower contamination risk, it was more difficult to handle than the other input methods (all $p < 0.01$).

Conclusions: The touchless input device provided superior or equal performance to the method of verbal instruction in the environment of operating room. Surgeons agreed that the device would be helpful for manipulating PACS in operating rooms with less contamination risk and disturbance of workflow. The touchless input device can be an alternative option for direct manipulation of a mouse in operation rooms in the future.

Keywords: *Touchless, Mouse, Picture archiving and communication system, Operating room*

The advancement of computer information technology has increased the accessibility to medical image information within hospital.[1-3] Digitization/storage/transmission of images, high-resolution display output, and large amount of computer information processing capability have given birth to the picture archiving and communication system (PACS), which has significantly increased temporal and spatial accessibility compared to the time when medical images were visualized through films. However, due to bacterial contamination for most of touch-based input devices such as a mouse, keyboard, and touch screen, the advancement of computer information technology could

Received January 8, 2020; Revised January 12, 2021;
Accepted January 12, 2021
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not fully maximize its potential in operating rooms (ORs) where the surgeons have to be in a sterilized condition.[1,4,5]

A sterilized cover is placed on the mouse to avoid the risk of contamination. However, this is not recommended because its installation and use are inconvenient and can actually increase contamination risk.[6] Alternatively, a request for assistance is made to personnel (nurses or resident doctors) outside the operation field, but there is a limitation in the number of personnel available in an OR. Furthermore, when the available personnel are inexperienced in PACS, even the simple controls have to be explained verbally. When they are not familiar with the anatomical structures, errors frequently occur and extra time is required for correcting control and measurement.[5,6]

A touchless input device can be a good candidate to solve this problem since a surgeon can use the computer directly without any physical contact. To date, several touchless input devices have been applied in ORs. Among them, the combination of Leap Motion Controller (LMC; Leap Motion, San Francisco, CA, USA) and GameWave (GW, GameWave App, v 1.5.6, Manage, Belgium) was found to be suitable for the OR environment because it is inexpensive, easy to install, and requires a small working space.[1] However, because of the low popularity and unfamiliarity with touchless input devices compared to that of touch-based input devices, the introduction of touchless input devices has been very limited in medical facilities. One of touchless devices has been found to be easy enough to get familiar with in a short time in a previous study.[6] As the combination of LMC and GW (LMC-GW) has more advantages over the other touchless devices,[1] we hypothesized that once the LMC-GW is introduced to surgeons, they would learn to use it in less than 1 hour and prefer to use it to computers, without taking off surgical suits.

In this study, tests were conducted to compare the LMC-GW to the other two conventional methods of controlling PACS in an OR: (1) direct control of a mouse by the surgeon himself or herself; (2) giving verbal instructions to another person to control the mouse and PACS; and (3) direct control of LMC-GW by the surgeon himself/herself. The goal of this study was to compare the time taken and subjective user experience for manipulating PACS in ORs using the above three methods.

METHODS

This study was conducted as a multicenter prospective comparative study in two medical institutions with level I trauma centers. This study was approved by the Institutional Review Boards of Ajou Medical Center and Eulji University Hospital (IRB No. EMC 2017-12-014-001, AJIRB-MED-SUR-18-029). Written informed consent was waived. The hospitals used the PACS of Infinitt (ver. 3.0.11.3 [BN103], Infinitt Healthcare, Seoul, Korea) and M-view (ver. 5.4.10.38, Infinitt Healthcare).

Definitions

To avoid confusion, we defined several terms used in the present study. Motion: Any movement an operator makes. It does not have to mean anything. Gesture: A single distinct meaningful element of motion. It should contain a meaning. Function: A unit of manipulation, which handles medical images. For example, zooming in or out, panning, windowing, or measuring of distance or angle. Task: A problem that can be solved with a set of functions. For example, selecting a third scenario, scrolling down through five pages, or measuring one edge of a square. Scenario: A set of tasks for testing various functions.

Participants

The participants were recruited among surgeons, interns, and residents working in the two hospitals who had at least three months of experience using PACS. A total of 34 participants were recruited in the two hospitals. The average age of the 34 participants was 29.6 years (range, 25–36 years) and 29 of the participants were male. The average experience with PACS was 4.1 years (range, 3–14 years); one doctor played video games about twice a month, and the rest of the participants had no experience in operating LMC-GW. All participation was voluntary without financial incentives. For verbal instructions, five nurses participated as assistants; their average age was 25.3 years (range, 24–29 years). They were all female and their average clinical experience was 2.2 years (range, 0–5 years). Everyone had experience in handling PACS less than five times per year.

