Automated Image Presentation for Backhoe Embankment Construction in Unmanned Construction Site

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***Abstract*— Automated and intelligent construction machines are very important in for unmanned disaster response. One of the tasks involved in this is embankment construction. Usually, this conducted by teleoperation of a backhoe construction machine by one operator. Meanwhile, another operator controls an external camera which presents a visualization of the machine and the construction environment to the construction machine operator. In this paper, we propose a method for automatic control of the external camera based on the requirement specifications of the construction machine operator for unmanned embankment construction. This method consists of two parts: first, in order to present the desired visualization to the construction machine operator, the requirement specifications are extracted through video analysis at actual unmanned construction sites, and through interviews with construction machine operator. Next, an automatic external camera control method based on these requirement specifications is developed. In order to evaluate the effectiveness of the proposed method, it is necessary to compare the satisfaction/dissatisfaction of the videos from the backhoe operator's point of view. Therefore, we conducted a comparative experiment with camera control that satisfied and did not satisfy the requirement specifications. The superiority of the proposed method is shown by questionnaire evaluation using the proposed method.**

I. INTRODUCTION

Japan is located in a crustal deformation zone, where several earthquakes and volcanic eruptions occur. In addition, the vast forest lands cover approximately 70% of the country, which has resulted in several rapid rivers and a large amount of precipitation. Therefore, natural disasters such as lava and debris flow, landslides, and river flooding, among others, due to eruption, earthquakes, and heavy rain, respectively, occur in various places. When such natural disasters occur, it is necessary to promptly conduct surveys and restoration activities to prevent further damage. However, there are disaster site where people cannot enter owing to the risk of secondary damage. Unmanned construction has been effective and used in such sites [3]. Unmanned construction is a technology used in construction, where a remote-controlled unmanned construction machine is operated from a remote place with no risk of secondary damage.

Roller compacted concrete (RCC) method is one of the methods used for unmanned construction. In this method, first, the concrete is poured in the formwork (made of soil)

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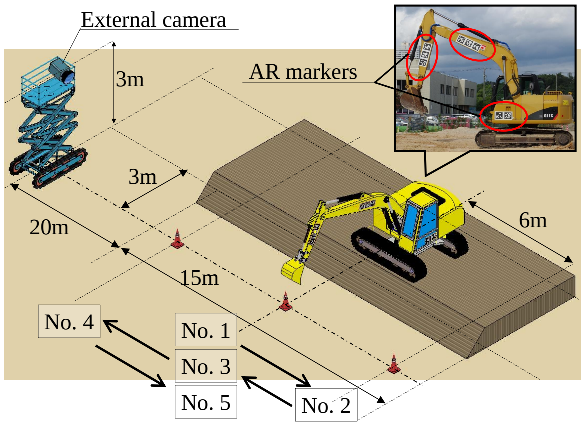
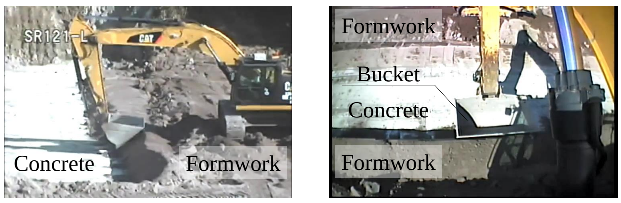


Fig. 1. Construction of embankment



(a) Sight of external camera (b) Sight of vehicle-mounted camera

Fig. 2. Presentation of camera images to the construction machine operator

and compacted with a vibrating roller for dam construction. Therefore, in formwork molding, embankment construction by backhoe is necessary as show in Fig. 1. This machine is operated based on cameras mounted on vehicles and external cameras as show in Fig. 2. This construction is operated by two people: a construction machine operator to operate the construction machine and camera operator to operate an external camera installed outside the construction machine. In Japan, where human resources are scarce owing to declining birthrate and aging population, automated construction and intelligent construction machine are requirement for unmanned construction. The automation of image presentation by the camera operator is also effective in this case. Therefore, this paper focuses on the automation of image presentation for embankment construction in unmanned construction sites.

