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TASK PLANNING AND VISUALIZATION SYSTEM FOR INTELLIGENT EXCAVATING SYSTEM

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ABSTRACT: The earthwork is essential procedure for all civil engineering projects. Because of its importance in terms of cost and time, it should be managed effectively. In light of this, The Intelligent Excavating System (IES) research consortium has established to improve the productivity, quality and safety of current excavating/earthwork system by the Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korea. This paper summarizes ongoing research aimed at development knowledge and presents a framework of task planning and visualization system for IES. The task planning and visualization system consists of three functions. 1) Using digital terrain model which created by 3D laser scanner, the system can divide it and generates global/local work area so that the excavator can work through the area. 2) In order to operate and/or control the excavator, the system exports the location, paths of boom, arm and bucket data of the excavator to control center. 3) The task planning system is visualized on the computer programming aided-graphic interface which simulates the planned work processes and eventually assists the operator for the control of the excavator. The case study which we have performed, demonstrates the effectiveness of the proposed system.

Keywords: Task Planning; Intelligent Excavation System; Visualization

1. INTRODUCTION

The earthwork is essential procedure for all civil engineering projects. The excavator or backhoe, which is the mostly used for earthwork, still frequently operates in dangerous environment such as steep slopes and often causes serious problems in safety. According to Sakaida [1], the performance of excavator is heavily rely on the skills of operator. It may causes difficulties in quality control and further overall project management. Table 1 shows the other characteristics of excavating work. Also, these problems have been constantly accelerated due to the social problems; aging society and accordingly lack of skilled operators.

Many automation techniques have been invented and applied to the construction site in order to improve current conditions. Its level of use, however, is quite lower than expectation because construction site environment tend not to support these techniques and of economic limitation. Moreover, many construction activities become increasingly rely on excavators for earthwork and earthmoving, an efficient operation of excavator can have a positive influence on construction project.

In light of this, the Intelligent Excavating System (IES) research consortium has established to improve the productivity, quality and safety of current excavating and/or earthwork system by the Ministry of Land, Transportation and Maritime Affairs (MLTM) of Korea.

Table 18. Characteristics of Excavating Work

	Characteristics
Excavating Work	□ Lack of skilled worker □ Labor-intensive □ Non-linear work environment □ Hazardous work condition □ Heavily depending on skill of operator □ Inefficient quality control

The main objective of this research was to develop knowledge and framework of task planning system for excavator and its visualization system. In our research, we have focused on firstly, 3D imaging system for terrain modeling, secondly, task planning system for excavator, thirdly, visualization of operation and work environment to assist the operator to control.

2. PREVIOUS STUDY

The research described in this paper is related to previous research studies within areas of task planning systems in particular for excavator and visualization of operation. This section summarizes previous research and account for integrating the previous efforts to achieve the goal of IES research.

2.1 Task Planning

There have been many efforts in order for excavator to operate fully autonomously. The LUCIE from Lancaster University project [2] and autonomous truck loading project from Carnegie Mellon University [3,4] are considered as good examples. There are still many studies focusing on the technologies in associated with excavator automation. Makkonen, Nevala and Heikkila [5] examined the possibilities of controlling a six degrees of freedom(DOF) excavator with the final objective of controlling the movements of the excavator by using a positioning system such as a GPS in conjunction with a CAD model of the road surface. A triangular terrain model was first compiled in the xyz file format and then equations were derived from the file in order to calculate the target transformation matrix used to control the position of the excavator bucket. Kolera and Bernold [6] researched the development of an intelligent utility locators to expect the location of utilities buried in the ground. They contrived the scanning routine to define pipe direction and a control program was created to actuate the antenna in a predefined scanning motion over the surface of the ground while collecting sensory data for underground metallic objects. Kim et al. [7] attached three sensors for detecting motions of human body to operate the excavator. In addition, using Bluetooth wireless communication, work commands can be transmitted to robot.

