Rapid Local Modeling in Construction Automation

권 순 욱*
Kwon, Soon-Wook*

Abstract

Techniques to rapidly model local spaces, using 3D range data can enable implementation of: (1) real-time obstacle avoidance for improved safety, (2) advanced automated equipment control modes, and (3) as-built data acquisition for improved quantity tracking, engineering, and project control systems. The objective of the research reported here was to introduce current rapid local modeling techniques and develop rapid local spatial modeling tools.

Key Word : Rapid local modeling, Construction automation, Object fitting, Laser scanning

1. Introduction

Construction site environmental characteristics vary in temperature, humidity, sound, lighting, and air quality. Noise from equipment and other disturbances can cause miscommunications between an equipment operator and the person who directs the operator. The busy physical environment of the construction site can lead to collisions between structures and equipment such as truck-mounted concrete pumps, man-lifts, back-hoes, or manipulators (Cho et al, 2001). Furthermore, as changes are continuously introduced in building units, target materials, and equipment positions, an equipment operator has to continuously monitor relative positions of everything in a conventional working environment.

Results from an Occupational Safety and Health Administration (OSHA) study on construction fatalities from 1985-1989 reveals that construction accidents can be categorized into five types: (1) falls from elevation (33%), (2) struck-by accidents (22%), (3) cause-in/between incidents (18%), (4) electrical shock (17%), and (5) other (10%). In many cases, construction equipment operations have played a role in such fatalities.

To improve safety and to address the limitations of the work environment, more accurate equipment controls are needed. Current research shows that graphical models that help visualize geometric information using descriptive three-dimensional (3D) models can improve equipment controls for construction operations such as material handling, heavy lifting, and earth moving (Stenz 1998, Cheok 2000, Haas 1995, Kim 2000).

The use of range scanners for obtaining 3D range data for a construction site scene is increasing quickly (Cheok 2000). It is now possible to rapidly capture range data because, unlike traditional surveys, no target reflectors are required. Nevertheless, rich and raw data provided by range scanners and cameras are not sufficient for automating the manipulation operation. If there is no application to manipulate the scanned data, these raw data cannot provide site information directly. Workspace modeling, which can be defined as a virtual representation of the equipment's working environment, can be employed to facilitate automation tasks (Johnson 1998).

* 일반회원, Senior Researcher, KICT(Korea Institute of Construction Technology)
본 연구는 한국공학재단 연구비 지원에 의한 연구의 일부임. 과제번호 2000-21-22.

1.1 Need for Workspace Modeling

1.1.1 Use of Range Information to Generate Workspace Modeling in Automation and Robotics

As shown in Figure 1, NIST proposed the open architecture prototype in the construction automation area (1994). According to their research, there are five necessary features for automation and system integration including (1) real-time construction site metrology and site modeling using sensors, (2) data acquisition and wide - band telemetry, (3) site simulation using virtual model and data standard for object representation, and (4) feed back by person-in-loop systems. Among these features, construction industry has displayed a growing interest in site metrology and site modeling using sensors.

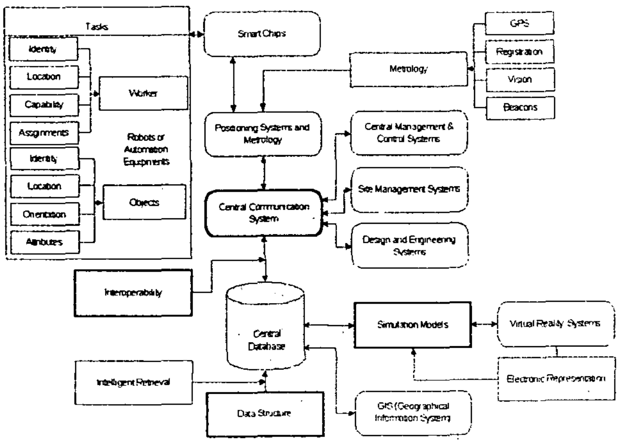

Figure 1. Open architecture prototype in construction automation

Considerable effort has been devoted to the development of various methods for extracting geometrical information from scenes. This extraction is still a major concern for both computer vision and robot vision (Lebegue and Aggarwal 1993, Tsukiyama 1996). The need for real-time determination of the 3D pose of rigid objects has been pointed out by a number of researchers (Simon, Hebert and Kanade 1993). Such a system needs to provide full 3D pose estimation of arbitrarily shaped objects in real-time. Such systems have been difficult to develop for three reasons: (1) there is less sensitivity for accuracy of 3D pose estimation in two-dimensional video image data, (2) the identification of features and correspondence with objects in the database are difficult in current 3D pose estimation applications, and (3) real-time 3D pose estimation is difficult to achieve due to the high computational load of existing methods (Simon, Hebert and Kanande 1993).