Several methods have been proposed for image presentation of construction machines [5, 11, 18]. In addition to construction machines, methods have also been proposed on image presentation for teleoperated robots [1, 2, 9, 13, 15, 17]. Kamezaki et al. [10] proposed a method to automatically select and present suitable views from multiple external cameras. In this method, based on the state of construction machine, the images taken from multiple cameras that were the easiest to comprehend were considered by the remote-control operator. However, this method has not been employed in the real environment because the shape and position of the object to be presented must be known. Therefore, this method has been used in simulations. Fujiwara et al. [6] proposed a system to present the construction lines to the remote-control operator in a sand formwork formation for unmanned construction. In this method, ink was applied to the construction points and the construction line was displayed at these positions to create the formwork. However, this method requirement a dedicated construction machine for preparation. Iwataki et al. [8, 14] proposed a system to create the bird's-eye view for construction machines. In this method, multiple fisheye cameras were installed on a construction machine and a bird's-eye view image was created by combining those images. However, this method could not recognize the unevenness of the ground and produced large errors in the depth direction in drilling operations. Tang et al. [16] proposed a tele-operation construction robot control system using the virtual reality space. In this method, a virtual reality space was created based on the images acquired from the actual construction site and presented to the operator. However, because this method assumes the site to be flat, it cannot cope with uneven construction sites. In addition, the parameters used for camera control are not described. In addition, there lies the problem that remote control can not properly present view desired by the construction machine operator [12]. Furthermore, in remote control, it is desired that the visual interface reduces the load on the operator [4].

As mentioned above, although there are studies on the image presentation of construction machines, automatic image presentation for embankment construction in actual unmanned construction site has not been explored. In addition, the actual unmanned construction site operation requires image presentation based on the construction machinery operator's requirements.

Therefore, the remainder of this paper is organized as follows. Section II describes the requirement specifications for image presentation. Section III introduces a camera control method based on these requirement specifications. Section IV verifies the proposed method in an outdoor environment. The effectiveness of the proposed method is evaluated by a questionnaire in Section IV. Finally, Section VI discusses conclusions and future works of this paper.

II. METHODOLOGY

We proposed automatic external camera control methods based on the requirement specifications of the remote-control operator at the actual unmanned construction site: a proposed method that focuses on three points (crawlers, buckets, and arm joints) of the construction machine. As a precondition, the layout of the external camera is the same as that of the actual unmanned construction site, as shown in Fig. 1. Fig. 1 also shows that backhoe recognition uses ArUco markers. ArUco is a marker detection tool that robust to change of lighting conditions and occlusion by using a local adaptive thresholding approach and multiple markers [7]. This enables automatic recognition of the body, crawler, arm joint, arm, and bucket.

A. Extract Requirement Specifications

In order to extract the requirement specifications, it is necessary to analyze the images presented to the construction machine operator at the actual unmanned construction site. Also, it is necessary to clarify the requirements through interviews. Therefore, we recorded, analyzed the work, and interviewed construction machine operators at the unmanned construction site at Mt. Unzen. There are several types of backhoe works for embankment. And the construction machine operator's attention point is different for each work. Therefore, in this study, the works of the backhoe that perform embankment were classified into "Compression / Shaping", "Moving", and "Turning". "Compression / shaping" is the work of compacting and shaping the embankment by hitting with the bucket by rotating the tracks. "Moving" is simply the work to move the backhoe by rotating the crawler. "Turning" is the work to turn the backhoe body. In all these works, the construction machine operator's attention point were measured with an eye tracker. The eye tracker can record the attention point of the construction machine operator during work by measuring the movement of the left and right pupils. As a result, "Moving" work resulted in gazing at the crawlers to move the backhoe parallel to the earthwork. In work other, buckets was gazed at, many times. In addition, "turning" resulted in gazing only at the vehicle-mounted camera images. Therefore, this study analyzed the presented positions of crawlers and buckets for the "Compression / shaping" and "Moving" tasks. As a result, a visualization was presented at the position shown in Fig. 3, and the following requirement specifications were extracted.

- The crawler track on the embankment side is displayed in the center right or left of the screen
- The bucket is presented near the center of the screen
- The joint of the arm is presented in the screen

B. Camera Automatic Control

The proposed method generates a rectangle that passes through the three points when it recognizes the arm joints, buckets, and bodies as shown in Fig. 3. The variables pn and Pn are the maximum and minimum values of the horizontal display range on the right and left sides, respectively. The variables t and T are the maximum and minimum values of the vertical display range of the bottom side. In addition, z and Z denote the maximum and minimum values of the vertical display range of the height of the rectangle and (w, h) denotes the resolution of the image. If a rectangle can be generated, then the pan is controlled so that the left side u_r satisfies Eq. (1).

$$p_1 w < u_r < P_1 w \tag{1}$$

If a rectangle left side ul is satisfied, then the zoom is controlled so that the left side u_l satisfies Eq. (2).

$$p_2 w < u_l < P_2 w \tag{2}$$

If the rectangle right side ur is satisfied, finally, the tilt is controlled so that the bottom side v_b satisfies Eq. (3).

$$th < v_b < Th \tag{3}$$

If the rectangle generation and Eqs. (1) to (3) are satisfied, it is determined that the image visualization satisfies the requirement specifications, and the camera is fixed at that position. Based on the requirement specifications of the remote control operator, the values listed in Table I are used in this research.

