Application of Appropriate Technologies to 3D Local Terrain Modeling in Real-time for Intelligent Excavating System (IES)

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Abstract

Automation in construction is considered as one of solutions to fundamental problems which the construction industry has confronted. The development of real-time 3D local terrain modeling is the core methodology of achievement of IES (Intelligent Excavating System) which is a mega-size research concerning automation in construction. Stereo vision technique was selected as an appropriate method to achieve 3D terrain modeling in real-time. The objective of this study is to suggest a conceptual method by use of the stereo vision and assess feasibility of practical application under various conditions of construction sites. Bumblebee XB-3 is adopted as the stereo vision system in a prototype of a 3D terrain modeling system. This study is to investigate fundamental theories of the stereo vision system and to conduct tests in indoor and outdoor environments for determining appropriate detection range, finding installation location of cameras, doing visual assessment of the technical appropriateness, and checking reliability of 3D visual data. These decomposed tasks present valuable information for establishment of the conceptual method and improvement on the limitations of the use of stereo vision system for 3D terrain modeling in real-time.

Keywords: automation, stereo vision, 3D, terrain model

1. Introduction

Many construction planners and site engineers have regarded enhancement of construction performances by high construction productivity and low unit costs as one of crucial factors for determining a success of construction projects. The shortage of experienced laborers, raise of labor costs, and debasement of construction qualities make construction industry in Korea face serious difficulties in achievement of high construction performances. Construction industry has tried to use emerging technologies that are capable of providing excellent construction performances. These efforts are especially witnessed in a field of construction equipment. A research project titled “Intelligent Excavating System (IES)” that is one of research projects supported by Korean government started with professionals in industries and researchers in academic institutes in Korea at 2007 is currently conducting (Ahn et al. 2008; Yu et al. 2008).

Stereo vision technique was selected as an appropriate method to achieve 3D terrain modeling in real-time in previous researches (Ahn et al. 2008; Yu et al. 2008). The objective of this study is to suggest a conceptual method by use of the stereo vision and assess feasibility of practical application under various conditions of construction sites. In this study, Bumblebee XB-3, a state-of-the-art stereo vision system, is adopted as the stereo vision system which is used in a prototype of a 3D terrain modeling system. In accordance with the goal of the research, this study is to investigate fundamental theories of the stereo vision system and findings by past researches related to this study. This study is to conduct tests in indoor and outdoor environments based on theoretical reviews. Indoor test allows us to determine an appropriate detection range by the stereo vision system and gives us basic information about installation location and installation angle of cameras on a cabin of an excavator. It would be primary information for establishment of a conceptual method for practical application. Outdoor test enables to do visual assessment of the technical appropriateness of the stereo vision system for practical application to construction sites. Accuracy test, another outdoor test, provides quantified differences of distance data of 3D images by the stereo vision system with comparison of the result by actual measurement. These decomposed tasks mentioned previously present valuable information for establishment of the conceptual method and improvement on the limitations of the use of stereo vision system for 3D terrain modeling in real-time.

2. Literature Reviews

Stereo vision technique is currently used in a broad range of various fields such as terrain model acquisition, object identification and tracking systems. This technique is implemented by two identical cameras placing separately, that is, those are placed on different horizontal level but the same vertical level (Yu et al. 2008). The pictures taken by two cameras are merged and produce a virtually instantaneous estimate of the distances to objects. These cameras detect images of an identical object with different horizontal locations and different distances. These two detected images are merged based on an identical matching point of the object, a corresponding pixel, and then creates one merged image. This merged image presents distance data from cameras to the object. Quick measurement in distance yields that this technique can be highly effective for detecting the object and segmenting the object and gauging its size and shape (Woodfill et al. 2007; Cho and Park 1997; Ahn et al. 2008; Yu et al. 2008).

Identifying distance data from the camera to the object is derived from figure 1 and the equation as below.

$$z = f \times \frac{b}{d} \qquad \text{: Equation (1)}$$

where, *z*: distance from the camera to the object point

f: focal length

b: baseline

d: disparity between the distances from the left image and the right image

$d = d_l - d_r$

d_l: the distance from the left image to the object point

d_r: the distance from the left image to the object point

As described the equation (1), computation of disparity based on the corresponding pixel in two images, the left image and the right image would be a technical issue in stereo vision technique.