Laser range scanners have been widely used to obtain 3D range data for construction site scenes. Unlike ultrasonic and stereo vision, the laser range scanner provides a large amount of precise data. Research related to the use of laser range scanners in construction has focused on issues such as capturing 3D-digital conditions of the construction project, tracking the construction process in order to enable project control, and integrating construction process information into life cycle data. Laser range scanners have proven to be beneficial for tele-operable control of semi-automated or automated equipment on large construction sites where timely, on-site decisions require rapid recognition and accurate measurement of objects in the workspace.

A limitation of most workspace modeling applications is their reliance upon analyzing dense point cloud data, which requires computationally intensive processing that cannot be used for real-time equipment control. The low accuracy in extracting objects from dense point clouds is an additional limitation of current modeling systems. For real-world robotic, semi-automated, or automated equipment, the geometric information of target objects must be obtained rapidly (Lebegue and Aggarwal 1993).

Current workspace modeling applications demand large amounts of computation due to large data sets. Furthermore, these applications may not be appropriate for symmetric objects (Johnson 1998). The reason is that their representation of these objects makes it difficult to execute automated path planning due to the high computational cost of scanning each point on the surface (Feddema 1997).

2. Related Developments

2.1 Non-intrusive Scanning for Construction Assessment

The objective of the research, implemented by Cheok et al. 2000 from the National Institute of Standards and Technology (NIST), is to develop a system which can measure terrain changes on a construction site due to excavation and to demonstrate the results in real-time (see Figures 2 and 3). A Riegel scanner, LPG98, was used to scan the terrain. The scanned terrain data was derived from two locations around the construction site. Post-processing consists of: 1) the registration of the two scans based on the pre-defined positions of the scanner, 2) fine tuning the registration visually to decide the regions, 3) the selection of the region of interest using the scanned data, and 4) computing a volume. Some disadvantages were noted in the field-testing: 1) the battery was used for power supply needed to be recharged after each use, 2) the second scanner mounted on the pole in the center of the construction site was disturbed by dirt piles and construction equipment located in front of the scanner, 3) manual fine-tuning of the scanned data to merge was extremely time-consuming, 4) supplementary volume computing may be awkward when the erection of a structure begins. The authors noted that human cognition is one of the most important forms of intelligence in identifying the discarded points.

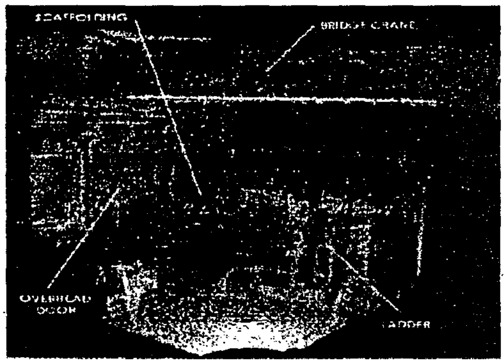

Figure 2. Actual scanning results using LADAR

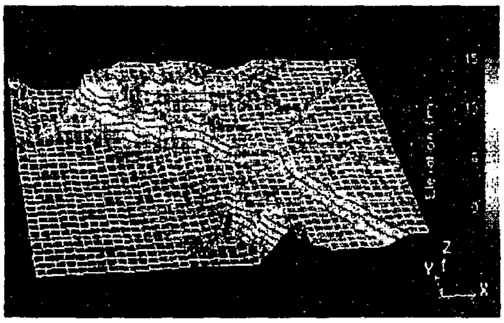

Figure 3. Meshed surface of scanned terrain

2.2 Autonomous Loading System (Stenz, 1998)

The Robotics Institute at Carnegie Mellon University has been developing the Autonomous Loading System (ALS). The ALS is a complete autonomous truck loading excavator which uses two scanning laser rangefinders to recognize and localize the truck, measure the soil face, and detect obstacles.

While the excavator digs its bucket of soil, the left scanner pans across the truck to automatically recognize, localize, and dimension haulage trucks, which are assumed to be parked to the excavator's side. Also, the left scanner measures the soil distribution in the truck bed for the calculation of the next desired dumping location. Meanwhile, the right scanner measures the dig face of the soil. Using an interpretation tree approach (Grimson, 1990), the simple model for a truck bed is matched to the segmented data region by region. The interpretation that matches most of the truck bed regions and survives the verification state is selected as the correct one.

