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REMOTE OPERATION SYSTEM OF ROBOT ARM WITH VISUAL SERVO MECHANISM BY TARGET SELECTION

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Abstract. *This paper proposes a remote operation system of robot arm employing the visual servo control based on template matching technique and forcefree control. The system mainly consists of operational side and working side. The working side has three cameras: one is equipped on the tip of working robot arm, the others are placed near the working robot arm to assist the human operator by capturing the environment. The template image for visual servo control is acquired by dragging a mouse on the image with target object, and then the working robot arm is governed by visual servo control. The size of template image is changed corresponding to the distance between working robot arm and target. The effectiveness of the proposed remote operation system was verified by experiments using actual robot arms.*

Keywords: Visual servo, Remote operation, Template matching, Articulated robot arm, Forcefree control, Target selection

1. **Introduction.** Recently, studies on the remote operation of robot arms have been energetically done with infrastructure construction of network system and development of robotic technologies [1, 2, 3, 4, 5, 6, 7]. Works of maintenance, inspection and repair in various places such as nuclear power station, deep sea, scenes of accidents, and outer space are the typical examples. Moreover, visual servo systems to make measurement plans autonomously, control the motion of robots appropriately and recognize their surroundings have also been extremely studied [8, 9, 10, 11, 12, 13].

Indeed, in [4, 5], the stability and performance of some bilateral remote control systems were analyzed. A design method for a compliance controller for a telerobot system was considered in [6] based on the neurofuzzy model. The effect of interactions among functional factors in performance of a telemanipulation system was also studied in [7]. However, in [4, 5, 6, 7], the visual servo mechanism for robot arms were not introduced. Although, in [11], the performance of an H_∞ filter-based robust visual servoing system was evaluated, the system did not consider the remote operation. Furthermore, a teleoperation system of a robot manipulator using vision-based human-robot interface was constructed in [12]. However, since the vision system was also used as the interface for the operation and heavily affected by the lighting condition, etc., the environment for the operation by human operator is severe and in general, difficult to handle it.

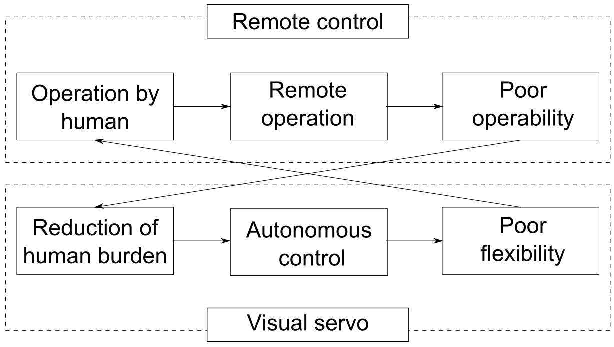

FIGURE 1. Relationship between remote control and visual servo

The relationship between remote operation and visual servo is illustrated in Figure 1. Although, in remote operation, the operator can realize the desired motion of robot arm by his/her manual operation, the operability is, in general, poor due to undesirable effects such as time delay caused by the distance and the traffic on the network. On the other hand, the visual servo technique can realize the autonomous control of robot arms. However, such an autonomous control system does not have the flexibility for the change of human intention. The integration of both techniques has a potential to mutually compensate the drawbacks, and may be able to establish advanced remote operation systems.

From this point of view, the authors developed a teleoperation system of robot arm by combining the remote operation and the visual servo in [8, 9].

To improve the accuracy of behavior of a remote operation system [2] of industrial articulated robot arm by using forcefree control [1], in [8], a teleoperation system of robot arms combined forcefree control with visual servo control was developed. Furthermore, in [9], the teleoperation system proposed in [8] was evaluated through experiments from the viewpoint of human operator perception. The experimental results showed that the success rate depended heavily on the optional assistance concerning the vision system including humans. Furthermore, although, in the vision system, the template matching technique was used to specify the final destination of tip of robot arm, the template image for template matching must be prepared in advance. Therefore, the vision system was affected by the experimental environment.

To cope with this issue related to vision system, in this paper, a remote operation system is developed by adding a function of target selection during experiments to the vision system. The proposed system may be applied to the remote operation of plant systems.