III. EXPERIMENT

We conducted experiments in an outdoor environment for the purpose of evaluating the effectiveness of our automatic camera control method based on the requirement specifications. It is necessary to compare the visualisation images that satisfied and did not satisfy the requirement specifications in order to evaluate the effectiveness of our propose approach. Therefore, we performed experiments on the camera control that satisfied and did not satisfy the requirement specifications, as shown in Table II. We recorded the external camera automatic control of three patterns used in the experiments for comparative evaluation. The recorded visualisation images were presented to the operator and were evaluated by means of a questionnaire.

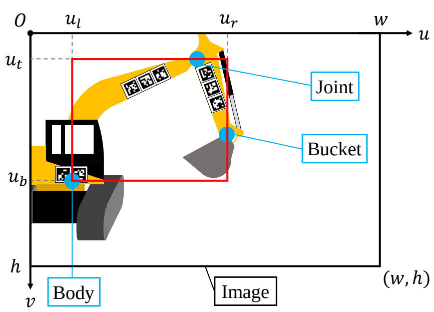


Fig. 3. Backhoe presentation position in proposed method

TABLE I
PARAMETERS OF PROPOSED METHOD

Parameter	Value	Parameter	Value
p_1	0.40	P_1	0.75
p_2	0.00	P_2	0.25
t	0.00	T	0.80

TABLE II
CORRESPONDENCE TABLE BETWEEN REQUIREMENT AND METHODS

Method	Requirement		
	Crawler	Bucket	Joint
Proposed method	○	○	○
Bucket Center Method	×	○	○
Gravity Method	×	×	○

A. Experimental Method

The backhoe must perform the same motion in the experiments of each proposed method for comparative evaluation. Therefore, the experiment set up the backhoe assuming embankment construction in actual unmanned construction site. In addition, as shown in the Fig. 1, the external camera, backhoe, and embankment were arranged to have the same positional relationship as the actual unmanned construction site. The vehicle-mounted camera images were also presented to the operator in the actual unmanned construction site. External camera images were used for "Compression/Forming" and "Moving" in actual embankment work. It took a lot of time to construct all the embankments in the experiment. Therefore, in the experiment, the tasks of "Compression / Forming" and "Moving" were set assuming actual embankment work. In the "Compression / Forming" task, the embankment is hit with a bucket. The task in the "Compression / Forming" was to hit the slope twice followed by hitting the top part twice with a bucket. Next, it is necessary to move the backhoe to confirm that camera control is possible when the backhoe is moved. At the actual unmanned construction site, the backhoe moved parallel to the embankment. Based on the position of the external camera, the movement from the front to the back reduced the backhoe in the image, whereas, the movement from the back to the front enlarged the backhoe. Therefore, to confirm whether the proposed method is effective for movement in two directions, we performed the tasks of the "Move". In the "Moving" task, the backhoe moves from No.1 to No. 5. These tasks of the "Compression / Forming" and "Moving" were alternately performed in a series of flow from No. 1 to No. 5 as show in Fig. 1. The purpose of this experiment is to compare the visibility of the images acquired by external camera automatic control, and the evaluation is a questionnaire. Therefore, in the experiment, it is important to faithfully reproduce the backhoe motion. To achieve this, boarding operation experiments were conducted.

B. Bucket Center Method

In the bucket center method, the bucket is presented near the center of the screen as shown in Fig. 4. The arm joints and crawlers are always presented on the screen. However, the position of the crawler in the requirement specifications is not considered. The magnification is controlled based on the size of the backhoe on the screen, which is calculated considering the ratio between the diagonal distance of the screen and distance from the arm joint to the bucket. In