These studies have identified many advantages by adopting state-of-the-art technology. However, there are few studies with task planning on how skilled operator works. Therefore, our approach is that examine the task planning methods or rules in construction site from supervisor and skilled operator.

2.2 Visualization

The use of visualization and virtual reality technologies of construction field has been studied in various aspects. The research of Kang and Miranda [8] was to implement automated robotic crane erection process. They implemented the intelligent crane in a computer system, iCrane, which can automatically generate the operation-leveled simulation of erection process and OpenGL, a graphical language broadly used in computer graphics, was used to implement the intelligent crane in a 3D graphical environment. Site layout and the tower cranes are visualized in the virtual world. The motion planning of iCrane is applicable to visualize excavation in the task planning system of IES. Kamat [9] capitalized on virtual reality technologies in planning and design of construction operations to generate alternate operations level virtual world scenarios for comparison, evaluation and "what-if" analyses. A 3D animation language named VITASCOPE(acronym for VIsualizaTion of Simulated Construction OPErations), which is capable of describing dynamic construction scenarios by properly illustrating all common construction tasks, was used for 3D visualization of operations level.

In order to achieve the goal of research, we need to further improve the degree of automation in task planning and visualization system. Our approach of task planning is focused integration of prior research (task planning and visualization technique) and heuristics of operator to enhance efficiency of operation and safety because the task planning system should reflect the way of skilled operator's work pattern.

3. SYSTEM DEVELOPMENT

Task Planning System (TPS) generates the comprehensive work plan by using planning algorithm with heuristics of operator and received DTM, which included global sensing, local sensing and work environment data. The work plan is devised after dividing the target terrain into global area, local area, and local package. Global area means the components dividing the whole area for the excavator to work, and local area means the components fixing the area considering a certain direction and continuity which are the work path characteristics of the excavator, also a certain standard of area where the excavator will work after being located at the platform, to be created after unit work area division. Local package means the components dividing the local area by considering the plan and the characteristics of each work path of the bucket when the excavator works.

To manage earthwork/excavation activity, the amount of earthwork is needs to be calculated in comparison of existing terrain model and sensing data. The work order is given after dividing areas at each stage and the movement path generation of the excavator and the work are performed based on the platform to be located for the excavator.

3.1 3D Imaging Systems for Terrain Modeling

In complicated work environment, such as terrain for earthwork, it is difficult to generate model for analysis. In task planning system, however, terrain model is essential in order to generate the task sequences and paths for excavation robot. There are several technologies to overcome this drawback; 3D laser scanning and machine vision system. Machine vision system, however, have lots of noise in image when applying this technique to the outdoor environment with many obstacles and objects [10, 11]. On the contrary, 3D laser scanning also known as LiDAR (Light Detection And Ranging) can be used for performing terrain mapping without data collision and human error. Therefore, in this research, we used LiDAR for creating digital terrain model (DTM). As shown in figure 1, there is a procedure to get 3D DTM of construction site.

Since this study is focused on the general type of earthwork (Roadway, Building, etc.), the construction site which we deal with is relatively large so that it requires multi-scanning to prevent slenderness effect and obstacles. By reason of this, the hardware of the scanning devices should be placed on vehicles, then it scans the construction site for various positions. Once the scanning is finished, scanning results for various positions should be merged into one DTM by using recognition targets which already installed at a critical position [12]. In order to edit and manipulate the DTM, the model should be extracted to CAD file format.