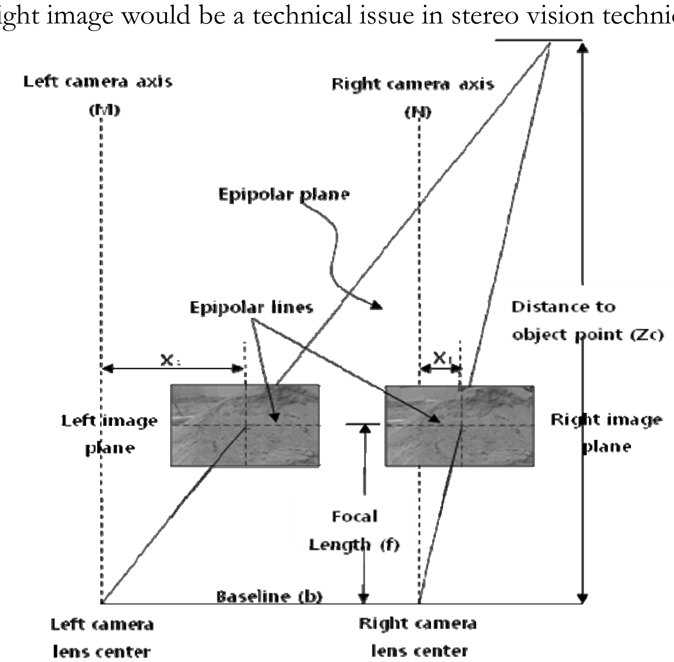

Figure 1. Diagram of basic operation by stereo vision technique

In addition to computation of the disparity, it would also be critical issue to find an appropriate corresponding pixel in an identical object with two images. Two methods have been introduced on the market: 1) feature-based method, and 2) area-based method to resolve this difficulty.

Primary conditions for achieving the objective of this study is to detect a terrain image in real-time without any interruption of equipment operation. One cycle of excavating is composed of "scooping out" and "unloading the earth". It generally takes 10 seconds for completing one cycle according to several equipment guide books and site observation. This information notifies us that all procedure including detecting and image processing would be completed within 10 seconds. Detecting terrain image is another limited condition in this study. Detection by cameras would finish as fast as it can so that it would not give any interruption during scooping and unloading the earth on the tray of trucks. These two limitations described previously would be resolved by technical specifications of state-of-the-art stereo vision system. The emerging technique of stereo vision system provides the technical solutions in that interpreting visual data to 3D from distance data takes generally 1 ~ 2 seconds and detecting the image takes milliseconds.

3. Conceptual Method of Stereo Vision for 3D Terrain Modeling

Appropriate conceptual method of stereo vision system requires that detection range of cameras and horizontal excavation range would be primarily determined. Careful study on installation of stereo vision cameras follows. These requirements make this study investigate the detection range of cameras by indoor tests and the excavation range by construction equipment references. The investigation allows this study to determine the appropriate installation location of the stereo vision cameras.

3.1. Estimation of detection angle

Available detection range of the stereo vision camera is delivered by an indoor test. According to the technical specification of Bumblebee XB-3, available angles are vertical viewing angle of 49.5 degree and horizontal viewing angle of 66 degree. Indoor test is required so that appropriate viewing angle for use in excavation operation. The system created 3D images based on two images captured by cameras which were located in 2 meter distance from a screen. The size of projected area in screen was 2.28 meter in width and 1.75 meter height. This result and proportional computation informed that appropriate angles by the stereo vision system were vertical viewing angle of 47 degree and horizontal viewing angle of 59 degree.

3.2. Installation of the stereo vision system

An excavator which is under development as a prototype shows 8.2 meter of maximum reach and 5.0 meter of maximum depth below ground. Previous study (Seo et al. 2008) indicated that appropriate horizontal excavating range was 3.4 ~ 7.67 meters when the specification data of the same excavator were delivered.