The rest of this paper is organized as follows. Section 2 describes the remote operation system considered in this paper. To verify the effectiveness of the proposed remote operation system, experimental results are shown in Section 3. Section 4 discusses the remote operation system and experimental results. Then, the effectiveness and efficiency of the proposed system are confirmed through discussion. The success rates of the current work and existing one are compared to verify the advantage of this paper. In Section 5, this paper is summarized.

2. **Remote Operation System.** The overview of the remote operation system in this paper is illustrated in Figure 2. The proposed remote operation system is broadly divided into two sides, operational side and working side. Rough motion of working robot arm is realized by remote operation, and accurate motion of working robot arm is realized by visual servo. The image (Image 1) obtained from USB camera equipped on the tip of working robot arm is displayed on both image processing PC and monitoring PC 1

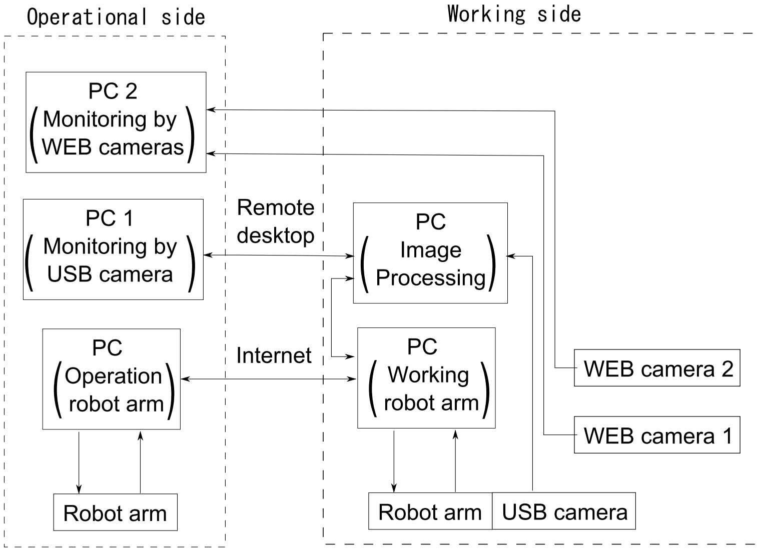

FIGURE 2. Remote operation system

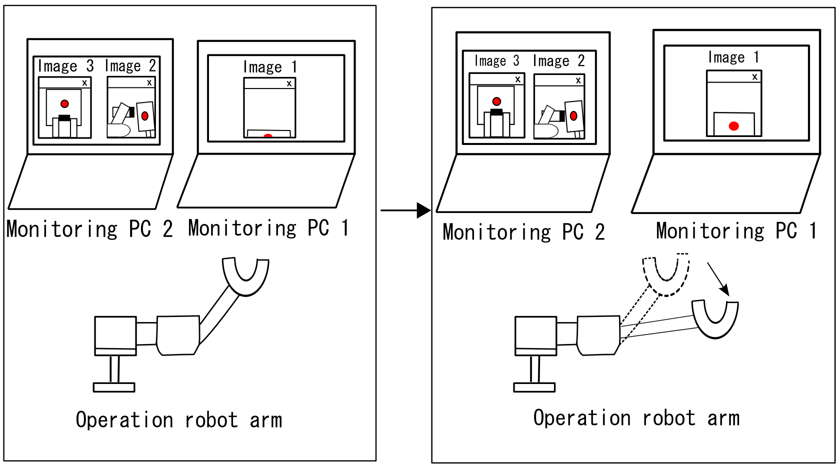

FIGURE 3. Remote operation

connected to image processing PC through remote desktop. Two web cameras (WEB camera 1 and WEB camera 2) are used to assist the view of USB camera and to monitor the circumstance around the working robot arm. Thus, watching three images from USB camera and two WEB cameras and operating the operation robot arm, the operator conducts the remote operation of working robot arm.

2.1. **Remote operation.** In order for the operation robot arm to move freely according to the external force by the operator, the forcefree control [1] is applied. The forcefree control is a control methodology to compensate the gravity and friction acting on an articulated robot arm and realize its passive motion according to the external force.