Test Environment

In every OR of the two hospitals, at least two computers were installed, and the computers mainly used by surgeons were equipped with dual monitors to show the images effectively. The experiments were carried out in ORs that were not in use for operation at the moment of experiments.

Input Methods

Comparisons were made between three usable computer input methods in the OR.

Conventional Method 1 (Mouse)

For the first conventional method, we assumed the operator would directly control the mouse after taking off the surgical suite.

Conventional Method 2 (Verbal Instruction)

For the second conventional method, simulations were carried out for the case where nonsterile personnel performed the relevant manipulations through verbal guidance of sterile operators. To test the verbal instruction method, five nurses who were working in the OR and unfamiliar with PACS were asked to manipulate the PACS through the mouse according to the verbal guidance of the operators.

Touchless Input Unit (LMC-GW)

LMC (Leap Motion) is a gesture-controlled input device that converts the motion of fingers or hands into input signals.[7] This device uses three infrared structured lights to create a three-dimensional depth map of the scene.[8,9] The LMC has a maximum field view of 150° and can update positional information up to 200 times per second. The controller can track motion with an accuracy of 1.2 mm in all directions.[10] The cost of the device is approximately $70.

The controller was connected to the computer using a universal serial bus connection and was placed in front of the keyboard (Fig. 1). Gesture recognition from the captured motion was performed by the drivers that came with the device rather than by the device itself.[11] A gesture control app (GameWave App, GW, v 1.5.2) was used to recognize the motion of a finger and hand as a gesture, which has a meaning, and convert it into input information to the computer. With reference to Pauchot et al.,[11] each function was matched to the gesture vocabulary of GW app (Fig. 2, Appendix 1).

Fig. 1. Photograph of the system with a leap motion controller. The controller is 76 mm in length and is placed on the table.

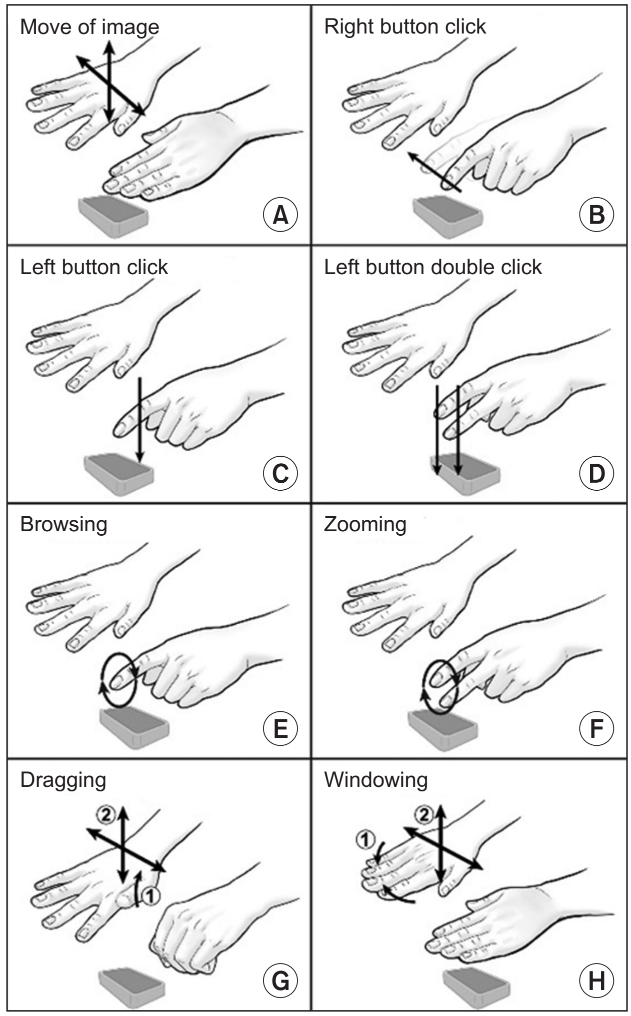

Fig. 2. Gesture arrangement. (A) Moving: move the open right hand parallel to the monitor. (B) Right button clicking: move the left second finger to the right side. (C) Left button clicking: move the left second finger toward leap motion controller. (D) Left button double clicking: move the left second and third fingers down. (E) Browsing: draw a circle with the index finger of the left hand. Counterclockwise rotation browses up and clockwise rotation browses down the dataset. (F) Zooming: draw a circle with the second and third fingers of the left hand. Counterclockwise rotation browses up and clockwise rotation browses down the dataset. (G) Dragging: after raising the thumb upward, move the open right hand parallel to the monitor. To release the pointer, release the thumb. (H) Windowing: keeping the fingers of the right hand together, move the open right hand parallel to the monitor. To stop windowing, open the right hand.

