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Development of an AR System for Excavators : AR Navigator

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***Abstract*—The Augmented Reality technology has developed across many different fields and attracted a lot of attention as an approach to increase the efficiency of construction projects in the field of civil engineering for the last ten years. This study thus set out to develop an AR system called AR Navigator to increase the efficiency of excavators with the use of AR technology. The AR Navigator was designed to perform three major functions to offer three types of visual information and provide excavator operators with information about changes to the field of excavation, distance between a bucket and the ground and between a bucket and the plan side, and the maximum operating radius of an excavator at an arbitrary position. The development of the AR Navigator would hopefully help to increase the efficiency of excavation works and ultimately establish a basic system for construction automation.**

***Keywords*—Augmented Reality, Excavator, Construction, Automation, Navigator**

I. Introduction

The Augmented Reality technology is widely used across several industry areas and has been growing remarkably especially in the field of games in recent years. AR has also gained interest from construction industry and many studies have tried to adopt AR in construction field (Lee et al., 2017). The present study aims to develop an AR system called AR Navigator for excavators.

The AR Navigator system provides an excavator operator with three types of visual information they need with the AR technology, thus supporting the efficient operation of excavators. To develop an efficient AR system for excavators, it is necessary to figure out the types of visual information which excavator operators critically require for their working.

Song et al. (2016) identified essential visual information that should be provided in excavation works. Visual information, we determined that the three types of visual information as in Table 1. Were appropriate to apply AR technology.

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Based on those three types of visual information, the AR Navigator was designed to consist of three modes: Hub Map, AR Depth and AR Radius. The Hub Map mode provides visual information about the real-time state of the excavation floors. The AR Depth mode provides visual information about the real-time position of the bucket according to its travel. The AR Radius mode provides visual information about the maximum operating radius according to the excavator data at the current or an arbitrary position.

II. AR Navigator Architecture

Fig. 1 shows the system to run the AR Navigator system. The AR Navigator was on the premise of getting essential data to its operation from the Machine Guidance (MG) system and the Control Center.

It would first receive the following data from MG real-time: the coordinates at the tip of the bucket, the position information of the excavator, and the excavator-centric coordinates. The concerned data would be used for intrinsic and extrinsic calibration, which would result in the view points and volumes to organize a virtual camera for AR images. The data provided by MG would be processed as bucket position data, which would in turn have huge impacts on AR images and as-is data.

It would then receive as-scanned and as-designed maps from the Control Center to supervise a construction project. While as-scanned maps are made with aerial photographs, as-designed maps refer to the field blueprints. Each of those map data would be provided at the beginning of construction works via Wi-Fi once a day. Those two maps would then be used to establish a base of as-is to display the current state. The as-is map would be updated according to the changing bucket positions.

Created with the data provided, the AR images and as-is maps would be superposed on real-world images to realize the three functions of the AR Navigator.

TABLE I. VISUAL INFORMATION FOR EXCAVATORS WITH POTENTIAL BENEEFITS FOR AR BASED ON SONG ET AL. (2016)

	Type of Visual Information
1	The real-time state of the excavation floor
2	The real-time position of the bucket according to its travel
3	The maximum operating radius according to the excavator data at the current or an arbitrary position