As shown in Figure 3, confirming the position of a target object via two images, Image 2 of WEB camera 1 and Image 3 of WEB camera 2 visually, the operator operates the operation robot arm manually.

Figure 4 is the flowchart of remote operation. First, the tip position of the working robot arm is transmitted to the PC in operational side. Secondly, the manipulated variable generated by the operation of operation robot arm is transmitted to the PC in working side through network. In working side, the angle command for working robot arm is generated

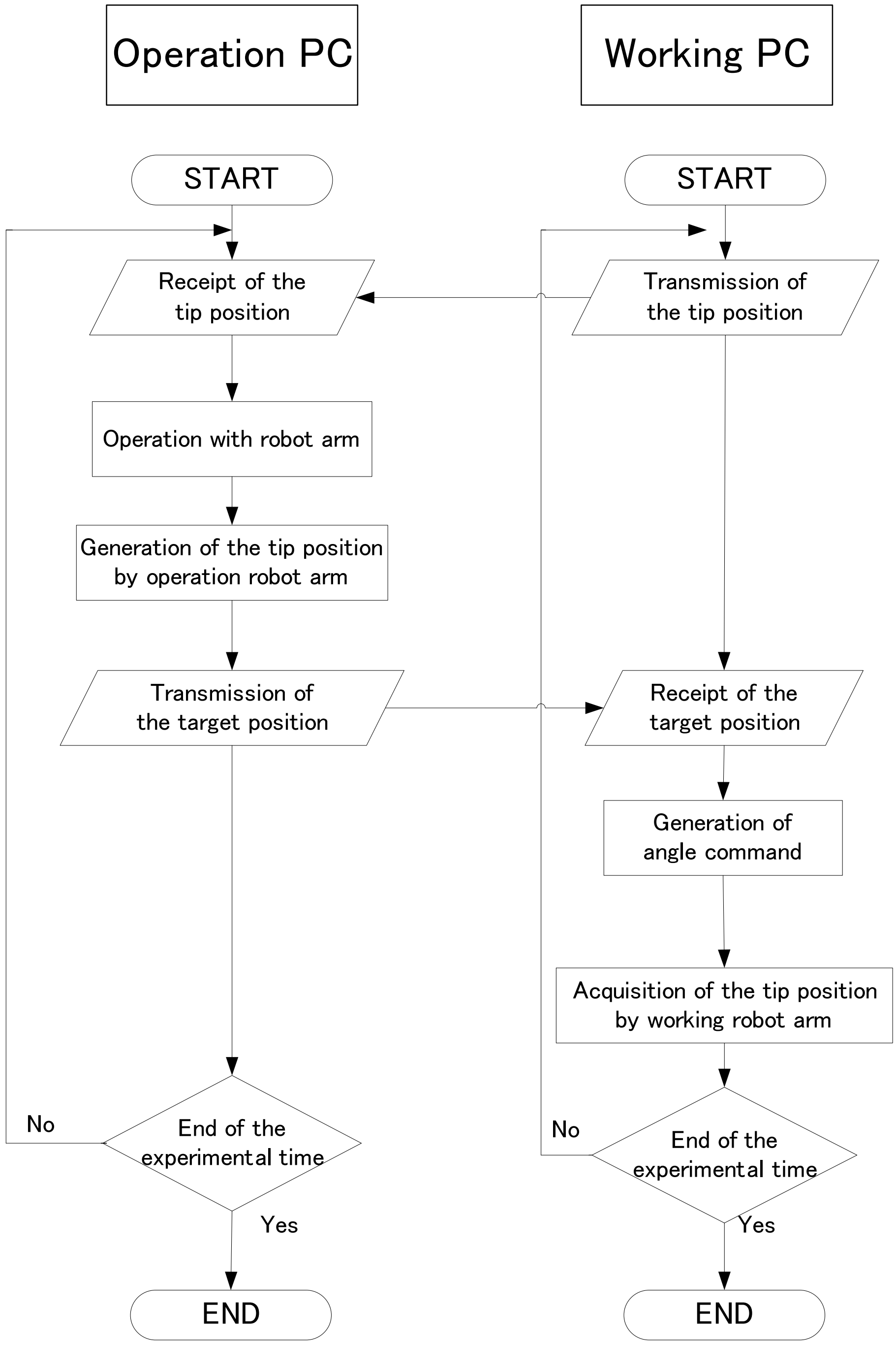

FIGURE 4. Flowchart of remote operation

by applying the inverse kinematics to the target position received from operational side. This operation is carried out until the USB camera captures the target object in its image (Image 1).

