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DETAILS OF PRACTICAL IMPLEMENTATION OF REAL-TIME 3D TERRAIN MODELING

Young Suk Kim[1], Seungwoo Han[2], Hyun-Seok Yoo[3], Heung-Soon Lim[3]

Jeong-Hoon Lee[4], Kyung-Seok Lee[4]

[1] Associate Professor, Inha University, Incheon, Korea
[2] Assistant Professor, Inha University, Incheon, Korea
[3] Ph. D. Candidate, Inha University, Incheon, Korea
[4] Graduate Student, Inha University, Incheon, Korea
Correspond to shan@inha.ac.kr

ABSTRACT: A large-scaled research project titled "Intelligent Excavating System (IES)" sponsored by Korean government has launched in 2006. An issue of real-time 3D terrain modeling has become a crucial point for successful implementation of IES due to many application limitations of state-of-the-art techniques developed in various high-technology fields. Many feasible technologies such as laser scanning, structured lighting and so on were widely reviewed by professionals and researchers for one year. Various efforts such as literature reviews, interviews, and indoor experiments make us select a structural light technique and stereo vision technique as appropriate techniques for accomplishment of real-time 3D terrain modeling. It, however, revealed that off-the-shelf products of structural light and stereo-vision technique had many technical problems which should be resolved for practical applications in IES. This study introduces diverse methods modifying off-the-shelf package of the structural light method, one of feasible techniques and eventually allowing this technique to be successfully utilized for achieving fundamental research goals. This study also presents many efforts to resolve practical difficulties of this technique considering basic characteristics of excavating operations and particular environment of construction sites. Findings showed in this study would be beneficial for other researchers to conduct new researches for application of vision techniques to construction fields by provision of detail issues about practical application and diverse practical methods as solutions overcoming these issues.

Keywords: Vision Technique, Excavation, 3D Model, Automation

1. INTRODUCTION

Construction industry has been regarded as the most conservative industry due to the difficulty in application of new technologies and emerging methods. This difficulty was derived from the uniqueness of construction project, which is the basic characteristic of construction.

For circumventing this difficulty, Korean government recently gives big supports to researches for accomplishment of combination of construction and new technologies. A research project titled "Intelligent Excavating System (IES)" launched by Korean government supports with professionals in industries and researchers in academic institutes in Korea at 2007 and has been conducting (Ahn et al. 2008; Yu et al. 2008).

The goal of the IES research is to provide users with an automatic intelligent excavating system enabling to acquire not only an enhanced productivity but also a safety on site. A real-time 3D terrain modeling and automatic soil volume computation is a part of task planning of IES, which is one of three categories of the IES research; 1) Task Planning, 2) Electronic System Implementation, and 3) Mechanical System Implementation.

Real-time 3D models reflecting amorphous terrain and computation of soil volumes is accomplished by identification of differences between the 3D terrain models acquired in real-time and the drawings illustrating the designed terrain levels.

The first step of this study was to find an appropriate technology to be applied for real-time 3D terrain modeling. The previous study by Ahn et al. (2008) presented a research methodology for selecting the optimum emerging technology using Analytical Hierarchy Process (AHP) and Preference Index (AI). According to this study, two techniques in vision technology, a vision system based on a structured light and a vision system based on stereo vision, were proved to be more applicable than other three technologies (Ahn et al. 2008; Yu et al. 2008)

As a second step, the study by Yu et al. (2008) suggested a conceptual design using a structured light-based vision system, one of appropriate technologies for practical applications (Yu et al. 2008).

This study was developed based on these two previous studies and provides a systemized algorithm and more details for practical application illustrating the method how to circumvent actual application problems.