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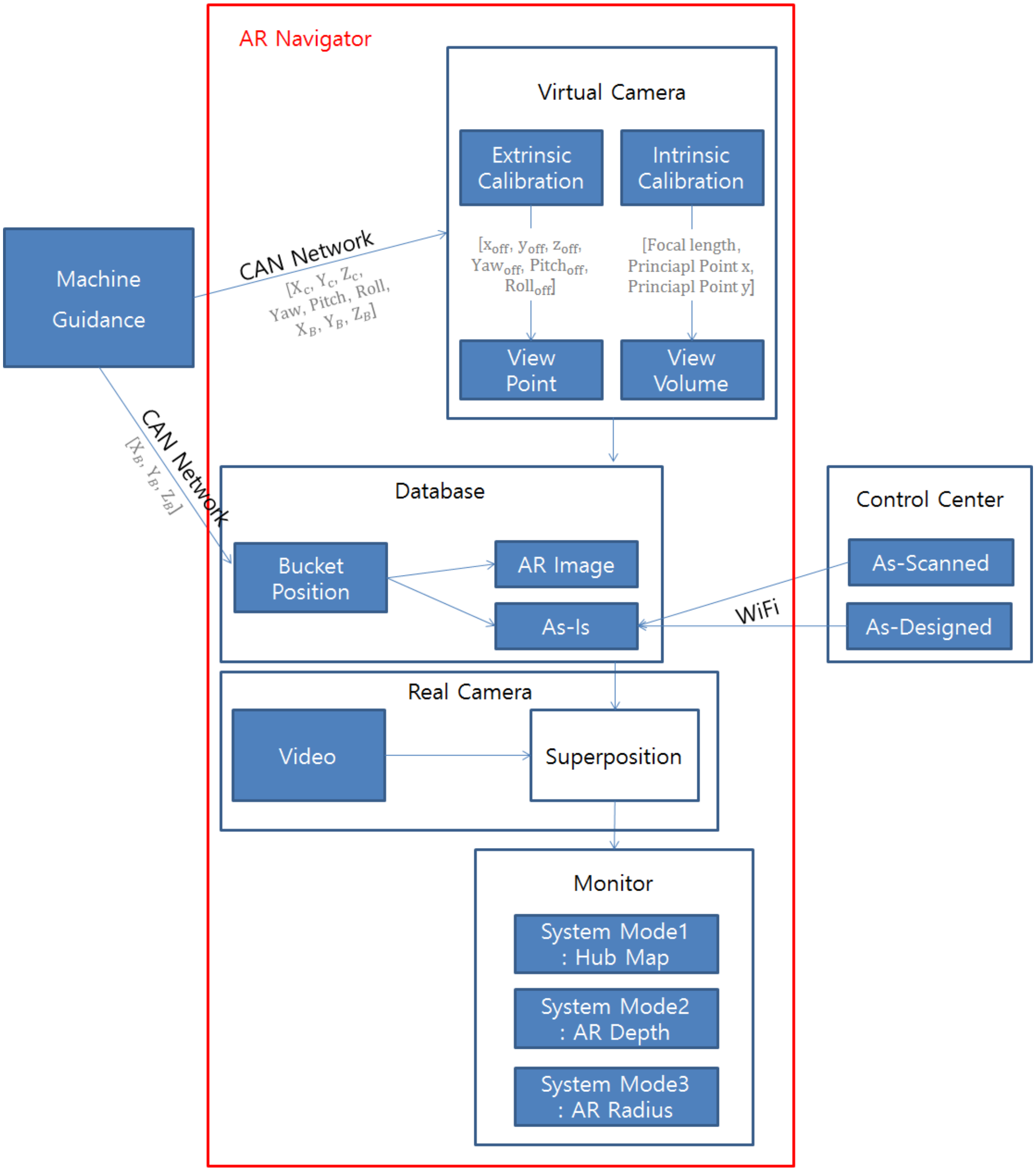

Figure 1. AR Navigator architecture

The AR Navigator was based on Windows 7 and made with the OpenGL, C++ codes. The testing environment of its implementation included Windows 7, 8GB RAM, and i5-4460 (3.6GHz) CPU. The hardware resources include the SY110M lens by Theia Technologies, the CM3-U3-13S2C camera by Point Grey, and PCAN-USB by Peak-System. The images used had the resolution of 1024×768×3channel and the input of 30fps. Fig. 2 shows the installed camera and hardware.

III. Modes of AR Navigator

A. *Hub Map Mode*

This function helps to figure out the real-time progress of works in the field of construction with a focus on excavators. The most important functions of the Hub Map are to display topographical maps and enable a shift to other modes. In the Hub Map mode, topographical maps provide three types of topographical map information including design drawings (as-designed), real-time field topographical maps (as-is), and topographical maps for the progress of works.

The three types of topographical maps show the altitude of field topography in colors. The design drawings, real-time field topographical maps, and topographical maps for the progress of works display the final target altitude of the field, real-time altitude changes, and differences in altitude between the design drawings and the real-time field topographical maps, respectively. Fig. 3 shows the Hub Map of the AR Navigator developed in the study.

The box at the upper left corner shows the tracking information provided by the Machine Guidance in real numbers. Users can make a shift to another mode by clicking the box at the upper right corner.

B. AR Depth Mode

This function helps to figure out the real-time state of bucket approaching on the excavation floor in case of excavation at a deep section. Based on real-time data of topographical maps, the function shows the vertical distance between the moving bucket and the field ground at an arbitrary point in imaginary lines and numerical information (Fig. 4).