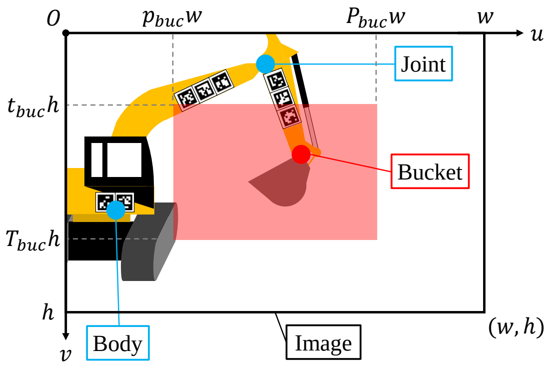


Fig. 4. Backhoe presentation position in bucket center method

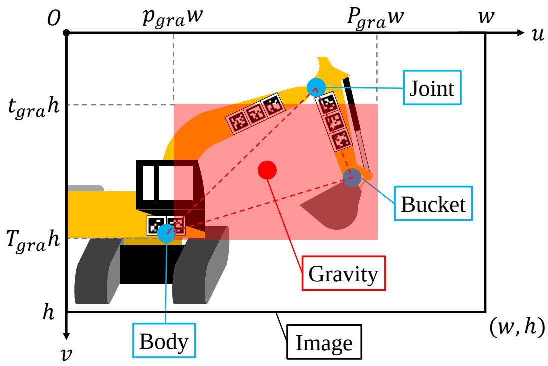


Fig. 5. Backhoe presentation position in gravity method

TABLE III
PARAMETERS OF BUCKET CENTER METHOD

Parameter	Value	Parameter	Value
p_{buc}	0.25	P_{buc}	0.75
t_{buc}	0.25	T_{buc}	0.75
z_{buc}	0.12	Z_{buc}	0.25

TABLE IV
PARAMETERS OF GRAVITY METHOD

Parameter	Value	Parameter	Value
p_{gra}	0.25	P_{gra}	0.75
t_{gra}	0.25	T_{gra}	0.75
z_{gra}	0.12	Z_{gra}	0.25

the external camera control, the coordinates of the bucket (x_{buc}, x_{buc}) and the distance from the arm joint to the bucket l are given by Eq. (4). In addition, based on the requirement specifications, the values listed in Table III are used in this research.

$$\begin{cases} p_{buc}w < u_{buc} < P_{buc}w \\ p_{buc}h < v_{buc} < T_{buc}h \\ z_{buc}\sqrt{w^2+h^2} < l < Z_{buc}\sqrt{w^2+h^2} \end{cases} \tag{4}$$

The bucket center method first recognizes the bucket. If the bucket is recognized, the bucket position is determined to check if it satisfies Eq. (4). Otherwise, the control is panned and tilted to move the bucket center near the display center. If the bucket satisfies Eq. (4), then the arm joints are recognized. If the arm joint cannot be recognized, the bucket is moved to the center of the display and the arm joint is searched. At this time, the body cannot be recognized if it is zoomed in. Therefore, it is determined whether the zoom magnification satisfies the equation. If zoom magnification satisfies Eq. (4), it is determined whether the body satisfies the equation. If the zoom magnification satisfies Eq. (4), it recognizes the body. And when all conditions satisfy Eq. (4), the camera is kept in the determined position.

C. Gravity Method

In the gravity method, the entire backhoe is presented near the center of display. The camera is controlled such that the gravity is presented near the center of display, as shown in Fig. 5. In this method, the bucket, arm joint, and body must be presented and the crawler and bucket presentation positions are not considered. Zoom magnification is controlled based on the size of the backhoe on the screen, similar to the bucket center method. In external camera control, the coordinates of the gravity and distance from the arm joint to the bucket are given by Eq. (5). In addition, based on the requirement specifications, the values listed in Table IV are used in this research.

$$\begin{cases} p_{gra}w < u_{gra} < P_{gra}w \\ p_{gra}h < v_{gra} < T_{gra}h \\ z_{gra}\sqrt{w^2+h^2} < l < Z_{gra}\sqrt{w^2+h^2} \end{cases} \tag{5}$$

The gravity method first recognizes the bucket. Bucket recognition is followed by recognizing the arm joint. Next, the zoom magnification is checked to determine if it satisfies the equation and then the body is recognized. When all three points are recognized, their gravitys are calculated to determine if the equation is satisfied. When all conditions satisfy Eq. (5), the camera is kept in the evaluated position.

IV. EVALUATION

A. Evaluation Method

A questionnaire based on the visibilit'y was conducted for the two operators to compare the recorded images. In the questionnaire, "Compression / Forming" in each situation was evaluated for visibility on a scale of 1 to 10. Similarly, "Compression / Forming" and "Moving" in the whole situation was also evaluated on a scale of 1 to 10. The subjects needed to have experience at actual unmanned construction sites. However, experienced unmanned construction operators are rare and it was difficult to get many subjects. Therefore, this evaluation was conducted using a questionnaire with two skilled unmanned construction experience.