Location and mounted angle of the stereo vision system are determined by information derived from appropriate detection angle and horizontal excavating range delivered previously. On-site observation of excavating operation informed that the stereo vision system was installed on a cabin of the excavator to obtain effective detection with appropriate coverage of the excavated area. Specification of the excavator used in this study says that that height of prospective installation location on the cabin is 2.8 meter. Figure 1 illustrates basic simulation chart of the excavator for searching appropriate installation location of the stereo vision system.

Figure 2 indicates that the stereo vision system needs to be installed on the cabin with 2.8 meter height and 30 degree incline to cover 3.4 ~ 7.67 meters of appropriate horizontal excavating area.

4. Application Analysis by Field Tests

4.1. 3D terrain modeling

There are a few of specific technologies such as Triclops SDK by Point Grey Research Inc., Open GL (Open Graphic Library) by Silicon Graphics Inc., and Microsoft Visual C^{++} compiler, version 6.0 by Microsoft Corp. which are utilized for 3D terrain modeling. Triclops SDK allows us to control the operation of stereo vision cameras and to transmit image data. It also includes conversion function from the image data to point cloud suing SAD (Sum of Absolute Difference) algorithm. Open GL makes the converted point cloud by Triclops SDK be illustrated in the user interface. Figure 3 presents basic diagram of functions by Triclops SDK and Open GL.

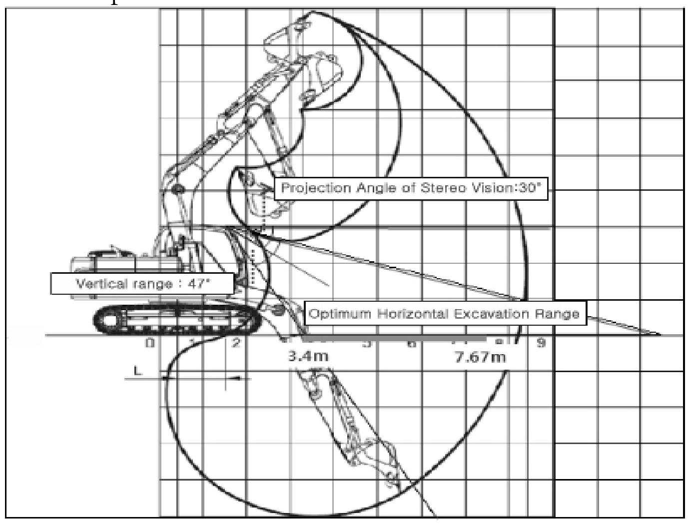

Figure 2. Operation chart of the excavator

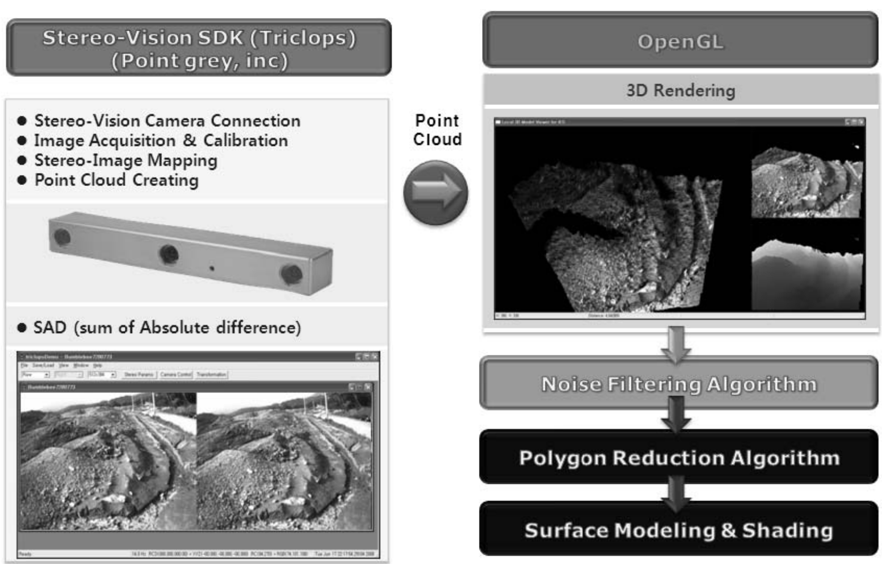

Figure 3. Diagram of functions by Triclops SDK and Open GL

The images detected by stereo vision cameras show 640× 480 resolutions in color and are merged based on the image captured by the camera on the right location. Figure 4 shows a 3D modeling display viewer which is composed with 3D terrain model display, 2D stereo image map created by matching two captured images, and a depth map illustrated as a grey scale index which is converted from the computed distance data. The conceptual method of stereo vision system conducted by this study enables the camera to detect the terrain image on the trigger signal by excavating system automatically or by manually. The merged image after matching then is automatically presented on the 3D modeling display viewer.