The ALS research team does not provide modeling time and accuracy information because their focus is more on fully autonomous motion control. The brief wire-frame image of the truck bed may provide sufficient geometric information for dumping soil into an approximate calculated location in the truck bed, which does not require high accuracy of position data. More accurate geometric information verification is needed before the technology can be applied to solid material lifting and placing operations. The ALS must repeat the computer process of model-to-scene region matches every time a new truck arrives for loading. A manually operated computer assisted or a remotely operated backhoe would use the operator to identity the nature and general location at the truck

Figure 4. Sensors Mounted on Excavator(Stenz et al, 1998)

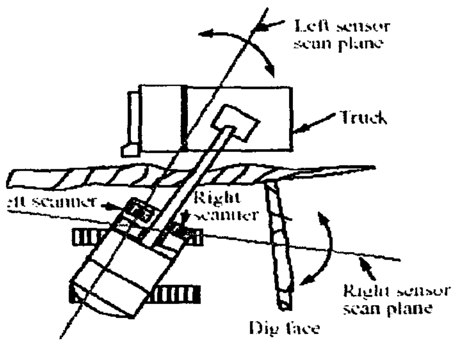

Figure 5. Top View for Sensors(Stenz et al, 1998)

2.3 3D Object Recognition System

Many related research studies have concentrated on developing a 3D object recognition method. Object recognition is a matching process between scene and model description. Efficient matching is a challenging problem because of the variability of object types, the difficulty in modeling some types of objects, and efficient verification for accuracy of fully automated equipment operation.

Johnson and Herbert (1999) developed an object recognition system using spin images which are used for matching different surfaces for efficient object recognition in cluttered 3D scenes. They used surface matching for:

- Model-based object recognition
- Aligning two surfaces of the same object represented in two different coordinate systems for the purpose of obtaining a transformation between two coordinate systems.

Their approach matches a surface based on matching individual points on two different scanned surfaces. The two surfaces are matched when the images of many points on the surfaces are similar. It is difficult to describe surface points so that they can be differentiated from one another. Though these researchers developed a new method which can recognize objects by collating object information stored in sensed 3D points, their method is not very efficient because it requires a large amount of time to filter dense point cloud.

2.4 Graphical Programming for Automating Construction

McDonald (1999) researched the use of robotics and graphical programming in construction automation. In his research, he has proved that model-based approaches are very effective in enabling non-experts to program robot systems: His system reduces robot operator training requirements while decreasing the programming time for even complex operations. Furthermore operators can visualize and understand the effects of complex commands before moving machinery.

This system improved safety problems in which:

- Hazards are predicted through simulation and locked out through program control
- Operator is warned of motions that cause near-collisions (the operator specifies the near miss distance)
- Motions that could potentially cause collisions are not allowed to be commanded to the robot without override permission
- The System verifies its own accuracy

2.5 Human-Assisted Fitting and Matching Methods

In this chapter, the background and motivations of the human machine interaction are methods developed here explained. Five different fitting and matching methods are introduced. Also, the detailed logic of the methods for rapidly modeling geometry primitives at construction sites is described.

Recent research has focused on automated object recognition to create world models (Eberst et al, 2000, McLaughlin 2002). Little research has examined the use of a human operator's cognitive skills for object recognition in a work environment, however. The human ability to recognize objects is valuable for rapid workspace modeling for construction site scenes since the object recognition methods currently being used require heavy computational loads and present accuracy problems (Kim 1998, Cho 2002). Successful results of overall efficiency and productivity have been achieved using human-machine systems (Trevidi 1).

Even though the development of a machine-based perception system is an important and demanding area, higher levels of perception such as recognition and matching issues do not have easy solutions. Trevidi observed that a human operator is able to give assistance for perceptual support in an integrated control system. This research explained that humans have a remarkable symbolic analysis ability. Thus, the possibility for the potential of human assistance in object recognition in construction automation and robotics exists and should be more fully explored.

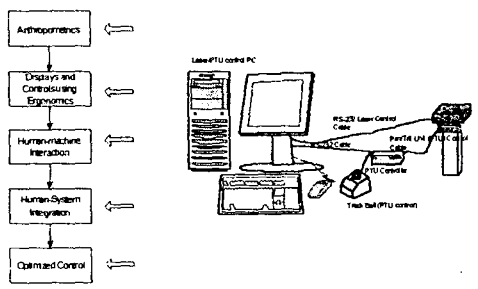

Figure 6. Human-assisted Machine Control System and Sensing System

2.6 Object Fitting and Matching Methods

Graphical workspace modeling can improve construction equipment control and operations. Equipment operators can use graphical workspace models as an interactive visual feedback tool while controlling equipment (Kim 1998). For the rapid modeling of construction site objects from sparse point clouds, four basic methods have been developed that address construction site objects: (1) the cuboid fitting and matching method, (2) the curved+flat surface and curved surface cylinder fitting and matching method, (3) the planar fitting and matching method, and (4) the sphere fitting and matching method.