Because one image acquired in the experiment was approximately 6 min long, if it was shown one by one, the memory load on the subject would be large and appropriate evaluation would be difficult. However, as the images of the

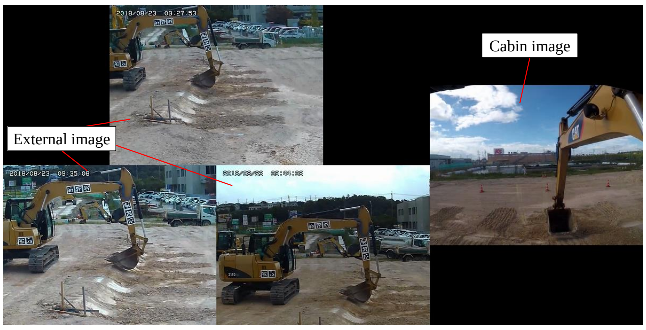


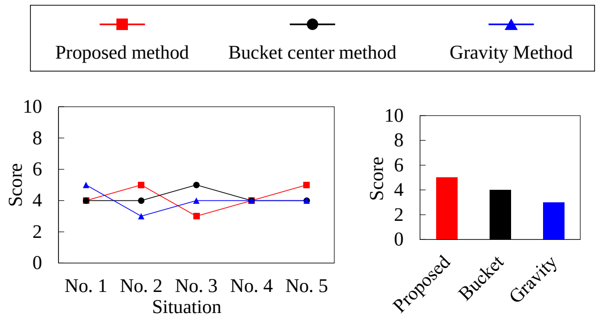
Fig. 6. Images presented in the questionnaire

three types of automatic controls were recorded separately, if they were presented simultaneously, the motion in each image would be different and appropriate evaluation would be difficult. Therefore, we synchronized the external camera image based on the vehicle-mounted camera images. We accelerated and decelerated three types of automatic control images for synchronized rising and lowering of the bucket and starting and stopping the movement of the crawler. In the process of the questionnaire, the vehicle-mounted camera image was presented on the right and three anonymous external camera images were shown on the left. The arrangement of the vehicle-mounted camera image on the right side and the external camera image on the left side was the same as the actual unmanned construction site. In addition, three external camera images were switched according to the subjects to prevent bias due to placement.

B. Evaluation Results

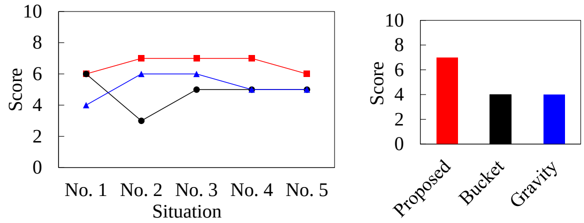
The questionnaire evaluated the visibility of the images for "Compression / Forming" in each situation shown in Fig. 1 to analyze each automatic control method. In addition, the overall visibility of the image was also evaluated. The evaluation results of subjects A and B are shown in Fig. 7 and 8, respectively. Each step evaluation in subject A was rated higher at least once in the propsed method, bucket center method, and gravity method. For the overall evaluation, the propsed method was scored the highest. In each step evaluation in subject B, the propsed method received high evaluation in all steps. In the case of subject A, the propsed method was scored the highest in the overall evaluation. According to the interview results of the questionnaire, the propsed method was more responsive than other methods for the movement of the backhoe. Considering the results of this interview, we determined that the propsed method has more constraints than other methods. From above results, it was shown that the propsed method has the best visibility.

It can be seen that Scene No. 3 received low evaluation from Subject A. It is considered that this was due to the fact the embankment on the front side of the backhoe was not presented. However, overall, it can be seen that the proposed method achieved a high evaluation score due to the high responsiveness of the camera operation. Compared to other



(a) Situation (b) Total

Fig. 7. Evaluation from subject A



(a) Situation (b) Total

Fig. 8. Evaluation from subject B

methods, the proposed method is based on the required specifications. Therefore, the responsiveness of camera operation highly corresponds to the motion of the backhoe. It can be seen that there were differences in the evaluation of the operators in some situations. However, the superiority of the proposed method, overall, can be seen in many situations.

V. CONCLUSION

In this paper, external camera automatic control methods were proposed based on the requirement specifications at the unmanned construction site. In addition, we compared the experiments with construction machinery using the proposed method. The proposed method that controls the camera based on a rectangle connecting the bucket, arm joint, and the body is determined to be superior, considering visibility. In future, we will evaluate the effectiveness of the proposed method by increasing the number of subjects. We will also quantitatively evaluate the effectiveness of the proposed method by conducting comparative experiments with camera operators.

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