Development of a Heuristics-based Task Planning System for Intelligent Excavating System

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Abstract

A research consortium called 'Intelligent Excavation System (IES)' has been formed in Korea with the support of the Ministry of Land, Transport and Maritime Affairs of Korea. The final goal of this research consortium is to develop a robotic excavator that can improve the productivity, the quality, and the safety of the conventional earthwork. The knowledge of the construction metrology and task level planning should be well fed into the robotic control mechanism in order for the machine to have the intelligence of the construction planner and the operator. Task Planning System (TPS) is one of the core technologies of IES. TPS generates an optimal earthwork system based on a virtual work environment updated in real time by work environment cognitive technology. TPS is an integrated module based on the heuristics of skillful excavator operators for effective and error-minimizing work planning. In this paper, the heuristics and the functions of system modules along with the virtual reality-based simulation results are presented.

Keywords: Intelligent Excavating System (IES), Task Planning System (TPS), Heuristics, Simulation, Earthwork

1. Introduction

1.1 Background and Purpose

The production lines in most industries now have been automated, which has brought many benefits such as the improvement of productivity and economical efficiency, the safety against industrial disasters and the quality of work. However, the automation in the construction industry has still depended on the labor input through the use of the construction equipment because of unstructured and dynamically changing work environment and the large handling capacity required by the heavy weight of construction materials. The development of construction robots as well as semi-automated construction equipment has been increased with the rapid development of IT (Information Technology) along with the needs of the construction automation recently. In particular, the development of earthwork automation system is on its way actively because of the highest demands among construction equipments. Now, the development of the IES for the earthwork automation is on progress since 2006 as a part of Construction Technology Innovation Program of Ministry of Land, Transport and Maritime Affairs in Korea. The development of the IES is being performed by the industrial, academic, research institutions of 16 in total such as Hanyang University, Korea Institute of Construction Technology, Korea Electronics Technology Institute, Korea University, Inha University under the principal investigation of DooSan Infracore Co., LTD. IES has a research plan of five years by organizing three research teams after dividing their roles on the basis of three detailed core technologies. The third-year research of the development of the IES is under way now. The system development for remotely-controlled excavator has been almost completed based on the element technical analysis, algorithm and the system structure design which is the first-year research content. The development is kept up on the basis of the close technical cooperation among each division until the fourth year, and the development of the IES will be completed at the end of 2011 by finishing the fifth-year research after going through the performance evaluation of the system.

The final purpose of this project is to improve the productivity, quality and safety in the earthwork, and to develop an intelligent unmanned robotic excavator to be able to overcome the lack of skilled workers and manpower. To do so, TPS, which can establish an efficient working plan by analyzing the geographic information acquired through 3D scanner, should be developed. After compiling a database of a skilled operators' heuristics, TPS is able to devise an efficient work plan.

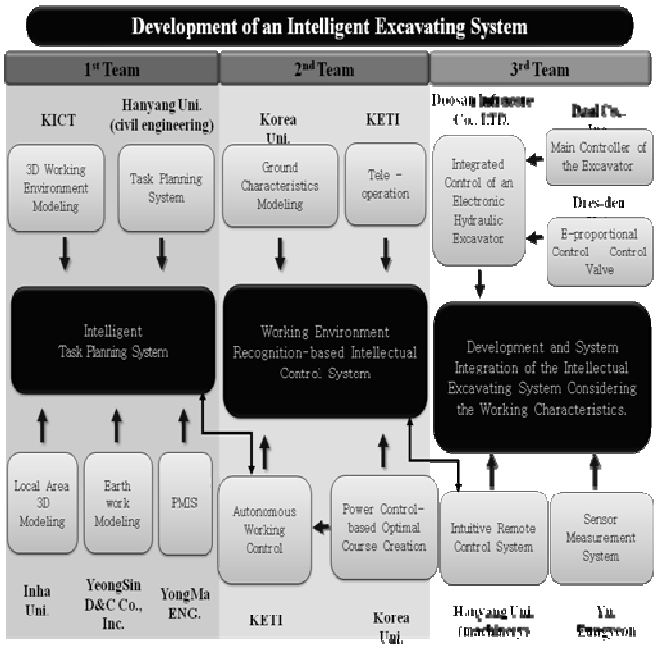

Figure 1. IES research system

1.2 Scope and Methodology

This research collected and compiled heuristics which is skilled workers' experiential knowledge of the earthwork. On the first-year research for the development of TPS, the algorithms for module development was devised based on the heuristics. Task planning simulator to plan and visualize the earthwork process with the virtual reality-based simulation was developed in the second year. The third-year research now is focusing on the integration of TPS with other modules of the IES such as sensors and equipment controller.