2.2. **Visual servo with target selection.** The flowchart of visual servo in this paper is shown in Figure 5. After capturing the whole target object within Image 1, the operator assigns the range of target object on the window by dragging the mouse as in Figure 6, and generates the object image corresponding to the selected range. Then, the motion is changed from remote operation to visual servo.

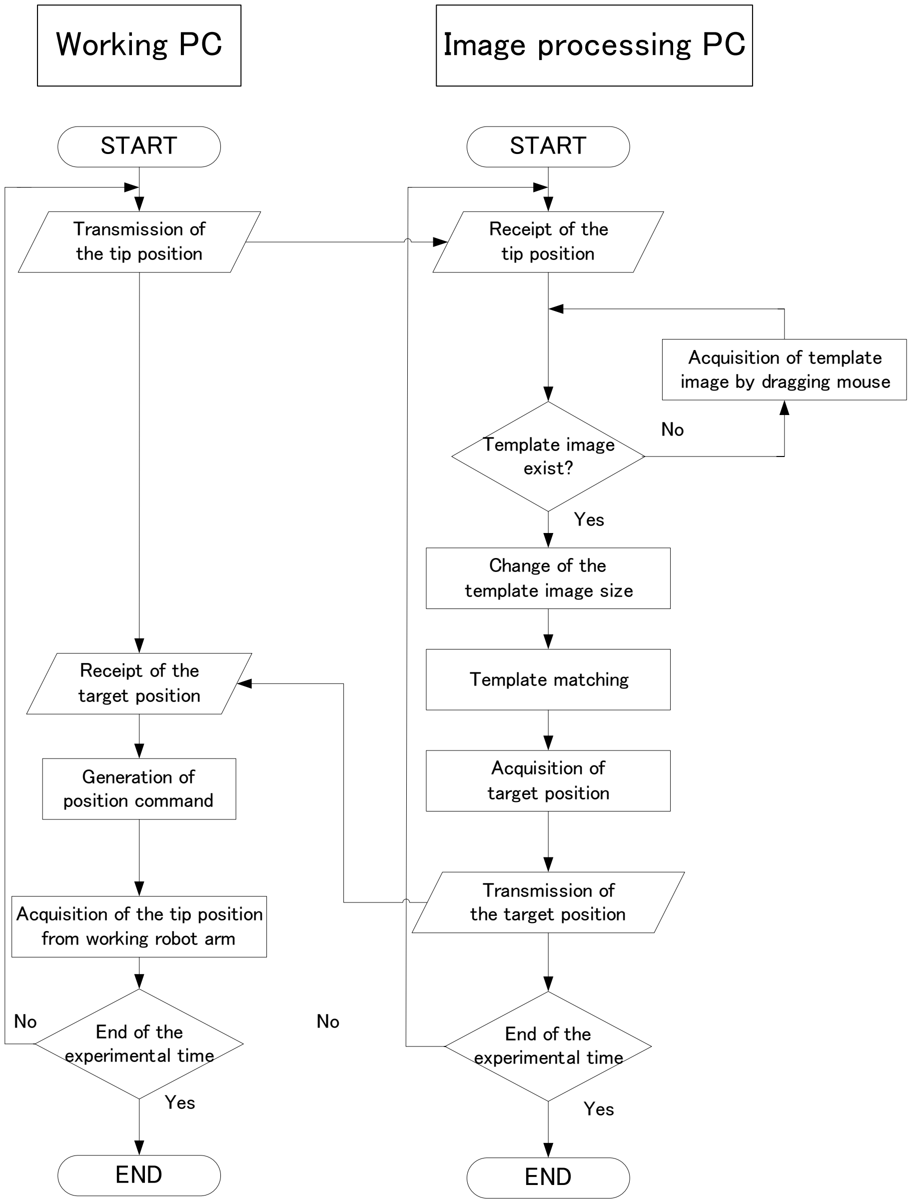

FIGURE 5. Flowchart of visual servo

The template matching technique [10] is utilized to specify the position of target object, where the object image generated in dragging the mouse is adopted as the initial template image. The position information is transmitted to working side via network communication. Based on the position information, working robot arm moves, and the position information of the working robot arm is also transmitted to the image processing PC. Since the USB camera is equipped on the tip of working robot arm, the object image becomes larger as the USB camera (i.e., the tip of robot arm) approaches the target object. Then, the size of the target object in Image 1 is different from that of the template image. For this issue, in this paper, the size of the template image is resized according to the distance between USB camera and target object.