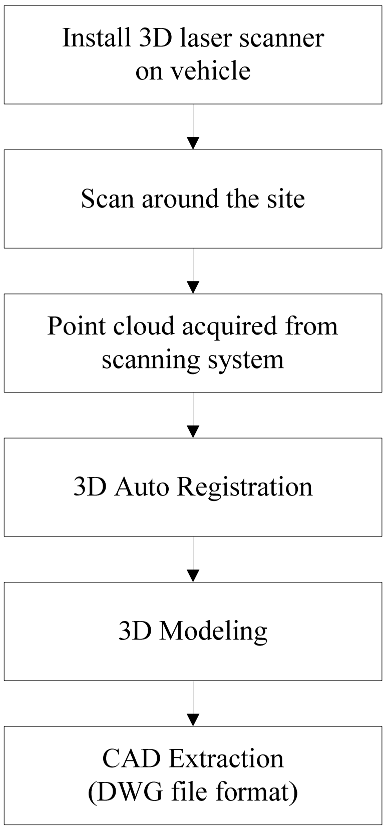
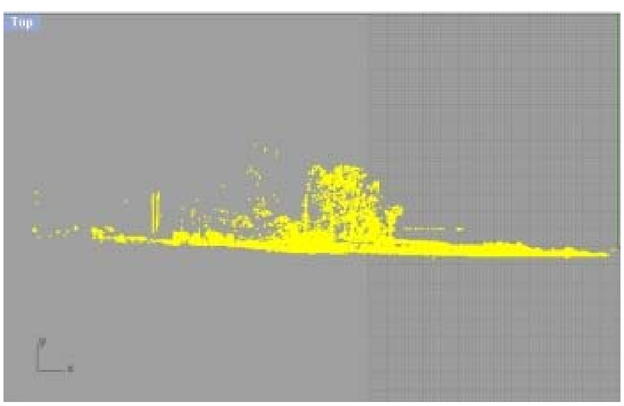


Figure 6. Terrain Modeling Procedure



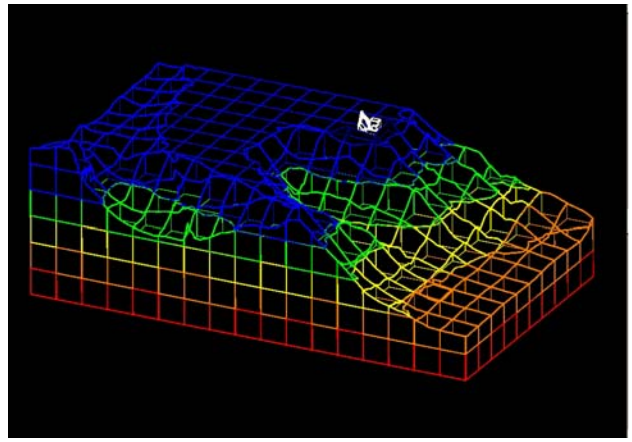


Figure 7. Acquired Point Cloud and DTM from LiDAR

3.2 Task Planning System

The main function of TPS is to generate the work plan and the supervisor's knowledge to enable IES to perform the optimal task plan virtual reality updated real-timely on the basis of the sensor data.

TPS performs many functions comprehensively includes the overall task plan for earthwork such as area division, the optimal platform creation, the general approach of work sequence, the optimal path plan, the quality control, and compile the whole work information into a database of Project Management Information System (PMIS) which is the construction management module, as shown in figure 3. Also, it is applied as a monitoring system by building the work contents through virtual reality simulation.

There are two technologies to acquire the working environment; 3D imaging system and local sensing. The role of local sensing is the process to map the data for the local area where becomes the target when the excavator is located at the platform to work.

In this study, we collected work pattern and related heuristics for developing the method of area division, which is the main function of TPS [13]. In the following subsections, the area division methods are proposed.

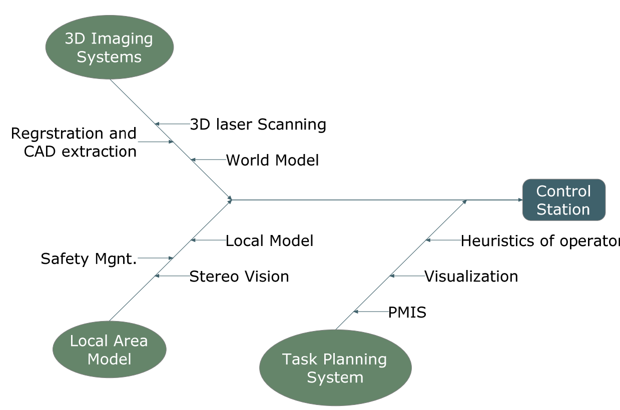


Figure 8. Task Planning System Development

3.2.1 Global area

Global area means the process to divide the terrain model horizontally using average excavating depth that is efficient most and that considers the safety at the excavating position in terms of excavator specification. A skilled operator consider many safety factors during work, and perform the work by making the cutting depth 2~3m deep of the optimal vertical excavating depth according to the excavator specification. Then the operator implements the work from top to down in the ground height.