2. STRUCTURED LIGHT TECHNIQUE

A structured light technique was originally from a stereo vision technique and developed to improve image accuracy better than stereo vision technique. A critical limitation of stereo vision technique was derived from difficulty in finding an identical matching point of a surface of and to calculate matching points for an object's surface of discontinuity. Conventional stereo vision technique provides users with only a capturing function by two cameras. The different captured images by two cameras are merged based on one identical point. However, this technique has a serious problem when one identical point is hardly captured due to discontinuity of a surface of the object to be captured. In excavation operation, earth to be excavated and moved was targeted as the object to be captured by cameras. Accordingly, general off-the-shelf package of stereo vision cannot make an appropriate implementation due to discontinuity of the earth. The structured light technique was created and developed for overcoming this limitation by the stereo vision technique. Figure 1 illustrates A basic concept of structured light technique, a core technique used in structured light-based system (Yu et al. 2008).

For achieving appropriate activation of the structured light technique, it is required that a camera for capturing object's image and a light resource for projecting coded patterns. The light resource projects light specifically coded patterns and the camera captures the image of the object which coded patterns are shown on the surface of. Multiple coded patterns of the light need to be projected at one time from the structured light module in order to acquire the full range image (Xu et al. 2006; Ahn et al. 2008; Yu et al. 2008).

It is required for implementation of this technique that a powerful light resource can be identified from the captured image by a camera under sunlight at daytime (Ahn et al. 2008; Yu et al. 2008).

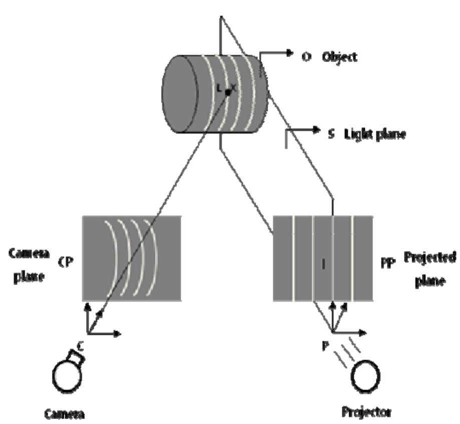

Figure 1. Structured Light Technique (Extracted from Yu et al. 2008)

3. BACKGROUND OF APPLICATION OF STRUCTURED LIGHT TECHNIQUE

Generally, in earth work, which is part of construction work, excavation work using an excavator is planned, and a location to be excavated is selected by setting up measurement stakes. In the case in which the measurement stakes are not required to be set up again after the excavation work is performed, the excavation work is performed again. When the excavation work reaches the level determined through planning, the number of trucks that transport soil excavated during excavation work is counted, so that the final excavated soil volume can be computed.

Further, a method of making the plan for the distribution and transportation of the volume of soil based on the empirical determination of a designer, machine operators performing earth work, land surveyors, dedicated to the construction field, setting up stakes so as to designate the work range, and the machine operators performing excavation work based on the work range has been used, and this method is completely dependent on manpower.

Further, development from the aspect of hardware, such as the function, size, and capacity of construction equipment, such as an excavator and a grader, which is required to perform excavation work, has been continuously realized. Meanwhile, in development from the aspect of software, such as the computation of the excavated soil volume, simple operations have been used. In the case of the computation of the excavated soil volume, a method of simply calculating the product of the number of earth transportation trucks and the capacity of the trucks has been used.

For example, in the case in which six one-ton trucks load excavated soil and then depart, a method of computing the excavated soil volume, that is, 1 ton * 6 = 6 tons, is used.

However, the prior art has problems in that the amount of earth yield loaded on an earth transportation truck is not always consistent, the amount of earth may be changed depending on the skill of an excavator operator, and thus the accuracy and reliability of the computation method are lowered, thereby decreasing the efficiency of work.

4. OVERVIEWS FOR PRACTICAL APPLCIATION

4.1 Technical Problems

Accordingly, the present invention has been made keeping in mind the above problems occurring in the prior art, and an object of the present invention is to provide a device and method for computing excavated soil volume using structured light, which can recognize excavated soil volume excavated using the bucket of an excavator in real time, and can compute the excavated soil volume using 3-Dimensional (3D) ground shape images.

Another object of the present invention is to provide a device and method for computing excavated soil volume using structured light, which can precisely compute the final excavated soil volume with respect to the area in which work has been completed.

A further object of the present invention is to provide a device and method for computing an excavated soil volume using structured light, which can develop and utilize an optimized earth work plan system using 3D ground shape images in real time.

