Research and Development of Construction Technology in Social Cooperation Program "Intelligent Construction System"

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Abstract -

This paper presents the developments achieved via the Social Cooperation Program "Intelligent Construction System," from three primary perspectives: environmental measurements, improvements in remote operability, and improvements in efficiency and automation of remote operation. For improvements in remote operation, environmental measurements of the disaster sites are critical. Therefore, a method to integrate the data from drones and ground-based vehicles in order to generate 3D maps was proposed. Another method for estimating the changes in soil volumes through a 3D map based on drone data was also proposed. Finally, to estimate the trafficability in disaster sites, a cone index-based method employing spectral images was proposed. Improving remote operability is essential to facilitate improved working conditions for operators. Considering this, a method providing human operators with a bird's-eye view of remotely operated machinery from any perspective was proposed. Additionally, to avoid the tumbling of remotely operated machinery, a running stability presentation method was proposed; this method presented the human operator with a tumble risk index. For improving efficiency and automation, an automatic camera control method, based on requirements of construction machine operators, was proposed. Using this method, the need for a dedicated human camera operator could be bypassed. Furthermore, for the automatic measurement of construction time and content, a method based on deep learning and using cameras for recognizing the actions of construction machinery was proposed. Preliminary experiments on some of the proposed methods in real environments yielded promising results.

Keywords -

Intelligent construction system; Environmental measurement; Improving remote operability; Automation; Efficiency improvement

1 Introduction

Japan experiences several earthquakes and volcanic eruptions as it is located on a crustal deformation zone. Moreover, the country also experiences heavy rainfall due to its dense forests (accounting for approximately 70% of the country's area). Such environmental conditions result in several natural disasters such as lava and debris flows due to volcanic eruptions, landslides caused by earthquakes, and flooding of rivers due to heavy rainfall. In the event of such natural disasters, it is necessary to promptly conduct appropriate investigations and restoration activities in order to prevent any further damage. However, disaster sites, i.e., the areas affected by these natural disasters, present a certain amount of risk due to secondary disasters. Disaster recovery efforts should be implemented soon after a disaster. Thus, considering the potential risk of secondary collapses or disasters, remotely controlled robots and remote-operated construction machinery are employed, which allows the human operators to work from a safe distance. However, such methods are associated with low work efficiencies, and they also prolong the time required for disaster recovery efforts. Therefore, a more efficient and intelligent construction system is necessary. For this purpose, a Social Cooperation Program "Intelligent Construction System" was organized by The University of Tokyo and Fujita Co., Ltd, in October 2017. The goal of this program was to research, develop, and establish an intelligent construction system for the inspection of infrastructures as well as for repair and disaster recovery efforts. This program focuses on utilizing intelligent construction technology achieved via advanced equipment, such as unmanned ground vehicles (UGVs) (including remote controlled robots and unmanned construction machines), drones, and information and communications technology.

This paper presents the advancements achieved via the Social Cooperation Program "Intelligent Construction System," from three main perspectives: environmental measurements, improvements in remote operability, and improvements in efficiency and automation of remote operation. For the environmental measurements, we introduce methods for generating 3D maps, estimating changes in soil volume, and determining trafficability. To improve remote operability, we introduce methods for providing a bird's-eye view of remote-operated machinery and for avoiding the tumble of UGVs. Finally, for the improvements in efficiency and automation, we introduce methods for presenting images via automatic control of external cameras and recognizing the actions of construction machinery.

2 Environmental measurement

2.1 Generation of 3D map with scale and slope information

At a disaster site, the topography and surrounding environment vary with respect to time. Therefore, unmanned construction machines should be operated based on the disaster scenes measured over a wide area as well as real-time data regarding changes in topography and surrounding environments. Therefore, studies have been conducted on environment map generation using UAVs [1]. To better understand the different conditions of a disaster site, we are developing a 3D map generation method that integrates data measured via drones and unmanned construction equipment [2]. By integrating the data acquired from drones and the inertial measurement unit (IMU) sensors mounted on UGVs, this proposed approach generates a 3D map comprising scale and slope information, as shown in Figure 1.

In addition, to monitor the ground information of disaster sites, we are developing a method to estimate the variations in soil volumes [3]. The ground at disaster sites is altered due to the gradual unloading of landslides and sediments. With regard to this, the proposed method compares a local map after terrain change with a global map prior to terrain change, in order to obtain the changes in soil volume as a 3D.