In early division level, the efficient work plan should be considered for excavator, so the system generates layers of terrain model through the horizontal division of the area. This is the process to divide the area by the similar works of each geographical feature, and divided according to the earthwork plan. This enables one to consider it when working out the work plan by designating the location of an obstacle or an intrusion by the district to be preserved having been recognized in the geographical information. One secures the transfer road and the working space by removing the intrusion that is not worth its keep and that can be removed by the excavator, and one designates it as a conservation district by recognizing the intrusion to be preserved as the work-excepting section for evading or selecting a detour.

3.2.2 Local area

Local area is the process to divide terrain layer that created former division into local area so that the excavator work through the paths. Platform means the position where the excavator is located, and the standardized area where the excavator works after being located once as a platform unit area, that is, as local area. A certain location of platform position is decided automatically as dividing unit work area into local area. The skilled operators perform the excavation as keeping up the angle between boom and arm to be nearly 180 degree for efficient working, and can improve the work efficiency by designating local area so that the horizontal rotation angle of the boom is to be applied within 90 degree when loading the truck.

When designing local area, the area for gathering the earth and the safety is designed by having the extra space. It is not only reduces idle-time of excavator but also improve the work efficiency by preventing the safety accident. Local area is unit area divided by a certain rule considering the trajectory of bucket and kinematics. The designed terrain model including each areas organizing local area is defined as local package. Local package standards are affected by the specifications of excavator and other working environment conditions. Local package algorithm was made to calculate standards according to algorithm if input variables being required respectively, and user interface for users' convenience was developed.

The input variables and designed local package through this supply the division standards that become the standards when performing the area division module, and are applied also to the impact data in performing other modules after user interface is configured on the initial screen before the performance of TPS modules First of all, the user inputs the track length, the vertical optimal excavation scope, the maximum horizontal excavation scope, the height to the center-joint which are the excavator dimension inputted to the earthwork as the input data of user interface. The optimal horizontal excavation scope length considering the excavating depth and the excavator's height by the inputted data, the radius of gathering the earth and the safety space length are to be calculated. The horizontal excavation angle applies 180 degree by considering a skilled worker's heuristics and the excavating efficiency. The following figure is the plan of the local package made by applying AutoCAD™.

4. VISUALIZATION

The task planning system is visualized on the computer programming aided-graphic interface which assists the operator and the supervisor for the control of the excavator. The precedent objective of IES is to embody a tele-operated excavator. In case of tele-operation, a closed-circuit television camera (CCTV) is attached on the windshield of cabin. This camera is the only eye the operator is able to make use of. Therefore the operator barely can take the sights except the front view. Excavator operators and supervisors are in need of awareness for the whole situation in fields. The task planning system offers additional eyes and performs the indicator.

There are five functions for visualization of the operation. First, the visualization of excavation itself. The operator needs to check whether the object is well-excavated or not. Second, the quality control. The remained object is opaquely visualized through side view of the excavator. This measures the amount of remained object Third, the indication of path. The sight degree of freedom for the operator is too limited to recognize the next spot to proceed. The task planning system plays the role of navigation. Fourth, the emergency stop and alarm. Almost every object such as cars, trees, various obstacles, etc are sensed in the process of global sensing. However there could be a non-foreknown alien object which can be equipment, electric facilities, animals or even a person. There accordingly must be a function for the case of emergency. Fifth, the awareness of whole progress. The globally sensed 3D terrain model and work progress are visualized for the supervisor to understand what is going on the field.