The scope of this paper is to present the detailed functions of TPS and to examine the characteristics and the advantages of TPS developed through the skilled operators' heuristics and equipment controller.

2. Intelligent Excavating System (IES)

IES is an excavator-based robot. The excavator robot senses the whole work environment in real-time through sensors and devises the optimal working plan based on the data of the earthwork design and the work environment. On the basis of this, the robot body performs the movement and the work through the intelligent self-control system.

IES is built upon three core technologies. The first technology is 'the intelligent task planning system', which is the development of the work plan creation system to play the core brain role of the IES. The second technology is 'work environment recognition-based intelligent control technology' which is the development of the technology related to the autonomous control as the robotic excavator creates the optimal path for the manipulators. The third technology is 'the development and the system integration of an IES considering the work characteristics', which develops the robot's body and hardware and integrates and manages all the developed system modules. The Fig 2 shows the detailed core technology.

3. Task Planning System (TPS)

TPS is the technology to create the working plans by granting the earthwork and the superintendent's knowledge to enable IES to perform the optimal earthwork plan on the basis of the virtual working environment in a computer identical to the practical working environment updated real-timely on the basis of the sensor data.

TPS performs the tasks related to the whole plan creation on the excavating works such as area division, the optimal platform creation, the sequential creation of works, the optimal excavator movement path plan and creation

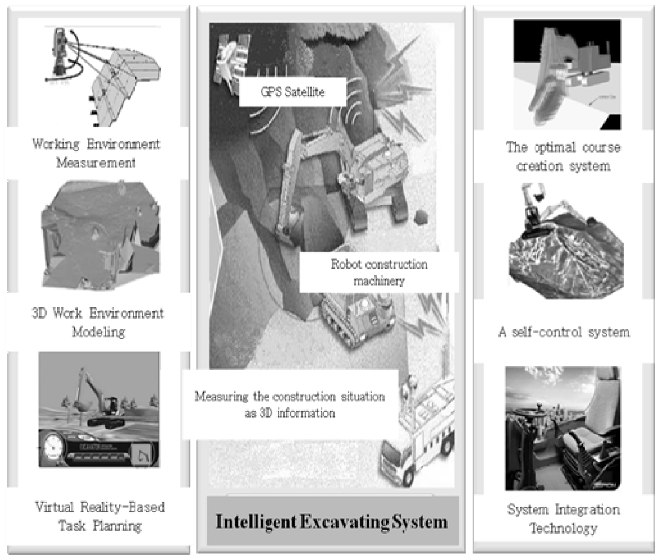

Figure 2. IES's detailed core technology

between the platforms, and the quality control of the working contents, and compiles a database of the work information through the linkage to Project Management Information System (PMIS) which is the construction management module. Also, it is applied as a monitoring system by building the working contents through virtual reality simulation. There are two technologies to acquire the working environment; global sensing and local sensing. Global sensing means the process to map the whole geographic data of the work through laser scanners, and local sensing means the process to map the data for the local area where becomes the object when the excavator is located at the platform to work.

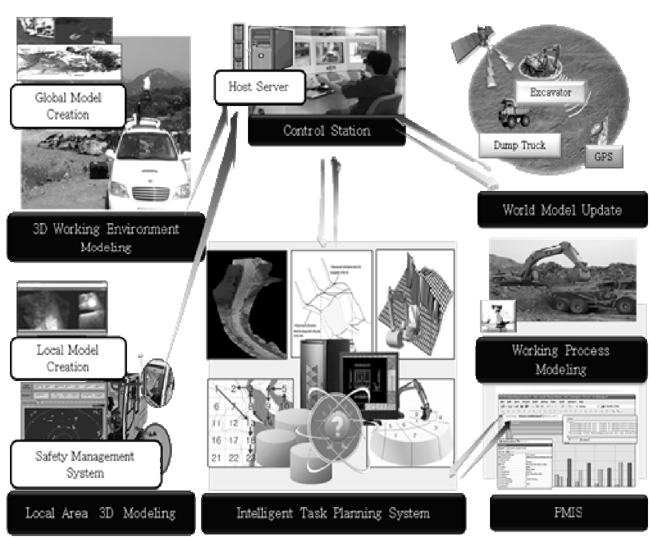

Figure 3. Intelligent TPS Development

4. Development of TPS Module using heuristics

TPS devises the working plan by each module algorithm real-timely by receiving the geographic data through global and local sensing after inputting the work environment data, the dimension information of the robotic excavator in advance. The plan for the work is devised after dividing the target terrain into Global Area, Unit Work Area, Local Area and Local Package. Global Area means the components dividing the whole area for the excavator to work, Unit Work Area means the components fixing the area considering a certain direction and continuity which are the work path characteristics of the excavator, and Local Area means 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.