Study Flow

With reference to the study performed by Wipfli et al.,[6] we planned a usability test for three different gesture control methods to control PACS. The tests were conducted in a serial way (Fig. 3). Participants were first introduced to the goals of the study and how to control the controller. The mouse, verbal instruction, and LMC-GW were tested in the sequence of familiarity as familiar methods do not require practice scenarios. Since the LMC-GW was an unfamiliar input device, the participants were allowed to learn it before the test for an hour. Learning and testing were all conducted in random order scenarios.

Establishment of Scenarios

Six essential functions for controlling PACS were selected, which consist of selecting an examination, panning and zooming, windowing (adjusting brightness and contrast), browsing (reviewing multiple images in an examination), distance measurement, and angular measurement. Fourteen scenarios were established for the practice and evaluation of LMC-GW. Each scenario included eight tasks that require six basic functions to solve. The 14 scenarios were assigned to each participant in a random order using the random-number generation function in Microsoft Excel (Microsoft, Redmond, WA, USA). Fourteen scenarios were proceeded in the following order: (1) the first 3 scenarios in the mouse method test, (2) the next 3 scenarios in the verbal instruction method test, (3) the next 5 scenarios in the LMC-GW method learning, and the last 3 scenarios in the LMC-GW method test.[6] With the randomly assigned values, the scenarios were produced using PowerPoint (ver. 2016, Microsoft) and uploaded to the PACS by saving them in JPEG files (Fig. 4, Appendix 2).

Outcome Measurements

With respect to objective measurements, time consumption and measurement value were recorded. The time consumed to perform each task was recorded with an accuracy of 0.1 second. The movement of a mouse pointer was regarded as the starting point of task. When measuring the time spent for direct control of mouse, the time spent taking off the surgical gown and then putting it on again after using the mouse was not measured or included. Also, when measuring the time spent for verbal instruction method, the time spent calling the nurse and preparing him/her for the manipulation of the PACS was not measured in this test. The difference from actual values were calculated by subtracting the true values from the measured values.

The evaluation for subjective experience was conducted with a questionnaire divided into two parts. First part consisted of evaluation of difficulty in performing the six functions with each of the different methods using a seven-step Likert response format (1, too easy; 7, too difficult). Second part was the questionnaire, which evaluated the various aspects of the three input methods. The after-scenario questionnaire by Lewis was modified to evaluate users' subjective perceptions regarding the ease of task completion, time to complete a task, potential risk of contamination, probability of error, potential interruption

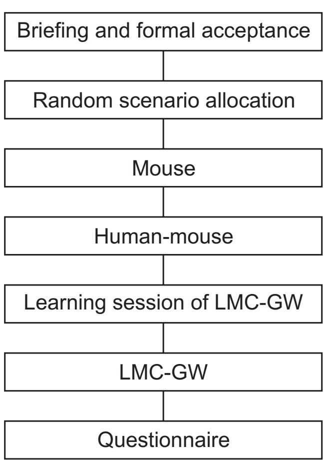

Fig. 3. Flowchart of the present study. After introduction of the purpose of the study and synchronization of measuring methods, scenarios were allocated randomly. After the tests using the mouse and verbal instruction, we had a session to learn LMC-GW, and then we performed input test using LMC-GW. A survey was conducted after all scenarios were completed.

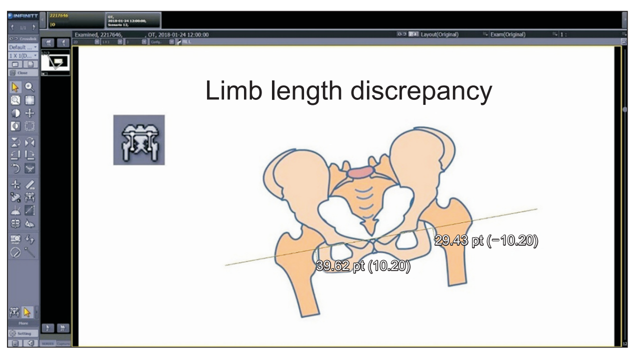

Fig. 4. The third task page of the scenario #12. The page indicates that the task of this page is to measure limb length discrepancy. The enlarged icon presented on the left side reminds the surgeons of measuring methods, which was synchronized before the initiation of the study. After surgeons pointed out four anatomical landmarks, the computer measured the discrepancy. The true difference was 12 points shorter on the left side on the presented task, while the measured difference was 10.4 points shorter on the left side.

of operation, intraoperative repetitive accessibility, and willingness to adopt the method.[5,6,12)]