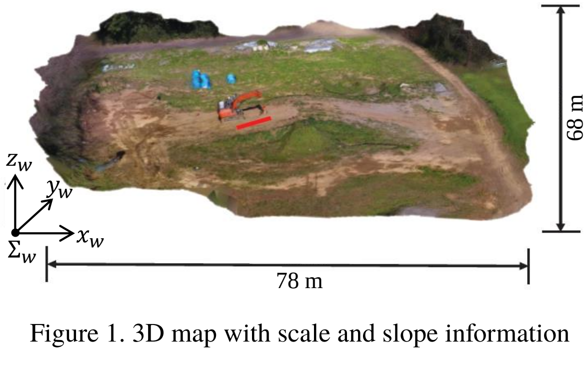


Figure 1. 3D map with scale and slope information

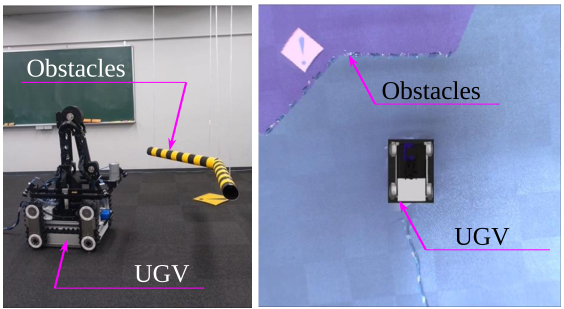
2.2 Trafficability judgment of UGV by ground measurement

Disaster sites can comprise soft soils, which cannot be traversed using UGVs, because such vehicles can get stuck and tumble in soft soils. Therefore, several researchers have studied the judgement the trafficability of UGVs [4]. However, no studies have focused on the non-contact judgement of trafficability with soft ground having a cone index of less than 200 kN/m^2, such as a landslide disaster site, as a target. Therefore, to ensure safe operation of UGVs at disaster sites, we are developing a method for judging the trafficability of UGVs without contact, based on the cone index [5]. The cone index is determined by the soil type and its water content. For this method, ground surfaces are evaluated via a multispectral camera, and the soil type and water content of the ground are estimated. The cone index is calculated based on these estimation results and used to determine the trafficability of UGVs.

3 Improving remote operability

3.1 Bird's-eye view image presentation

Remote-operated UGVs are effective for disaster recovery and inspection work in environments that are difficult for people to enter. When working with a remote-operated UGV, it is necessary to present an image to the operator. If the operator is presented with multiple camera images, the effectiveness of recovery or inspection efforts can be degraded. A single video depicting the surrounding environment is more effective. Therefore, several studies have been conducted on image presentation for improving the remote operability of UGVs [6]. To ensure improved operability, to view the remote-operated UGV as a single image, under this project, we are developing a bird's-eye view image that can be viewed from any angle. The proposed method generates a bird's-eye view image by using a laser range sensor and multiple fish-eye cameras mounted on a UGV [7]. The proposed method involves measuring the surrounding environment using a laser range sensor and generates a 3D mesh model of the wall. The wall is assumed to be perpendicular to the ground. A bird's-eye view image in an indoor environment is generated by projecting the image acquired from each fisheye camera on the generated 3D mesh model. By presenting a single bird's-eye view image, it is possible to recognize the rel-



(a) External view (b) Bird's-eye view image

Figure 2. Obstacles presentation on bird's-eye view image

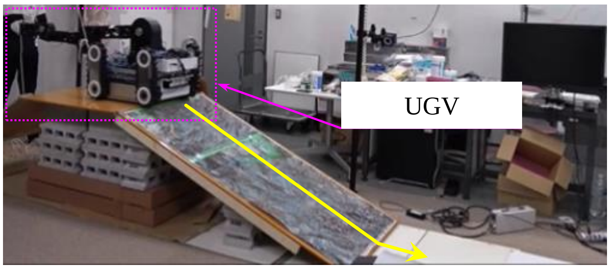
ative positions of the UGV and the wall and to improve remote operability in an indoor environment.

Furthermore, the path of the UGV can be obstructed by obstacles. Information regarding the relative positions of the UGV and obstacles can be effective for obstacle avoidance. Therefore, we are also developing a bird's-eye view image depicting the obstacles, as shown in Figure 2 [8]. This method generates a bird's-eye view image with a fish-eye camera mounted on the UGV. In addition, the surrounding environment is measured using the distance sensor mounted on the UGV. Finally, the obstacle is presented in the bird's-eye view image by integrating the different types of information. By presenting a single bird's-eye view image, it is possible to recognize the relative position of the UGV and the obstacle and to improve remote operability.

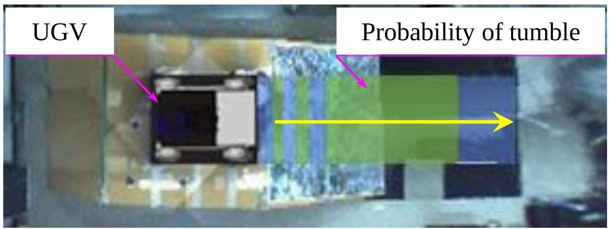
These methods involve measuring the distance to the object with a sensor. However, we are also researching a method to estimate the depth from only image information [9]. In this study, high- and low-spatial-frequency features were extracted from two images with different viewpoints, and two types of features with different frequency features were extracted. We generated a single feature by mixing these two different features. Finally, the depth was estimated via depth regression based on a single feature.