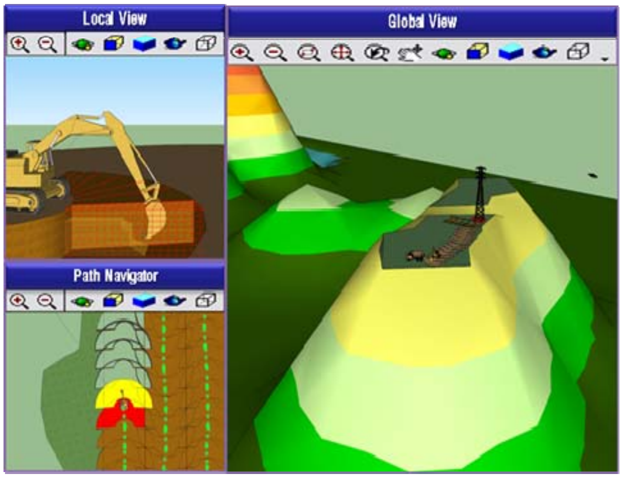


Figure 9. The Framework of Visualization of Operations

There are three separate windows work at the same time; Local view, path navigator, and global view.

Local view is requires complicated mechanism because of its various kinds of data. After the global scan data is transmitted to the task planning system, the platform and excavation spots are marked and transmitted to move the excavator. When the arrival to the designated platform is completed, the task planning system sends the action-sign to initiate excavation and receive the local scan data. The coordinates which are sensed through hydraulic cylinder sensor, of joints between the boom with are and arm with bucket are sent to the task planning system in every bucket move. The excavator components are materialized with the coordinates in 3D computer graphic. The data traffic is completed more frequently than local scan data trade-offs. The remained object is conspicuously visualized with local scan data. The vanishing soil is showed in every moment local data is transmitted. When one bucket area is clear, the task planning system transmits the swing-sign and the excavator is swung to the next bucket area.

Path navigator basically plays the role of navigation for the operator. It is run only when the excavator is moving and taking turns. After receiving the global scan data, the task planning system marks the excavator moving paths, platforms and obstacle location on the terrain model and transmits it to move the excavator. Current location coordinates of Global Positioning System (GPS) is real-timely exchanged. When the excavator is in need of taking turn, the task planning system alarms the operator and indicates the direction. In case of emergency, alarm and stop is launched then the location of non-foreknown alien object is marked on path navigator. After the object is removed, the task planning system transmits the work-resume sign.

Global view is composed of the simplest principle and can be visualized only by its own data without communication network. Global view shows the whole topography of the work field and the located excavator. The vanishing local area and layers are expressed in global view.

5. IMPLEMENTATION

The task planning first initiates the process to divide the terrain model horizontally on the basis of the average excavator operators' excavating depth that is most efficient and safety-considered. Skilled operators reduce the risk of a skid by considering the bearing capacity of the ground, and perform by cutting 2~3m depth and carry out high to low topographical height of the ground. According to this heuristics, the task planning system executes the layered-division by uniform height. The scanned global data is converted to 3D model through mesh configuration [Fig. 5].