The brief seven-item questionnaire was composed in a seven-step Likert response format (1 = strongly agree, 7 = strongly disagree). The modified questions are as follows: (1) Ease of task completion: I think it was easy to complete the tasks in this scenario. (2) Time to complete a task: I think it took a short time to complete the tasks in this scenario. (3) Potential risk of contamination: I think the interface provided low risk of contamination. (4) Probability of error: I think the interface provided low probability of error to complete the tasks in this scenario. (5) Potential interruption of operation: I think the interface provided low risk of interruption during operation. (6) Intraoperative repetitive accessibility: I think I could use the interface no matter how many times I want to access the PACS in an intraoperative setting. (7) Willingness to adopt the method: I want to continue using this method when I need to operate a computer after I have scrubbed into the OR.

After evaluating tasks, the participants were asked to fill out the questionnaire with the knowledge that an additional 5 minutes would be spent taking off one's surgical gown, using the mouse, washing their hands, and then putting on the gown again in an actual OR setting. Moreover, when evaluating the verbal instruction method, an additional 2 minutes would be spent calling nonsterile personnel and making them to prepare to control PACS.

Statistical Analysis

For all intrasubject comparisons, a Kolmogorov-Smirnov test was applied in order to evaluate whether the distributions were normal. For analysis of the questionnaires, data were treated as an interval scale because the distances between the seven-step Likert scales of the responses were assumed to be equal.[13)] Each analysis was paired between mouse and LMC-GW and LMC-GW and verbal instruction. For distributions that met the criteria for parametric tests, a paired two-tailed t-test was applied. For distributions that did not meet the criteria for parametric tests, the Wilcoxon signed rank test was used. We used a Bonferroni corrected alpha = 0.017 in order to determine significant differences.

RESULTS

In all eight tasks, manipulation using the mouse took significantly less time than the other methods ($p < 0.05$) (Table 1). On the comparison between manipulation through verbal instruction and LMC-GW, study selection,

Table 1. Time Taken to Complete the Tasks with 3 Inputting Methods and Measurement Errors of Each Method

Function	Time (sec)					Measurement error				
	Mouse	*p*-value	Leap motion	*p*-value	Human-mouse	Mouse	*p*-value	Leap motion	*p*-value	Human-mouse
Study selection	1.94 ± 0.47	< 0.001	3.44 ± 1.64	< 0.001	4.29 ± 1.28					
Panning and zooming	20.97 ± 5.66	< 0.001	44.49 ± 14.48	< 0.001	78.61 ± 18.27					
Windowing	10.74 ± 5.10	< 0.001	42.59 ± 16.71	0.293	45.02 ± 19.27					
Scrolling	8.49 ± 1.55	< 0.001	23.81 ± 8.03	0.001	28.33 ± 9.04					
Distance measurement	5.29 ± 1.46	< 0.001	41.88 ± 21.31	0.005	63.41 ± 25.57	0.12 ± 0.40 mm	< 0.001	0.79 ± 0.99 mm	0.626	0.71 ± 0.62 mm
Leg length discrepancy measurement	11.84 ± 2.62	< 0.001	66.04 ± 24.14	< 0.001	80.49 ± 34.43	1.76 ± 1.05 mm	0.8	1.71 ± 0.61 mm	0.664	1.81 ± 0.62 mm
Angular measurement	8.45 ± 1.06	< 0.001	24.26 ± 19.02	0.296	21.59 ± 5.33	1.39° ± 1.19°	0.8	1.48° ± 2.07°	0.644	1.19° ± 0.96°
Inclination measurement	8.21 ± 1.54	< 0.001	45.24 ± 18.08	0.080	49.65 ± 14.06	1.31° ± 0.86°	0.22	1.64° ± 1.21°	0.972	1.63° ± 1.05°

Values are presented as mean ± standard deviation.

panning, zooming, scrolling, distance measuring, and leg length measurement took significantly less time when LMC-GW was used (all $p < 0.01$) (Table 1). However, with regard to measuring the angle and changing the screen brightness and contrast (i.e., windowing), manipulation through LMC-GW and verbal instruction did not show significant difference. Regarding the task of measuring the angle of geometric shapes, manipulation through verbal instruction took less time on average but a statistically significant difference was not shown (Table 1).

For the difference from actual values, only in the length measurement of a quadrangle did the mouse show statistically significantly low difference from actual values compared with other methods ($p < 0.001$) (Table 1). However, when the limb length discrepancy and two types of angles were measured, all three methods showed similar differences from actual values (Table 1).