4.2. Field tests

Many field tests on various construction sites are conducted to assess the practical application of stereo vision system for 3D terrain modeling. Various shapes of terrain and objects which may exist in construction sites are detected in field tests.

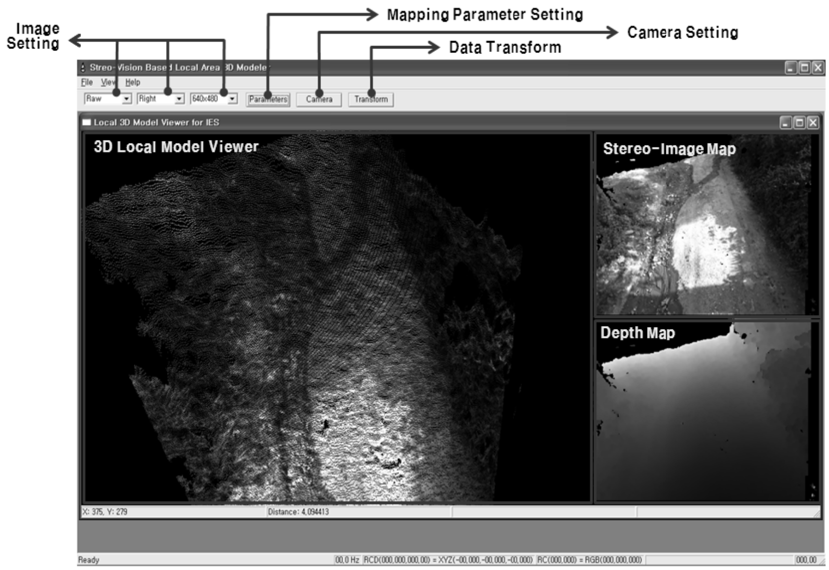

Figure 4. 3D modeling display viewer

The stereo vision system is mounted on a tripod of 2.8 meter height and 30 degree incline from the horizon. The images is detected with 640×480 resolutions in color. Total 98 images are captured by total 5 field tests. Basically, all captured images are converted to 3D image via a specific display system which was developed in this study. Consequently, assessment of noise conditions and processing time makes the conceptual method of stereo vision system feasible or improved further.

Figures 5 and 6 show 3D terrain images of various shapes of terrain and with various types of objects existing in construction sites, respectively. All 3D images converted from the captured images shown in Figures 4 and 5 are assessed and determined whether these are sufficiently appropriate to be applied in excavating works.

Professionals agreed that most 3D images showed appropriate accuracy with consideration of a broad range of operation tolerance of excavation. This favorable test result is due to easiness of finding corresponding pixels in terrains while detecting various patterns in terrain.