4.2 Technical Solution

The present invention includes a illumination module having a lamp for projecting structured light which is coded patterned light onto a work area, a structured light module having a camera for capturing the reflected light of the projected patterned light from the work area, and a microcontroller for computing an excavated soil volume in the work area using the captured reflected light.

4.3 Advantageous Effects

The present invention, including the above-described configuration, has advantages in that precise measurement of excavation work performed by an excavator in a construction work field can be conducted, in that the final excavated soil volume can be extracted in a 3D ground shape image form, in that an optimized earth work plan can be made, in that the work order in consideration of the characteristics of the land, the automatic control of an excavation robot through autonomous traveling and the control of traveling speed depending on the angle of incline and operation direction are possible, in that a safe work environment can be realized, in that the reputation of the construction industry can be improved, in that substitution can be performed on a measurement process, and in that the efficiency of the construction management business can be increased.

5. DETAILS FOR PRACTICAL APPLCIATIONS

5.1 Workflow of a System using the Structured Light Technique

As discussed earlier, a conceptual design of real-time 3D terrain modeling system is implemented by the structured light technique.

Figure 2 shows basic workflow of this system. As shown in figure 2, once the excavator is positioned on the spot which was directed by task planning system, the structured light module projects coded patterns to the targeted terrain. The targeted terrain on which projected patterns were shown is captured by a camera located on a excavator’s cabin. The captured image is transferred to a micro controller and converted to a 3D image.

This created 3D image is compared with another 3D image which was created right before this one cycle of operation. Volume of soil to be moved is finally calculated from the deviation of two 3D images.