The results of the subjective evaluation of input methods for each function showed that controlling the mouse was perceived as the easiest method for every function (Table 2). On the comparison between manipulation through verbal instruction and LMC-GW, it was found that in every function evaluation, using the LMC-GW was more difficult than using the verbal instruction method, and the difference was statistically significant ($p < 0.01$) (Table 2).

In the questionnaire that subjectively evaluated the various aspects of the overall usability of respective input device, the participants felt that LMC-GW was more difficult to handle than the other input methods while the recognition error was higher, and although the subjects actually spent less time completing the task, they felt that it took longer (all $p < 0.01$). However, they all agreed that the LMC-GW requiring no touch was a good interface for preventing contamination ($p < 0.01$) (Table 3). Although LMC-GW provided significantly higher accessibility than the mouse, there was no significant difference observed in terms of accessibility when compared to the verbal in-

Table 2. Likert Scale for the Difficulty of Completing the Scenario with Each Input System

Variable	Mouse	*p*-value	Leap motion	*p*-value	Human-mouse
Study selection	1.44 ± 0.55	< 0.001	3.74 ± 1.04	< 0.001	2.53 ± 0.70
Zooming	1.29 ± 0.52	< 0.001	3.09 ± 0.98	0.001	2.15 ± 1.31
Panning	1.44 ± 0.55	< 0.001	3.82 ± 0.78	< 0.001	2.74 ± 0.85
Windowing	1.26 ± 0.50	< 0.001	4.71 ± 1.38	< 0.001	2.06 ± 1.37
Scrolling	1.26 ± 0.50	< 0.001	3.12 ± 0.93	< 0.001	1.62 ± 0.69
Distance measurement	1.53 ± 0.61	< 0.001	3.71 ± 1.07	< 0.001	2.12 ± 1.60
Angular measurement	1.74 ± 0.66	< 0.01	3.76 ± 1.00	0.009	2.85 ± 1.44

Values are presented as mean ± standard deviation.

Table 3. Likert Scale for Subjective Opinion after Completing Scenario

Variable	Mouse	*p*-value	Leap motion	*p*-value	Human-mouse
It is easy to complete the task.	1.41 ± 0.49	< 0.001	3.18 ± 1.07	0.001	2.06 ±1.06
I feel that the time it takes to complete the task is short.	2.94 ± 1.21	0.018	3.65 ± 1.35	0.007	2.79 ± 0.99
I think this method has a low error rate.	1.24 ± 0.42	< 0.001	4.32 ± 1.32	< 0.001	2.56 ± 1.26
It is possible to maintain sterility when operating the computer.	5.18 ± 1.38	< 0.001	1.68 ± 0.53	< 0.001	2.79 ± 0.90
If used aseptically, it will not interfere with the progress of surgery.	1.62 ± 0.69	0.51	2.00 ± 0.69	0.103	2.06 ± 1.37
This method has good accessibility and can be used repeatedly at any time during surgery.	3.44 ± 1.56	< 0.001	1.76 ± 0.77	0.21	2.41 ± 1.33
I would like to continue using this method in the future when I need to operate the computer after I have scrubbed into the operating room.	2.79 ± 1.30	< 0.001	4.50 ± 1.31	0.002	3.03 ± 1.32

Values are presented as mean ± standard deviation.

struction ($p < 0.001$, respectively) (Table 3). With regard to the intention to use in the future, LMC-GW had the lowest score ($p < 0.01$) (Table 3).

DISCUSSION

In an OR, the ideal input device should be easy to use, respond quickly, require no touching to maintain sterility, and occupy a small space in the OR for easy access by the surgeon.[14,15] Since touchless devices do not require any physical contact, they are strong candidates for use in the OR. Thus, attempts have been made to apply them as computer input devices in the medical field.[1,5] However, as far as we know, no one has asked medical personnel to compare the combination of LMC and GW to conventional interfaces in the OR environment.

Various methods have been tried in an OR as an input device. Placing a sterile cover on the mouse allows quick and direct control similar to that of the mouse by itself. However, contamination prevention by sterile covering could fail during covering process. And there could be difficulty in controlling the mouse.[6] Another type of input device is the foot pedal, which can be used without the risk of contamination in ORs. However, performing sophisticated or repetitive control is limited and it may cause a balance problem and fatigue of the surgeon since one foot has to support the body while the other foot controls the device.[16] While a speech control has been tried, it often triggered unintended commands and required smooth modification as every control cannot be made with speech (e.g., for window leveling).[17]

In contrast to the other input devices, LMC is very small with the size of two adult fingers. It responds very quickly with an accuracy of 1.2 mm in all directions, high spatial resolution,[1,10,16] and faster frame rate (200 times per second). Since it occupies a small working space of 0.23 m^2, it is easy to turn on and off upon entering and leaving the space, respectively.[1] The system works reliably with wet rubber gloves.[8] Using infrared, the interference of astral lamps can be overcome.[8] Moreover, the cost of the sensor is low. In any country, it can be easily implemented in clinical settings.[1] Ebert et al.[8] showed that with use of touchless gesture control devices in the field of medicine, disturbance of surgical flow can be avoided and contamination during sterile procedures such as surgery, radiological intervention, or autopsy can be prevented.