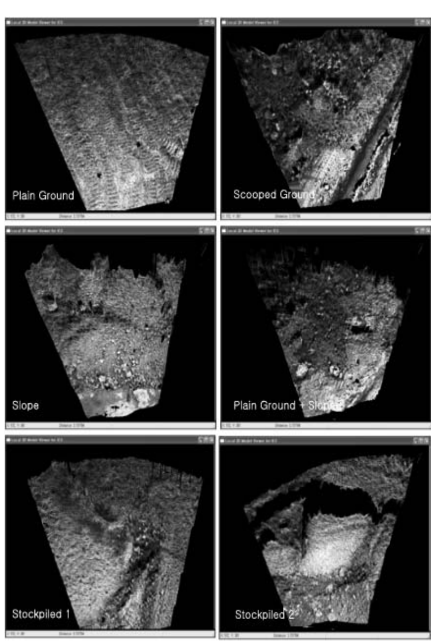

Figure 5. 3D terrain images of various shapes of terrain

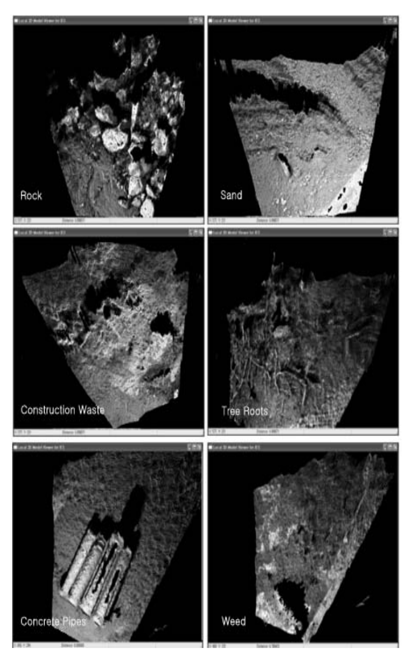

Figure 6. 3D terrain images with various objects

Unlike most 3D images, the images that concreted hume pipes and surface water were captured in are determined not to be used due to poor quality caused by not finding corresponding pixels. This limitation would be resolved by controlling camera's shutter speed and creating noise removal algorithm. Figure 7 shows the 3D images of terrain with concrete hume pipes and surface water in poor quality

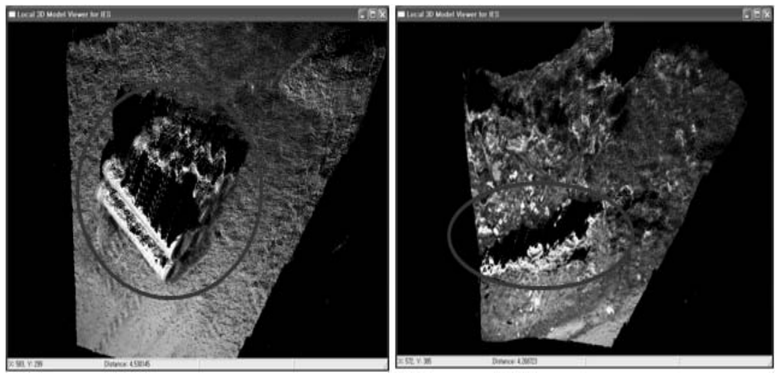

Figure 7. 3D terrain images with concrete hume pipes and surface water

Visual assessment shown in figures 4, 5, and 6 show proper result in accuracy. It doubts whether 3D images created by stereo vision system are perfectly matched with actual terrain information or not. Consequently, the accuracy test requires that the distance data in 3D images by stereo vision system need to be compared with those by actual measurement.

Figure 8 shows an accuracy test conducted in construction sites.

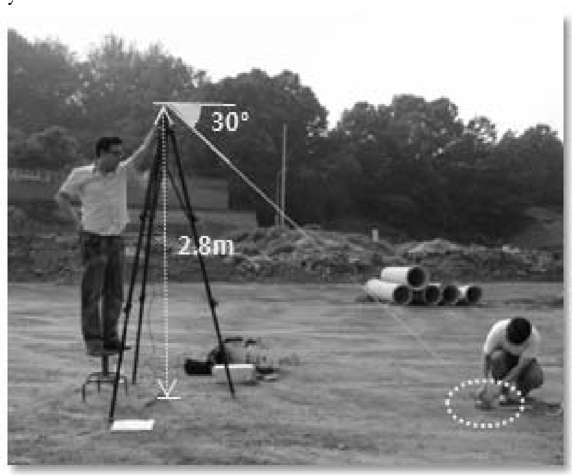

Figure 8. Accuracy test of stereo vision system

As shown in figure 8, the accuracy test is conducted that the stereo vision system which is located in 2.8 meter height and 30 degree incline detects targets which placed randomly within 2 ~ 11 meters. The distance data by stereo vision system are compared with those by actual surveying in that the distance from the camera to the target is measured manually.

Comparison of total 148 samples of the distance data between 3D images and actual measurements indicates 0.051 meter of an average deviation and 0.168 meter of a maximum deviation. Graphs where deviations analyzed in the 4th and the 5th field tests were illustrated in figure 8. In addition to deviation graphs, table 1 presents analysis results of deviation by distance from the camera and the target.