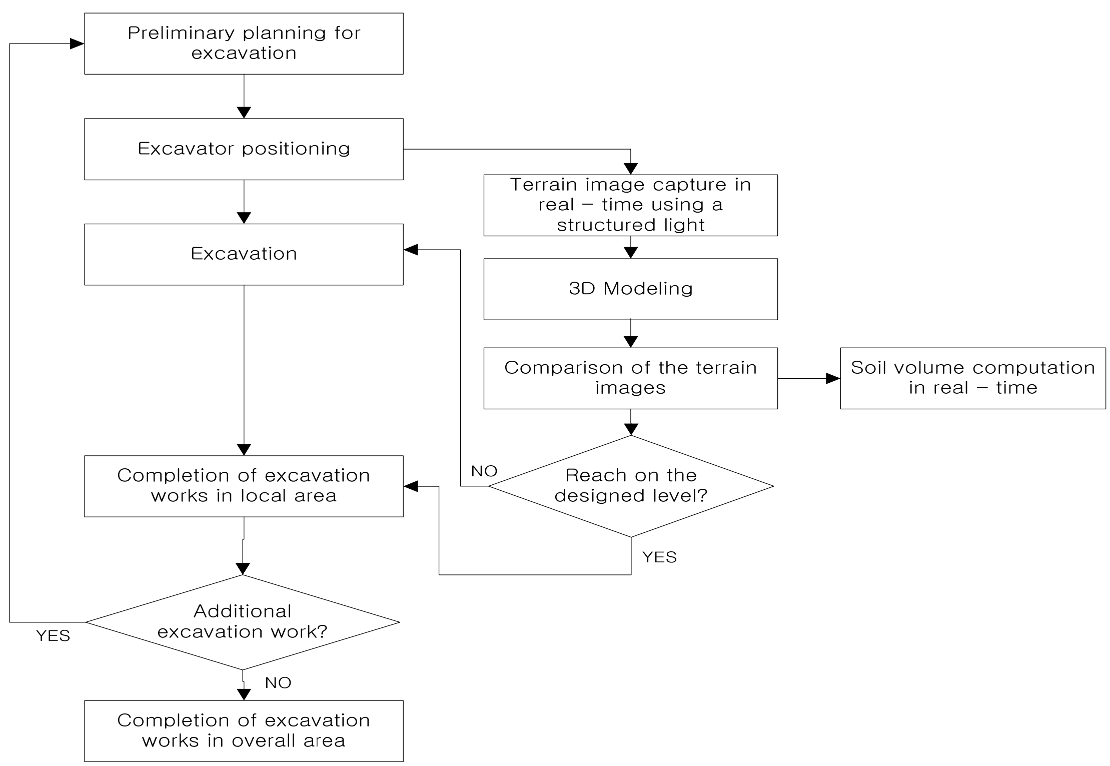

Figure 2. Basic Workflow of Real-time 3D Terrain Modeling

5.2 Conceptual Design

The real-time 3D terrain modeling system is conceptually designed with three modules: 1) control sensor unit, 2) micro controller, and 3) structured light module with a digital zooming camera and a projector.

In order to acquire appropriate 3D terrain modeling, accurate numerical raw data need to be collected without any interruption of operation. If the system needs to quit or be delayed for a while to acquire numerical data at a stable position, it would cause serious delay and deliver the reduced productivity and efficiency of this operation.

The conceptual design suggests that a light resource projecting light with coded patterns and a digital zooming camera capturing terrain images need to be installed on an appropriate location, top on the cabin of an excavator for achievement of appropriate and efficient operation. The light resource and the camera do not have to be activated all time during excavation. This system requires only one shot of picture taking a different terrain image right after the excavator digs out. Accordingly, supplementary instruments are additionally required for providing signals for control of appropriate focusing of a light resource and zooming for a camera (Yu et al. 2008).

Another key issue of this system is that appropriate distance information from the structural light module to the targeted area needs to be provided the micro controller and the structured light module. The distance information would be used as basic information on the zooming activity for the digital camera and focusing activity for the structured light. For providing this information, control sensors are installed at each joint of a boom, an arm, and a bucket. These sensors provide the location data indicating each joint in real-time. These data fundamentally provide basic information of bucket's location. The digital zooming camera and the structured light were controlled to project the patterned light and take a picture with appropriate zooming and focusing based on the information of bucket's location in real-time (Ahn et al. 2008; Yu et al. 2008).

Figure 3 illustrates the conceptual design equipped with the functions and activities described in this section.

The reason of selecting the structured light technique instead of the stereo vision technique is that the digital zooming camera easily enables to capture the terrain image with the coded pattern from the light resource. A light resource is accordingly the crucial factor for implementation of the structured light-based vision system that is preliminary phase for IES. The light resource needs to be capable of providing bright coded patterns so that they can be identified under daylight. Currently, it recommends that a metal halide light is used in this system. According to specifications by vendors, the metal halide light has 3,000 lm of initial light volume and 7,000 ˚K of color temperature, approximate two times of that of sunlight. However, it doubts whether the patterned light from a resource on an excavator can be reached without light's diffusion to the targeted earth that is located maximum 8 ~ 10 m of distance from the excavator. This study suggests the use of a focusing instrument that can project patterned light on to the targeted earth with less light diffusion. Figure 6 shows the conceptual design of the focusing instrument for light projection (Yu et al. 2008).

5.3 Systemized Algorithm

A systemized algorithm needs to be designed for a preliminary operation of the system under the conceptual design. As stated earlier, interviews with professionals and literature reviews on the previous studies and technical specifications of the off-the-shelf structured light package indicated that the structured light technique could be feasible on this system.