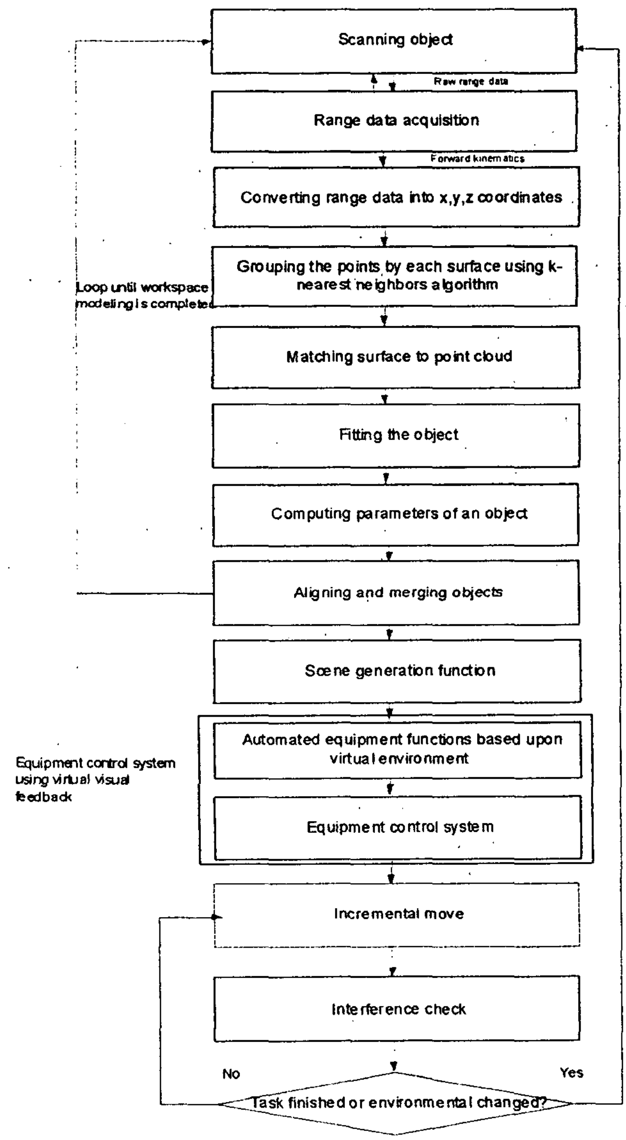

Figure 7. Fitting and Matching Process

Since a cuboid consist of 6 planar surfaces and a cylinder of two planar surfaces and one curved surface, the methods that have been developed are based on surface fitting and matching methods. Method development and revisions were based on lab experiments. By using these methods the following were achieved: (1) accurate and reliable methods saving computational cost and time, (2) improved fitting and matching methods to attain real-time execution, and (3) increased modeling accuracy with operator's assistance. Figure 7. shows the object fitting and matching process which additionally includes merging and aligning method and automated control functions that were not covered in this dissertation research.