In the present study, control by using the mouse, which was the most familiar interface to participants, consumed the shortest amount of time. When a surgeon reviews image information using direct control of a mouse during a real operation, it implies that after taking off the gloves and scrubs, he or she uses the mouse and then resumes the operation after surgical scrub. As 3 minutes are generally recommended for surgical scrub, additional 5 minutes are expected to be taken for the surgeon to resume surgical procedures after controlling mouse directly. In addition, if expendables such as surgical gown and gloves are taken into consideration, it will offset the time saving effect compared to the other interfaces. Therefore, when LMC-GW is used, the benefits of time and cost saving can be obtained while reducing the risk of contamination.

On the comparison between the control through the verbal instruction and LMC-GW, the total time consumed was less when the touchless device was used, similar to other studies.[6] The participants consumed significantly less time with LMC-GW than with the verbal instruction method when simply reviewing images and carrying out functions, such as study selection, panning, zooming, and scrolling. In addition, the time spent to call a nurse and wait for the nurse's preparation to control the PACS was not included in the present study. When applied to the real world, the verbal instruction would be more time-consuming than what was measured in the present study. Furthermore, control through personnel with little experience in using PACS is more prone to error, thereby increasing the control time even more.

Larger difference from actual values with the LMC-GW occurred in the simple length measurement compared to the difference from actual values in the other measurements due to the difference of control methods in our PACS. For length measurement, participants must drag the mouse pointer from the beginning to the end of the length, while the angle and leg length discrepancy measurements are to click the left mouse button once at the start and end points, respectively. When performing the drag function, there were difficulties because of hand muscle fatigue. Repeated inaccuracies due to fatigue often caused GW to fail to understand the meaning of the motion correctly. This problem can be easily solved by designing a PACS function implementation method with gesture control in mind. For example, for functions that do not require drag, such as length measurement, you can change them by clicking the left mouse button once at the start and end points.

In the questionnaire for subjective evaluation, the participants said that on average LMC-GW was the most difficult to use and they felt that the longest time was consumed even though it was not the case, contrary to the results of a previous study.[6] The following two factors could have affected the subjective evaluation. First, the familiarity with LMC-GW. Although one hour was given for participants to get used to the LMC-GW prior to conducting the test, they might not have had enough time to learn to handle it as well as a mouse.[18] Second, the limitations of the device itself. As LMC captures the gestures in images looking upward, some gestures cannot be recognized by LMC.[5,18,19] Repeated failure of recognition makes participants think the device is difficult to use.

The most widely used input devices in computers are keyboards and mice. Hence, most PACSs were designed with the assumption that both a mouse and a keyboard will be used. Unlike the mouse, gesture control devices are used by raising two arms; thus, users are prone to fatigue. Additionally, owing to the recent spread of touch screens, there are gestures commonly used by people for the zooming and panning functions. In this study, controlling the PACS using LMC-GW was subjectively evaluated as challenging. This was interpreted as the users finding it difficult to link gestures to the functions because the PACSs were not developed under the premise of using a gesture control device, and the motions commonly used by people were not included in gesture vocabulary of GW.

Some limitations of the present study are worth noting. The participants showed huge differences in terms of familiarity with the mouse and LMC-GW. Prior to conducting the test, the participants were given time to familiarize themselves with the LMC-GW. However, the time was not enough to handle it as well as the mouse. In addition, it may take more time for older surgeons to familiarize with LMC-GW. Also, the attempt was made to implement the LMC-GW in situations similar to real ones, but there were differences from stressful situations, which are the lack of time and human resources experienced during actual surgery. Lastly, the gesture setting used in this study was limited to gesture vocabulary of GW. The gesture vocabulary and the basic functions needed to control the PACS were assigned as intuitively as possible so that the interface control could be learned relatively easily (Supplementary Material 1). However, it failed to overcome the limitation that only the designated gestures of GW could be used. In the future, the demand cannot be denied for computer control while maintaining the aseptic technique in the medical field. Therefore, given the fact that touchless input devices are needed in the medical field, it will be necessary to organize a touchless input system and the PACS program effectively.