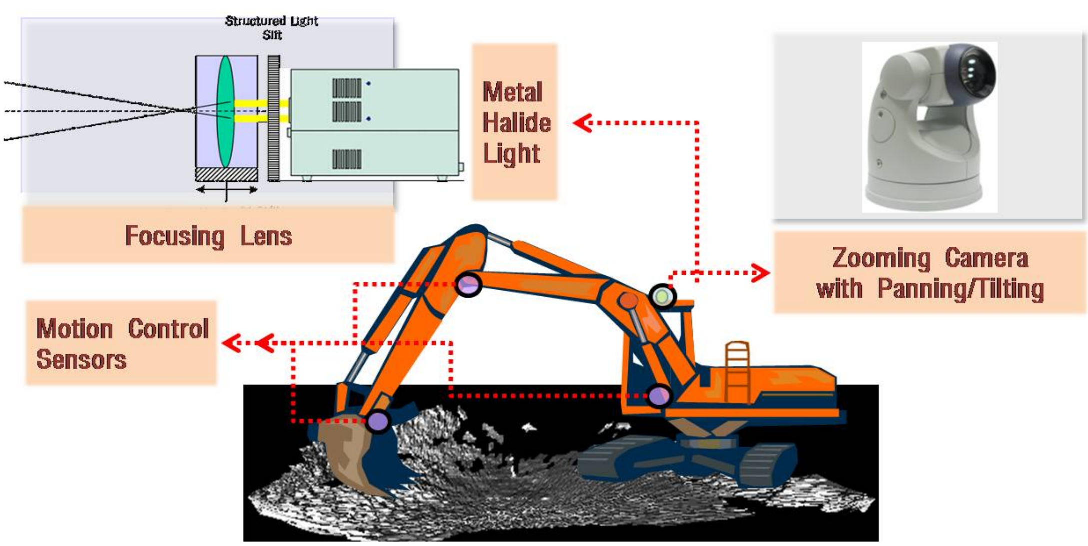

Figure 3. Conceptual Design of Real-time 3D Terrain Modeling System (Extracted from Yu et al. 2008)

However, the fact that the distance from the structured light module to the targeted terrain is maximum 8 ~ 10 m causes serious technical limitation in practical application. It requires the use of a digital camera with high resolution that zooming and focusing functions are supported in order to circumvent this limitation. The control sensors mentioned earlier provide the information of bucket's location, which eventually give the information of the distance and the time for light projections and image captures. Activities from light projections to image captures completes within 0.6 seconds in that this short duration does not make any interruption during normal excavating operations. While a bucket approaches to the targeted earth, the control sensors installed at each joints transmits the location information of the bucket. The focusing instrument then adjusts focusing power based on the location information of the bucket. The micro controller is required for receiving all signals and information and controlling hardware's motions such as focusing and zooming of the light resource and the camera, and panning and tilting of the system (Yu et al. 2008).

Figure 4 illustrates a basic systemized algorithm which was described above.