Figure 8. Scene Picture

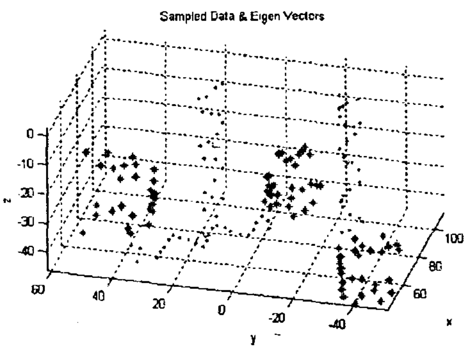

Figure 9. Raw Range Data of Scene

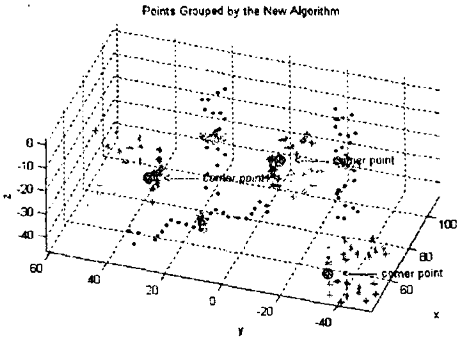

Figure 10. Segmentation and Fitted Result

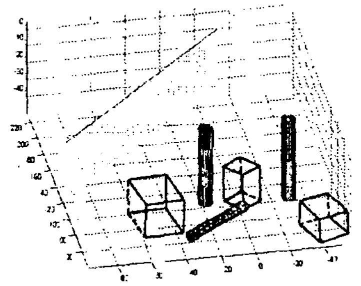

Figure 11. Completely Fitted and Matched Scene

3. Conclusions & Recommendations

A rapid 3D modeling approach that combines human recognition and a simple laser range finder has been developed. The short modeling times possible (minutes per scene) and the relatively small errors obtained in the modeling of primitives (usually no more than 5 percent for cylinders and cuboids) show that this method can be used to model construction-site objects at a sufficiently rapid rate and with reasonable accuracy. This method is computationally efficient and suitable for use in applications such as safety enhancement in equipment control. It is also acceptable for generating construction as-builts.

References

1. Cho, Y., Haas, C. T., Saidi, K., Liapi, K., and Sreenivasan, S. V., "Rapid Local Area Modeling for Construction Automation," Proceedings of 18th International Symposium on Automation and Robotics in Construction, Krakow, September 2001.

2. Occupational Safety and Health StandardsExcavation Final Rule, Occupational Safety and Health Admin., Fed. Register, U.S. Dept. of Labor, Vol. 54, p 209, Washington, D.C., 1990.

3. Kim, Y., and Haas, C. T., "A Model for Automation of Infrastructure Maintenance Using Representational Forms," Journal of Automation in Construction, Elsevier, pp.57-68, October 2000.

4. Stentz, A., Bares, J., Singh, S., and Rowe, P., "A Robotic Excavator for Autonomous Truck Loading," Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, Vol. 3, pp. 18851893, 1998.

5. Haas C. T., Skibniewski, M., and Bundy, E., "History of Robotics in Civil Engineering," Journal of Microcomputers in Civil Engineering, Vol. 10(5), pp371-381, 1995.

6. Cheok, G., Lipman, R., Witzgall, C., Bernal, J., and Stone, W. C., "Field Demonstration of Laser Scanning for Excavation Measurement," Journal of Automation in Construction, Vol. 9, pp 463-477, 2000.

7. Johnson, A., Hoffman, R., Osborn, J., and Hebert, M., "A System for Semi-automatic Modeling of Complex Environments," Proceedings of International Conference on Recent Advances in 3-D Digital Imaging and Modeling, pp. 213-220, May 1998.

8. Stone, W., "Non-Line-of-Sight (NLS) Construction Metrology", NIST Construction Automation Report No.1, 1996.

9. Simon, D., Hebert, M., and Kanade, T., "Real-time 3-D Pose Estimation Using a High-Speed Range Sensor," Techical report CMU-RI-TR-93-24, Robotics Institute, Carnegie Mellon University, November 1993.

10. Feddema, T., and Little, C., "Rapid World Modeling: Fitting Range Data to Geometric Primitives," Proceedings of the IEEE International Conference on Robotics and Automation, Vol. 4, pp. 28072812, 1997.

11. Johnson, A., and Hebert, M., "Using Spin Images for Efficient Object Recognition in Cluttered 3D Scenes," IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 21, No. 5, pp. 433 449, May 1999.

12. Macdonald, D., Space and Advanced Robotics Ltd., 9445 Airport Rd., Brampton, Ontario, Canada L6S 4J3, Tel. 905-790-2800,

13. Eberst, C. et al, "Robust Video-Based Object Recognition Integrating Highly Redundant Cues for Indexing and Verification" IEEE Proc. of Int'l Conf. on Robotics and Automation, April 2000.

14. McLaughlin, J., "Rapid Human-assisted Creation of Bounding Models for Obstacle Avoidance in Construction," Master's thesis, Department of Mechanical Engineering, University of Texas at Austin, Austin, Texas, 2002.

15. Trevedi, M., Chen, C., "Developing Telerobotic Systems Using Virtual Reality Concepts," Proceedings of the 1993 IEEE/RSJ International Conference on Intelligent Robots and Systems,Yokohama, Japan, July 26-30, 1993.

16. Kim, Y., Haas, C., and Greer, R., "Path Planning for a Machine Vision Assisted, Teleoperated Pavement Crack Sealer," ASCE Journal of Transportation Engineering, Vol. 124, No. 2, pp. 137-143, Mar./Apr. 1998.

Acknowledgements

This paper is based on the research funded by the National Science Foundation (Grant no. CMS-0000137) and National Institute of Standards and Technology (Grant no. NA1341-02-W-0742). The authors gratefully acknowledge their financial support and encouragement throughout this study.