3.2 Tumble avoidance

When driving on the uneven grounds of a disaster site, it is necessary to avoid tumbles. However, it is difficult for operators to avoid tumbles using only information from the UGV's onboard sensor feedback. Therefore, several researchers have studied the tumble avoidance of UGVs [10]. We are currently developing a UGV running stability visualization method [11]. This method calculates the "stability" of a UGV using 3D ground surface information acquired via environmental measurements, through a dynamics simulation. Thereafter, the probability of a tumble along the route selected by the operator is presented, as shown in Figure 3. In addition, we are constructing a method for the autonomous avoidance of tumbling; in this method, a manipulator mounted on the UGV is autonomously controlled to mitigate any detected tumbles. This method prevents the UGV from tumbling by moving its center of gravity via the autonomously controlled manipulator. Accordingly, the posture of the UGV is altered and its stability is improved.



(a) External view



(b) Bird's-eye view image

Figure 3. Presentation of the probability of tumble

4 Improvement of efficiency and automation

4.1 Image presentation by automatic control of external camera

During the embankment work of unmanned construction, the operator operates unmanned construction machinery based on external camera images. In such cases, the unmanned construction machine and the external camera are operated by the machine operator and the camera operator, respectively. Such an arrangement can lead to operation-related issues, because the camera operator may not present the view required by the machine operator. Several studies have been conducted on image presentation for remote construction [12].We are currently developing a method for the automatic control of external cameras [13]. In this method, to present the images desired by the machine operator, the video presented to the machine operator, the operator's gaze, and the machine operator's voice were recorded and analyzed, in an actual unmanned construction site. Based on the results, the required speci-

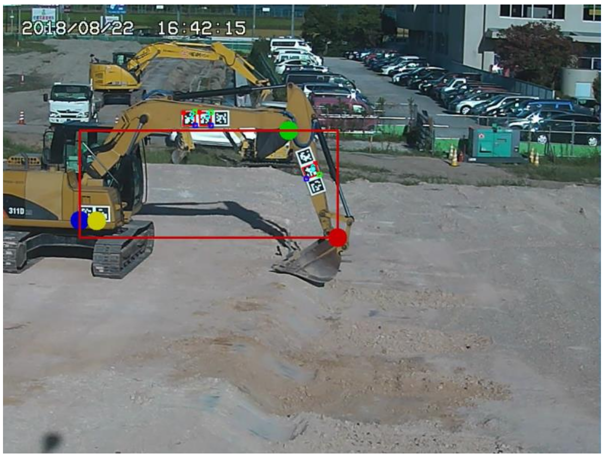


Figure 4. Automatic control External camera image

fications of the external camera image were extracted. The proposed method automatically controls the pan, tilt, and zoom of external cameras based on the extracted requirements for embankment work. Thus, appropriate external camera images are automatically presented to the machine operator, based on the construction requirements, as shown in Figure 4. Equivalent results were obtained for work time and visibility through a comparison between the image obtained using the proposed method and the image operated by the camera operator.

4.2 Hydraulic excavator action recognition

For effective management of construction machineries, it is essential to quantitatively determine the operation times and actions of these machineries. There are several studies on the action recognition of hydraulic excavators based on images [14]. In previous research, the action of the hydraulic excavator was recognized via deep learning, based on learning from actual hydraulic excavator videos. However, collecting a large amount of video data of actual hydraulic excavators is a significant challenge. To improve generalization, it is necessary to collect a large amount of data on hydraulic excavators of different sizes, colors, and shapes. Therefore, we are developing a method for recognizing the actual hydraulic excavator action via deep learning using simulation data of the hydraulic excavator action as a training dataset [15]. This method involves creating the data for recognizing the action of a hydraulic excavator in the dynamics simulation. We focused on three actions—digging, piling, and turning. These actions are learned based on simulation data. Then, a video filter is used for each data point to address the gap between the simulation data and the actual data. As a result, the action is recognized with an accuracy of 53.7%. This result shows the effectiveness of the proposed video filter, which is more than 20% higher than the action recognition result obtained using CNN+LSTM under the same data condition.

5 Conclusion

This paper presents the advancements resulting from the Social Cooperation Program "Intelligent Construction System" for environmental measurements, improvements in remote operability, and improvements in efficiency and automation of remote operation. For the environmental measurements, we introduced methods for generating 3D maps, estimating variations in soil volumes, and determining trafficability. For the improvement of remote operability, we introduced methods for presenting a bird's-eye view of remote-operated machinery and for the tumble avoidance of UGVs. For improving efficiency and automation, we introduced methods for presenting appropriate site images via automatic control of external cameras and for recognizing the actions of construction machinery.

As future efforts, we plan to validate the proposed methods at actual construction sites. In addition, we aim to further improve the construction efficiency, reduce manual labor, and improve intelligent construction.

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