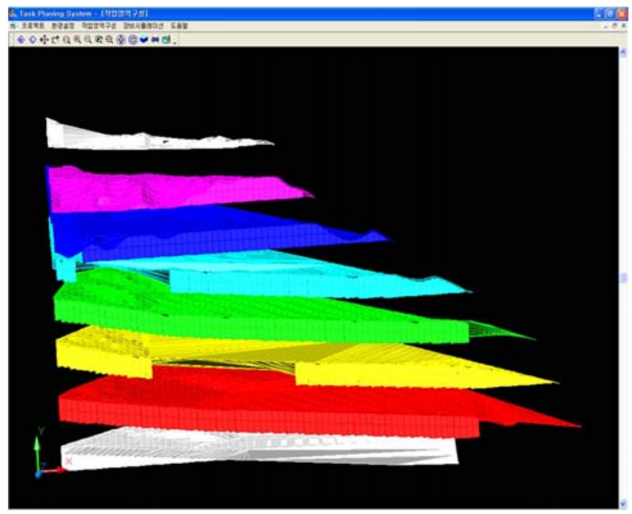


Figure 5. 3D Model of Layered-Division

Local package algorithm was made to calculate standards according to algorithm if input variables being required respectively and Graphical User Interface (GUI) was developed. The user inputs the track length, the vertical optimal excavation scope, the maximum horizontal excavation scope, the height to the center-joint which are the excavator dimension inputted to the earthwork as the input data of the interface. The task planning system creates local package standards by inputting the data necessary in designing local package.

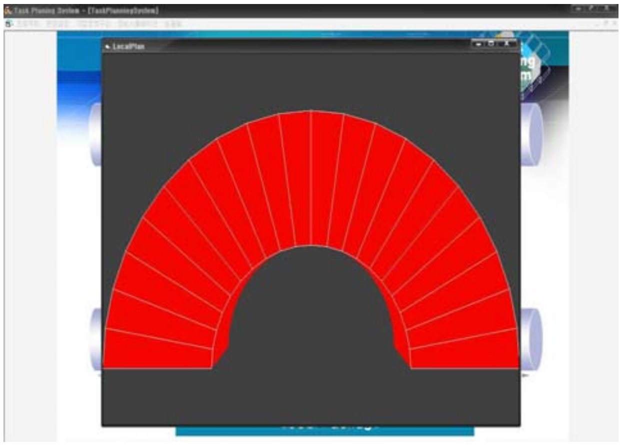


Figure 6. Top View of Local Package

Each layer is derived to designate the unit work and local areas. The topography of Jinhae city, in Korea, was used as a case study and eight layers were derived from the mesh terrain model. The highest layer always appears the bumpiest state. Therefore the local planning needs to be designated most carefully on the first layer. Figure 7 shows the derived first layer by computer-programmed the task planning system.

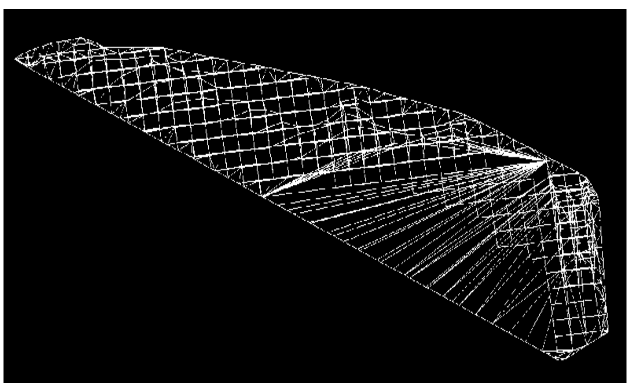


Figure 7. The Highest Layer of Global area

After a layer is derived, unit work areas are designated though the unit work area algorithm that considers the topographical edges, obstacles (transmission towers, various facilities, underground pipes, etc), drainage, configuration of terrain, and so on. Unit work areas are designated with taking of spreading shape because of the transportation roads are concerned. After the unit work areas are defined, local areas can be demonstrated immediately because each unit work areas are consist of local areas in advance. Figure 8 shows the 3D solid model based concept of unit work area and local area.

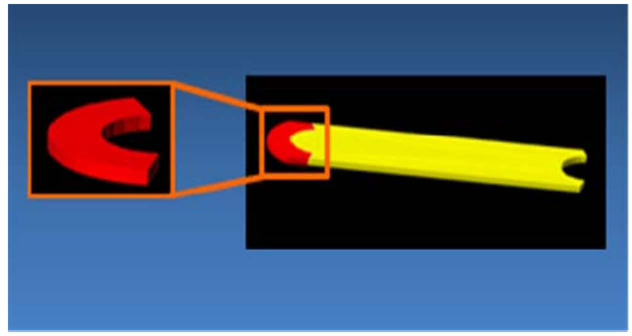


Figure 8. The 3D Model of Local Area

6. SUMMARY AND CONCLUSION

The study proposes an integrated framework of task planning and visualization system for intelligent excavation system. The approach presented in this paper intends to provide integrated task planning system so that the operator can operate effectively and safely even if the operator has no experiences. The method uses the heuristics of operator in order to establish a general task planning in excavating. By using digital terrain model which generated by 3D laser scanning, we divide into global area, which includes horizontal, vertical division, local area, which includes boom, arm, and bucket paths of excavator.