3. **Experiment Using Actual Robot Arms.** In order to verify the effectiveness of the proposed remote operation system, experiments of remote operation were conducted by using the forcefree control and visual servo.

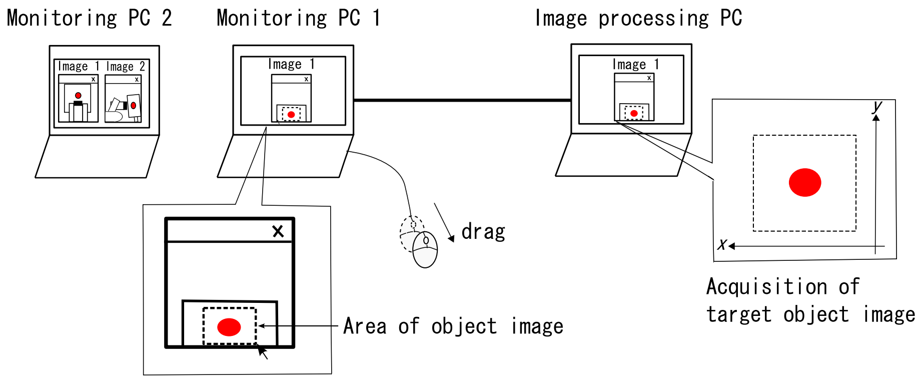

FIGURE 6. Generation of object image by dragging mouse

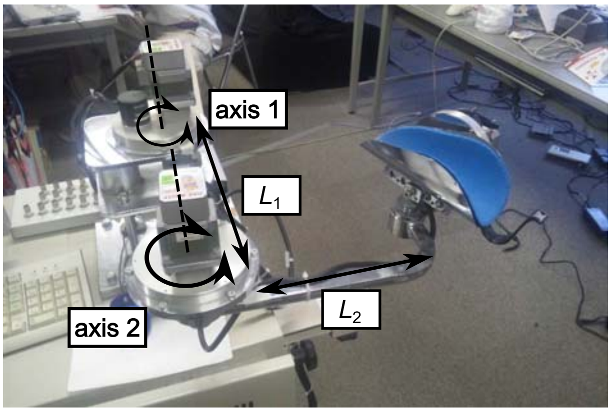

FIGURE 7. Operation robot arm

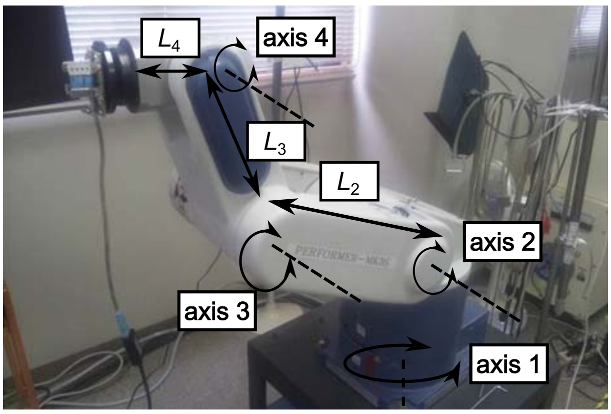

FIGURE 8. Working robot arm

The operational robot arm and working robot arm used in the remote operation system are shown in Figure 7 and Figure 8, respectively. The operational robot arm is a horizontal articulated one with 2 degrees of freedom. The working robot arm is a vertical articulated one with 5 degrees of freedom, where, in this paper, 4 axes are used. The movement of the axes 1 and 2 of the operational robot arm corresponds to that of the axes 2 and 3 of the working robot arm, respectively. The experimental environment is illustrated in Figure 9.