Although participants considered the touchless input device difficult to use as it was not familiar to general users, it provided superior or equal performance to the method of verbal instruction in the environment of ORs. With the consideration of surgical scrub, it was superior for saving time for manipulating PACS. Surgeons agreed that the device was helpful for manipulating PACS in ORs with less risk of contamination and disturbance of workflow. The touchless input device can be an alternative option to direct manipulation of a mouse in ORs in the future.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGEMENTS

We thank Jeehyoung Kim (MD) for providing line drawings of the pelvis and proximal femur (https://blog.naver.com/kjhnav/220797857032).

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SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org. Supplementary material.

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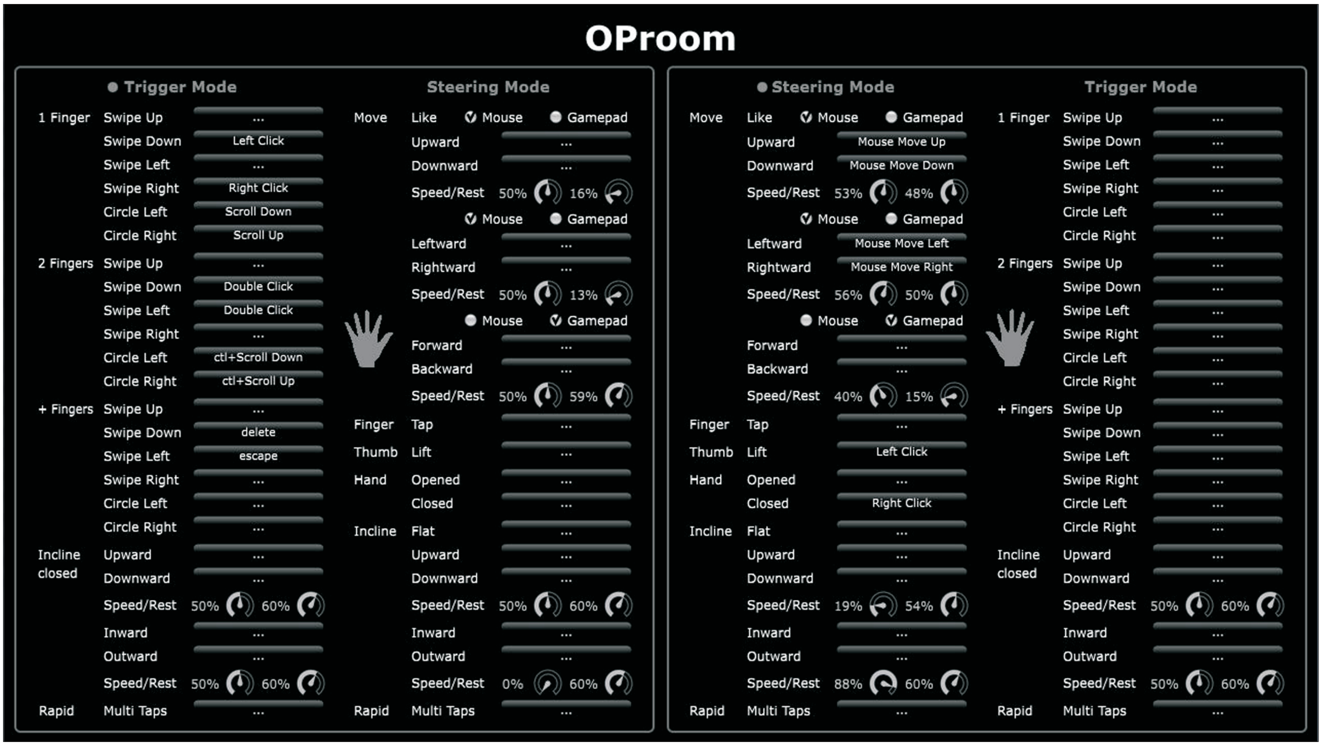

Appendix 1. Recognizable gestures are pre-set in GameWave. The execution behaviors of the mouse and keyboard matching the corresponding gestures can be adjusted in Settings. In this study, the gestures explained in Fig. 2 were matched to the execution behavior as shown.