The study is expected to provide a solution to improve planning of excavating operations by combining 3D laser scanning and visualization technique to navigate in accordance with task planning, and hence overcome drawbacks of the existing methods and conditions. Although task planning system has not fully implemented and integrated with mechanical and electro-hydraulic system in terms of protocol and types of data transfer so far, we believe that much of this research will be practice for future autonomous robotic excavator.

Acknowledgement

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REFERENCES

[1] D. C. Yuki Sakaida, Kuniaki Kawabata, Hayato Kaetsu, Kajime Asama, "The Analysis of Excavator Operation By Skillful Operator," in *ISARC*, Tokyo, 2006, pp. 543-547.

[2] D. A. Bradley and D. W. Seward, "Developing real-time autonomous excavation-the LUCIE story," in *Decision and Control, 1995., Proceedings of the 34th IEEE Conference on*, 1995, pp. 3028-3033 vol.3.

[3] A. Stentz, J. Bares, S. Singh, and P. Rowe, "A robotic excavator for autonomous truck loading," in *Intelligent*

Robots and Systems, 1998. Proceedings., 1998 IEEE/RSJ International Conference on, 1998, pp. 1885-1893 vol.3.

[4] A. Stentz, J. Bares, S. Singh, and P. Rowe, "A robotic excavator for autonomous truck loading," *Autonomous Robots,* vol. 7, pp. 175-186, Sep 1999.

[5] T. Makkonen, K. Nevala, and R. Heikkil, "A 3D model based control of an excavator," *Automation in Construction,* vol. 15, pp. 571-577, 2006.

[6] B. Kolera and L. Bernold, "Intelligent utility locating tool for excavators," *Journal of Construction Engineering and Management,* vol. 132, p. 919, 2006.

[7] D. Kim, J. Kim, K. Lee, C. Park, J. Song, and D. Kang, "Excavator tele-operation system using a human arm," *Automation in Construction,* vol. 18, pp. 173-182, 2009.

[8] S. Kang and E. Miranda, "Planning and visualization for automated robotic crane erection processes in construction," *Automation in Construction,* vol. 15, pp. 398-414, 2006.

[9] V. R. Kamat and J. C. Martinez, "AUTOMATED GENERATION OF DYNAMIC, OPERATIONS LEVEL VIRTUAL CONSTRUCTION SCENARIOS," *ITcon,* vol. 8, pp. 65-84, 2003.

[10] C. H., "Extended Earthmoving with an autonomous excavator," in *Carnegie Mellon Robotics Institute*. vol. Master: Carnegie Mellon University, 1999.

[11] M. Chae, G. Lee, J. Kim, H. Yoo, and M. Cho, "Development of the 3D imaging System and Automatic Registration Algorithm for the Intelligent Excavation System (IES)," *Korean Journal of Construction Engineering and Management,* vol. 10, pp. 136-145, 2009.

[12] M. Chae, H. Yoo, J. Kim, M. Cho, J. Jang, and D.S.Jang, "3D IMAGEING SYSTEM FOR THE INTELLIGENT EXCAVATION SYSTEM (IES)," in *International Symposium on Automation and Robotics in Construction*, Lithuania, 2008, pp. 286-291.

[13] S. Lee, J. Kim, S. Kang, and J. Seo, "Development of task planning system for intelligent excavating system applying heuristics," *Journal of the Korean society of civil engineers,* vol. 28, pp. 1-11, 2008.