The purple line and the purple box containing numbers at the lower left corner show based on the data of design drawings the distance between the moving bucket and the design depth at an arbitrary point in imaginary lines and numerical information. The green line at the same position shows the distance between the current ground and the moving bucket in imaginary lines and numerical information.

The AR Depth mode shows the situation inside the excavation side, which is not directly visible, in imaginary lines and helps to improve vision-dependent intuition, thus increasing job efficiency.

Both intrinsic and extrinsic calibration has enormous effects on the realization of AR Depth. Intrinsic calibration calibrates errors inside the camera by figuring out focal length, principal point, and distortion inside the camera. The current AR Navigator had a pixel error (RMSE) of 0.99 thanks to intrinsic calibration. Extrinsic calibration calibrates errors by obtaining information about the camera coordinates on the global coordinates and the viewing position of the camera. In the study, 131 photographs were used in the test, whose results led to the current AR Navigator's 11.4 pixel error (RMSE) thanks to extrinsic calibration. Fig. 5 shows the images of actual extrinsic calibration with purple lines on images. The results indicate that 11 pixel errors or so will not cause much

Figure 2. Installed AR Navigator hadwares

Figure 3. Hub Map Mode

Figure 4. AR Depth Mode

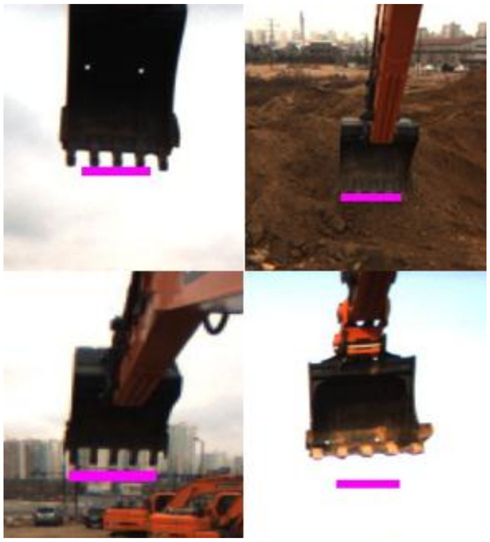

Figure 5. Extrinsic calibration error

difficulty with usability.

C. *AR Radius Mode*

The AR Radius mode uses the information about the positions of excavators and the real-time data of topographical maps provided via CAN communication to display the maximum radius of excavation calculated from the center of an excavator and help the excavator stop at an optimal position (Fig. 6). It is essential to reflect the position of an excavator when realizing the AR Radius mode. If users do not reflect the position of an excavator, they will get results like in the left image of Fig. 6 and thus become confused.

Unskilled excavator operators have a difficult time judging an excavation radius at the current position. If their judgment of excavation radius is wrong, they will suffer much time damage by having to move the excavator again. The AR Radius mode shows an operating radius that the bucket can reach on the floor that is visible to the human eye and thus helps them make an intuitive judgment of operating radius, contributing to higher job efficiency.

IV. Conclusions

The AR technology is widely used across many different fields and has The present study developed the AR Navigator to increase the efficiency of excavation works. Before its development, the investigator identified three types of visual information that would be the most proper to run the AR Navigator and selected three modes for the AR Navigator accordingly. The three modes include the Hub Map mode, which displays the overall map of the current job environment, the AR Depth mode, which shows the distance between the tip of the bucket or plan side and the current ground visually, and the AR Radius mode, which shows the maximum operating radius from the current position visually.

In case of AR Depth mode, in particular, the findings show that both intrinsic and extrinsic calibration had impacts on the errors of the AR Navigator, which had an internal pixel error (RMSE) of 0.99 based on intrinsic calibration and an external pixel error (RMSE) of 11.4 based on extrinsic calibration with 131 photographs. Given that the resolution of images was 1024×768, they were small errors accounting for only about 1% and caused no difficulty for its actual uses by users.

The AR Navigator was tested for its operation in similar situations to the actual field, but there was no test in which it was put in the actual field and examined for its utility. Follow-up study will thus test its utility with the NASA-TLX method in the actual field and improve its performance further through the enhancement of its GPS function and the optimization of its system.

If the AR Navigator is actually used in the field, it will contribute to the incredible increase of job efficiency at the construction field. In the end, it will serve as the AR system applicable to all equipment and a basic system for the automation of processing in civil engineering.

Figure 6. AR Radius mode before and after the application of excavator position information

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