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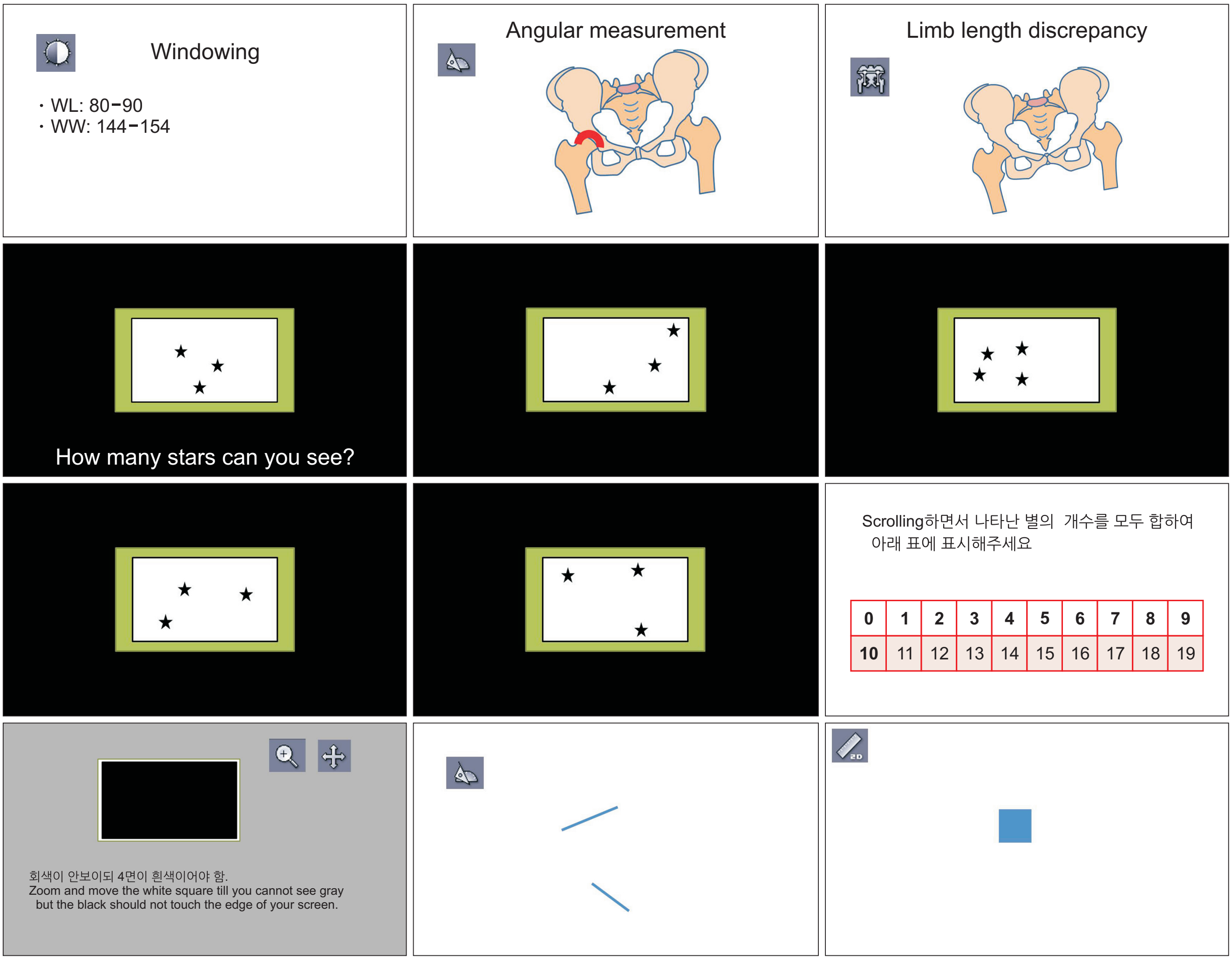

Appendix 2. Each scenario is configured with eight problems (two for distance measurement and angular measurement) to evaluate the following six features: examination selection, zooming and panning, windowing, browsing, distance measurement, and angular measurement. The twelve pictures provided are examples of a single scenario: examination selection, choosing the desired examination (inspection units such as simple radiograph or computed tomography [CT]) and bringing it to the screen with double clicks; zooming & panning, zooming in or out to the desired magnification and moving the picture to the desired position; windowing, adjusting the brightness and contrast as desired; browsing, flipping the images if there are many images in an examination (e.g., CT or magnetic resonance imaging); distance/angular measurement, measuring distance or angle with picking landmarks. Using line drawing to control the true value enables co-working with a third party who does not know the anatomical landmark in the image, as well as determination of the accuracy of the measurement. The time spent performing each function was measured, and the measurement was evaluated together with the measurement error. Using Microsoft PowerPoint, the locations of the geometric figure and the line drawings of the pelvis and femur were moved as much as indicated on the table of random numbers made with Microsoft Excel. Finally, the whole drawing was rotated according to the table of random numbers again, simulating intraoperative positions of patients. Each slide is saved in jpeg format and sent to the picture archiving and communication system (PACS) to offer the same environment when reviewing the patient's images in the operating room.