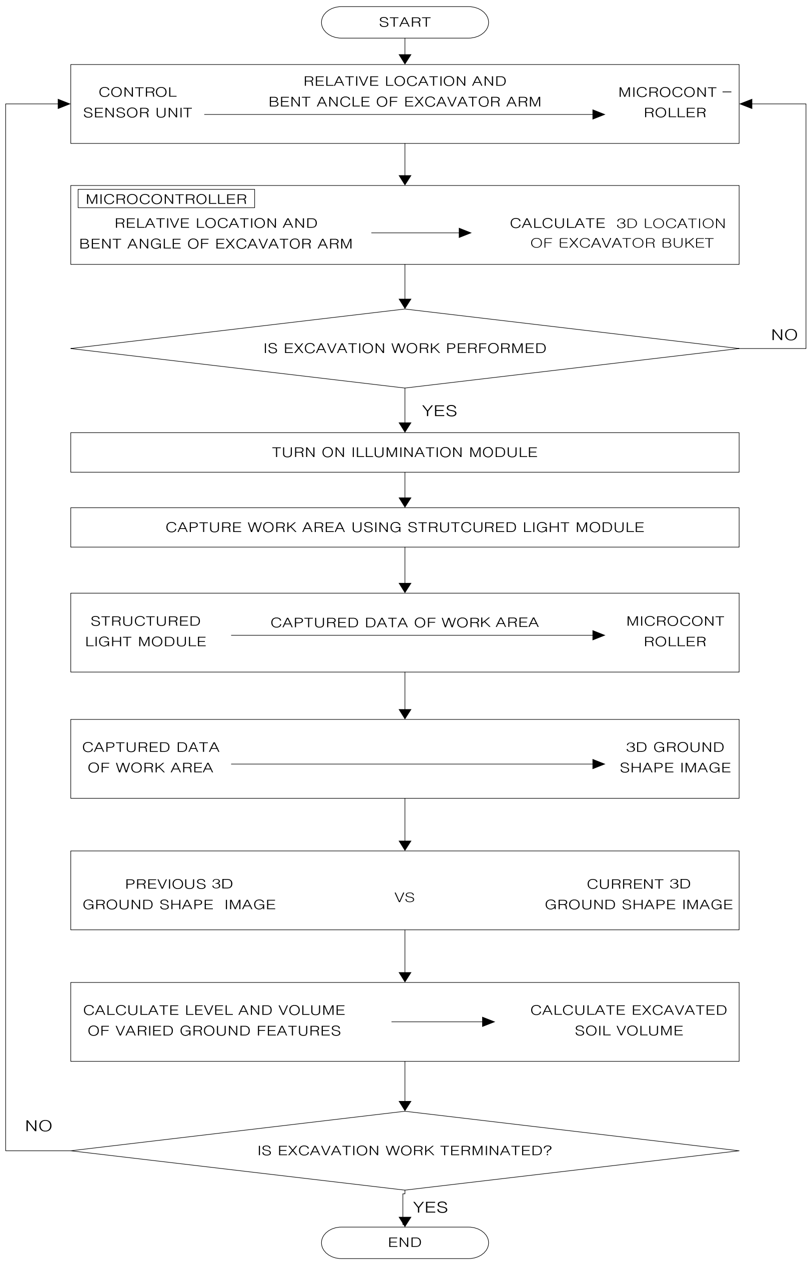

Figure 4. Basic Systemized Algorithm of the System

6 CONCLUSIONS AND FUTURE WORKS

Preliminary studies of excavation task planning, a part of the research of IES results in the followings;

- Selection of appropriate techniques; the structured light and the stereo vision techniques
- Conceptual design using the structured light technique
- Systemized algorithm based on the structured light technique for practical application

The first study for selection of appropriate techniques was conducted by Ahn et al. (2008), and the conceptual design using the structured light technique was suggested by Yu et al. (2008).

This study for conducting the systemized algorithm present details of algorithms and the developed conceptual operation design based on the structured light technique with research goal of accomplishing real-time 3D terrain modeling.

This study presents the details for practical application of the structured light technique for accomplishment of real-time 3D terrain modeling. The technical specifications and literature reviews on off-the-shelf package of this technique showed serious limitation on practical application in condition with 8 ~ 9 meters of the distance for projecting a light and capturing the images.

For resolving the problems caused by this condition, the systemized algorithm is designed. This algorithm implements proper activities for real-time 3D terrain modeling as followings;

Step 1. Excavator is positioned at the location where task planning module indicated.

Step 2. A control sensor unit gives basic location information of the bucket to a micro controller

Step 3. The micro controller control operational position and attitude of a structured light module

Step 4. The structured light module projects a light with coded pattern to the targeted earth

Step 5. A digital zooming camera captures the terrain image and transmits numerical distance data to the micro controller

Step 6. The micro controller converts the numerical data to 3D ground shape image

Step 7. The created 3D ground shape image is compared with the previous 3D shape image

Step 8. The changed soil volume is computed based on the deviation between the previous and the new 3D ground shape image.

Step 9. The data is recorded to the micro controller and transmitted to task planning module.

Activities of steps 2 to 5 performed within 0.5 seconds not causing any interruption of excavation operations. Other activities of steps 6 to 9 are completed within 5 seconds. Considering total duration of one scope of the earth to be moved is approximate 10 seconds, total 5 seconds would be appropriate time enough not to give any interruption of one cycle of excavation activity.

This study addresses the systemized algorithm and details in order to provide technical supports to the conceptual design suggested by Yu et al. (2008).

The suggested algorithm and details would allow researchers and practitioners in job site to perform practical application of the structured light technique for real-time 3D modeling. Indoor experiments and outdoor field tests are following as the next research phase. In addition, the alternate method, a stereo vision technique, has currently being investigated as one of research scope of IES. As consecutive research phase, it follows that further investigations for hardware and software integrations, and integrations of total modules with task planning, electronic implement, and mechanical implementation.

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