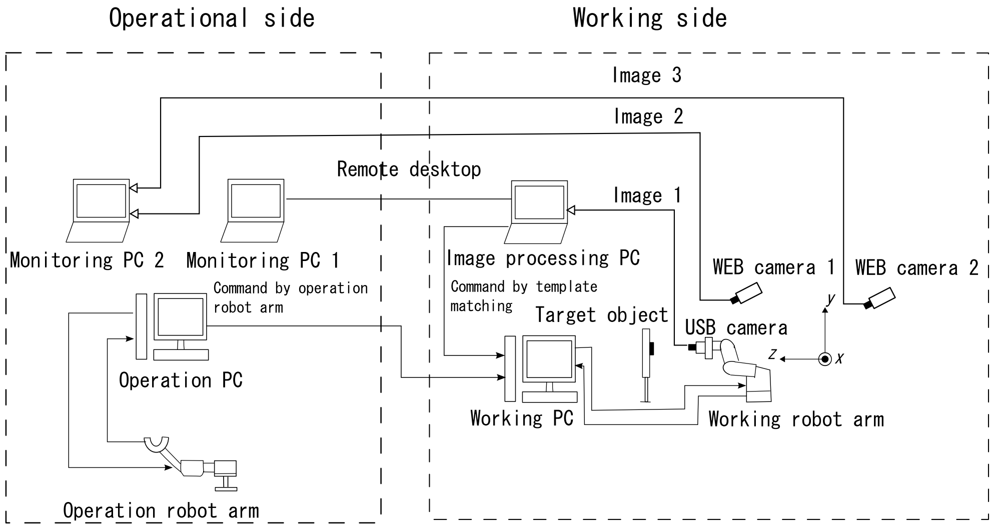

FIGURE 9. Remote operation system

3.1. **Experimental conditions.** Experimental time was 11 [s]. The sampling intervals for the control of working robot arm and operational robot arm were 4 [ms] and 50 [ms], respectively, and the sampling interval for the image processing of USB camera was 200 [ms]. The initial tip position of robot arm was $(x, y, z) = (0, 0.3, 0.3)$ [m]. The width and height of the input image from USB camera were $W = 320$ [pxl] and $H = 240$ [pxl], respectively. The distance between the tip of working robot arm and the target object was given by $p_z = 0.375$ [m] as the initial distance for visual servo. As the target object, a red-colored button with diameter 0.02 [m] on white board was used. After switching the motion from forcefree control to visual servo, the working robot arm is controlled for the tip of working robot arm to approach (or press) the button by the position control for z-direction.

3.2. **Experimental results.** Figures 10-12 show the experimental results, where the trajectories of the tip of working robot arm for x-direction, y-direction and z-direction are depicted in Figures 10-12, respectively. The solid line is the behavior of tip of working robot arm, and the broken and dash-dotted lines are the control commands from operational and image processing sides, respectively. The experimental results indicate that the tip of working robot arm successfully reached the final destination after generating the image of target object at 8.08 [s] by dragging the mouse and then switching to the visual servo. Figure 13 depicts the images obtained from USB camera (upper), WEB camera 1 (middle) and WEB camera 2 (lower) from 0 [s] (a) to 11 [s] (l), where, in (i)-(l), the white box shows the location of the button detected by template matching. In Figure 13, the remote operation was performed from (b) to (h), and the visual servo was done from (i) to (l). Although the USB camera did not capture the target object at 0 [s] (a), the target object was included in the image at 7 [s] by the suitable remote operation. Furthermore, after obtaining the template image by dragging the mouse, the visual servo successfully achieved the autonomous control for the tip of working robot arm to reach the destination. As the tip of working robot arm approached the target object, the size of target object in the image from USB camera was larger. However, the robot arm was appropriately controlled by the template matching with the enlargement of the template image corresponding to the distance between the USB camera and the target object. Furthermore, to verify the effectiveness from the viewpoint of the repeatability, 25 experiments were done. The success rate was $(21/25) \times 100 = 84$ [%].