As shown in figure 9 and table 1, it notes that more distance from the camera to the target has bigger deviations of the distance data between the 3D images and actual measurement. It explains that the stereo vision system has limitation for practical application to detecting terrain where is located with long distance from the camera due to difficulty in finding the corresponding pixel.

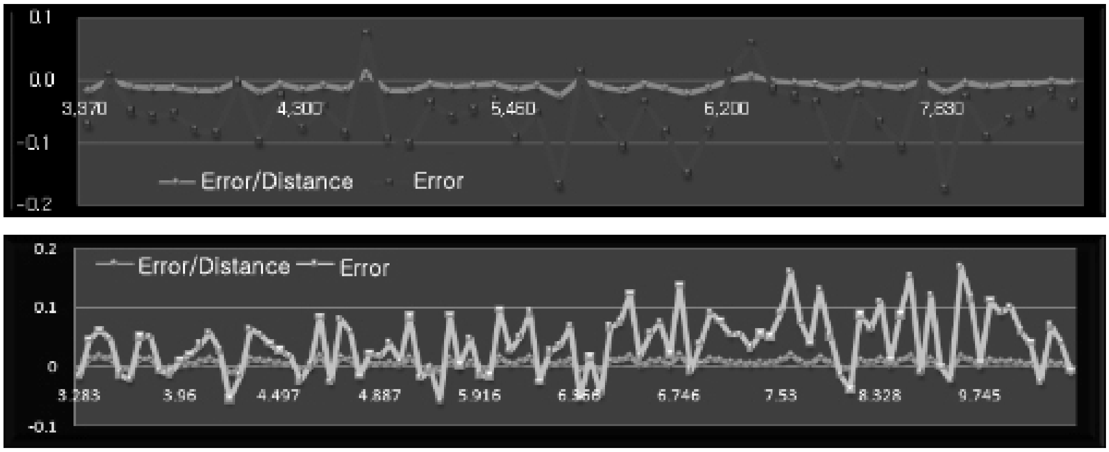

Figure 9. Deviation graphs in the 4th and the 5th field tests

Table 1. Comparison result of deviations (unit: meter)

Distance range	Maximum deviations	Average deviations	Standard deviation	Variance
3 ~5	0.083	0.034	0.0213	0.0005
5 ~7	0.136	0.050	0.0336	0.0011
7 ~9	0.158	0.068	0.0431	0.0019
9 ~11	0.168	0.065	0.0484	0.0023

5. Conclusions and Future Works

This study introduced the conceptual method of stereo vision system to be applied to create 3D terrain model in excavation operation. The stereo vision system has been deployed in broad ranges of area where it is normally limited to stationary objects in outdoor environments or steady-state objects in indoor. The application of stereo vision system to construction operation for creating 3D terrain model would face many challenges which are totally different with past researches. Accordingly, this study conducted many experiments using stereo vision system in construction sites in order to achieve appropriate applications and assessed technical characteristics including limitations. These experimental results suggest conclusions as follows:

- Indoor experiment conducted to find appropriate installation of stereo vision system on cabin of an excavator. Experimental results inform that the camera on the excavator is located in 2.8 meter height and 30 degree incline for acquiring available detecting areas.
- As result of several field tests in construction sites, most targeted terrain is well detected and created in 3D images. A few of images detecting concrete hume pipes and surface water have a problem that white hole is witnessed due to mismatching two images. It, however, would be overcome with use of more advanced algorithm for noise removal. The accuracy test of the distance data of 3D images showed that average deviation of distance data between 3D images and actual measurement was 0.051 meter. These deviations were gradually bigger while the distance from the camera to the target became more.
- In this study, the conducted tests of accuracy of 3D images by stereo vision system were limited only to visual assessment of 3D images and comparison assessment of distance data between 3D images and actual measurement. Although these tests provided basic guideline to the conceptual method, well-designed experiments need to be continuously developed. Accuracy and stability of this system on vibration by an excavator and reliability and accuracy of the acquired 3D images would be further experimented.

The primary findings and conceptual method suggested in this study would be applied to not only an excavator but also a dozer, a loader and other construction equipment. Based on findings in this study, further studies for achieving accurate 3D terrain model would be conducted in IES research project.

Acknowledgement

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