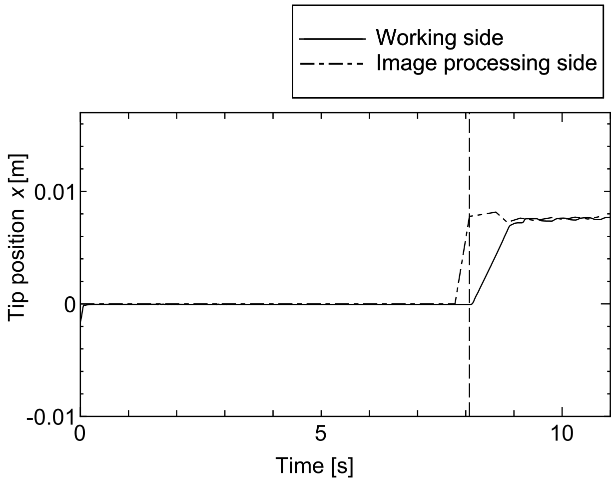

FIGURE 10. Tip position x

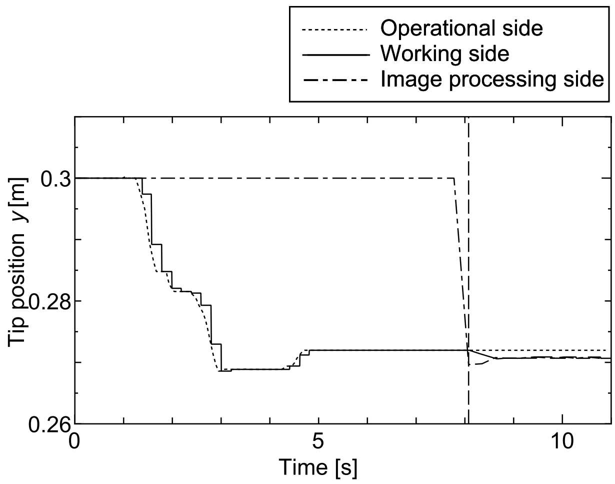

FIGURE 11. Tip position y

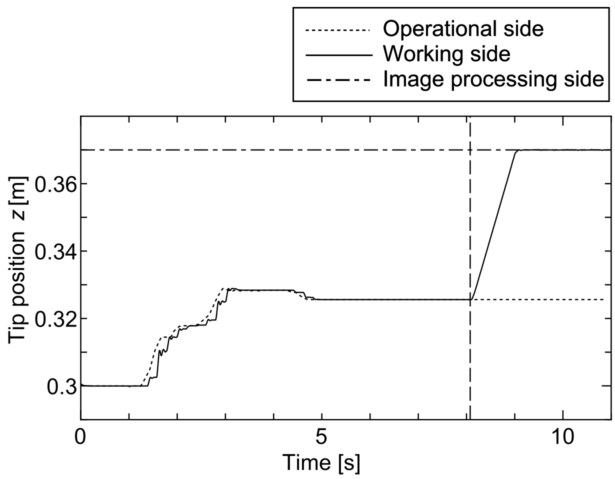

FIGURE 12. Tip position z

4. **Discussion.** In the remote operation before switching to the visual servo, the working robot arm was moved until the USB camera captured the whole shape of the button as

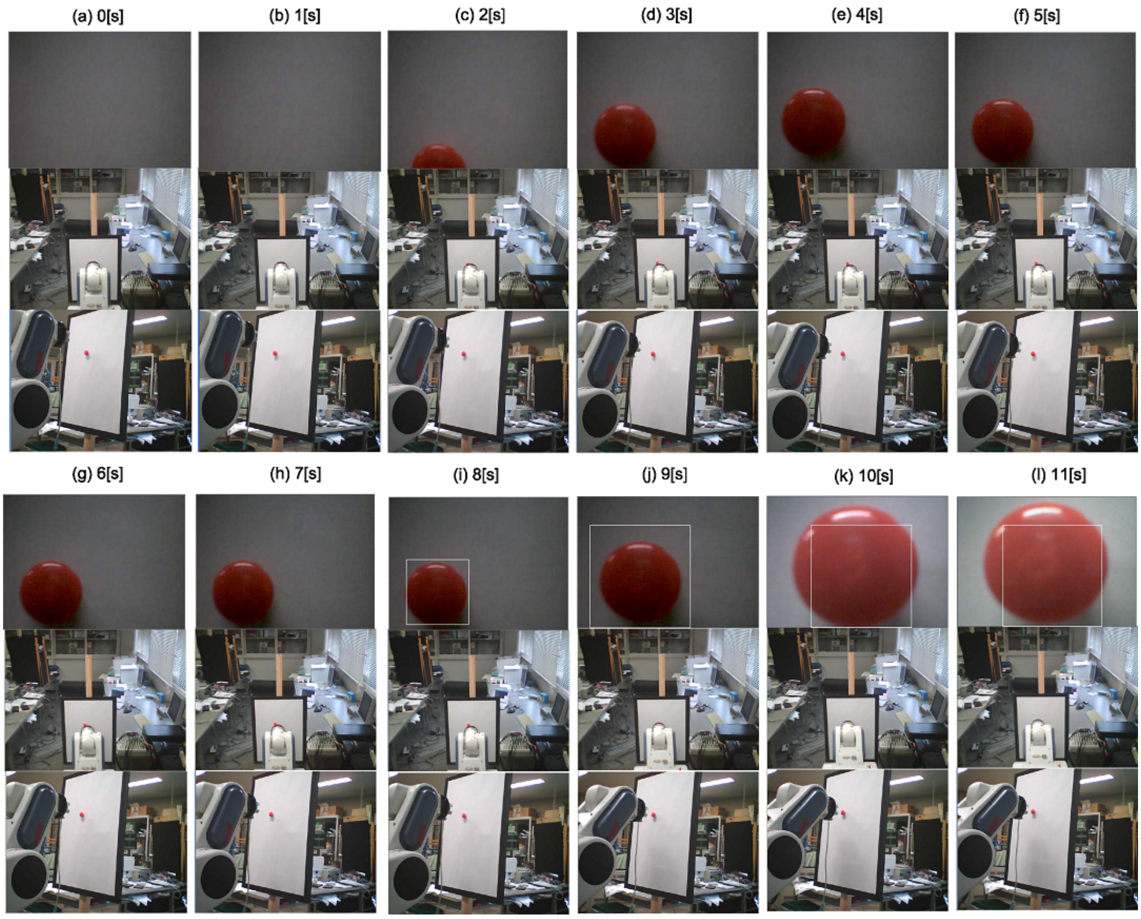

FIGURE 13. Images from USB camera and two WEB cameras

the target object based on images from two web cameras. Then, by maintaining the position for the USB camera to capture the target object in the center of the image, the autonomous behavior was realized. By generating the template image via the mouse drag, the flexible adaptation for the environment of image acquisition is achieved. The use of multiple web cameras is suitable for the verification of the circumstance in working side even if it is difficult to guarantee the view from an only USB camera necessary to the remote operation. Since the success rate of experiments by the remote operation system in [9] under the same condition except the function of target selection was 73.1 [%], the success rate was improved. This is an important innovation.

5. **Conclusions.** In this paper, a system to acquire the target image during operation for the remote operation of robot arm with forcefree control and visual servo was proposed. By introducing the function of target selection for vision system during experiment, the system considering the environment factors during experiment such as lighting condition was established. This is the significant and novel contribution of this paper. The effectiveness of the proposed remote operation system was confirmed through experiments using actual robot arms. The experimental results revealed that the success rate of the remote operation was improved compared with that of the remote operation in [9] without any optional assistance. The repeated use of the target selection via mouse drag has a potential to realize more flexible motion for the multiple decisions by human operator's intention.

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