The earthwork plan and the earthwork amount of whole work are calculated through the comparison analysis between the data of the real and the designed geographic data. The work order is given after dividing areas at each stage, and the movement path creation of the excavator and the work are performed based on the platform to be located for the excavator.

The Fig. 4 shows the contents on the module and the performance process of TPS designed by applying heuristics.

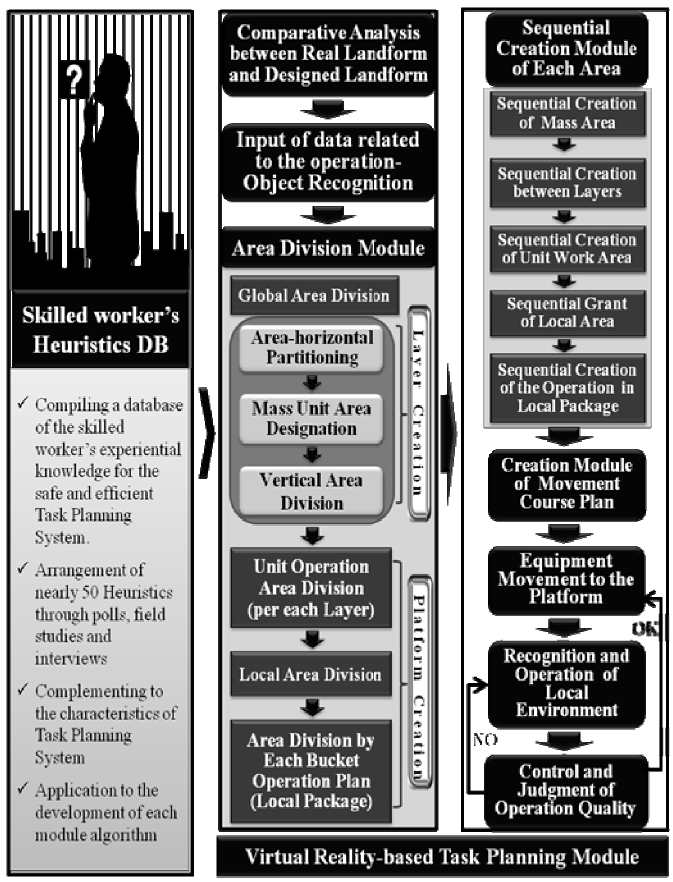

Figure 4. TPS Module & Process

4.1 Division of Global Area

4.1.1 Horizontal Division

This is the process to divide the geographic data horizontally on the basis of the average excavating depth that is efficient most and that considers the safety at the excavating point suitable for the excavator dimension. A skilled operator reduces the risk of a skid by considering the bearing capacity of the ground, and performs the work by making the cutting depth 2~3m deep of the optimal vertical excavating depth according to the excavator dimension at one point, and carries out the work from the high to the low topography in the ground height.

So, as the basic phase or devising the efficient work plan of the excavator, it created layers through the horizontal division of the area according to each phase and district.

4.1.2 Designation of Mass Area

In case of the earthwork field having various peaks, time and cost is saved by minimizing the travel distance of the excavator, and change of direction is saved by applying the work order according to the area after dividing into the mass unit for the whole area.

Global area division performs the work from the upper layer after dividing the geographic data according each layer. Therefore, the location in stages of the excavator on the earthwork field carries out the work by stages from top to down for the efficiency of the excavation and the transport, and the efficient work plan devising can occur if carrying out the work from the upper layer unconditionally without considering the mass unit area.

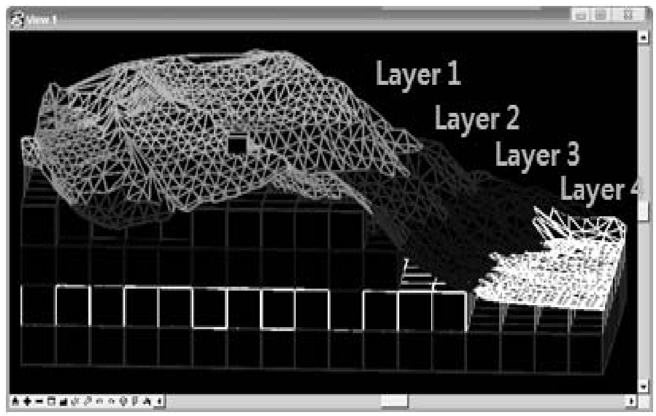

Figure 5. Horizontal Division of the Area

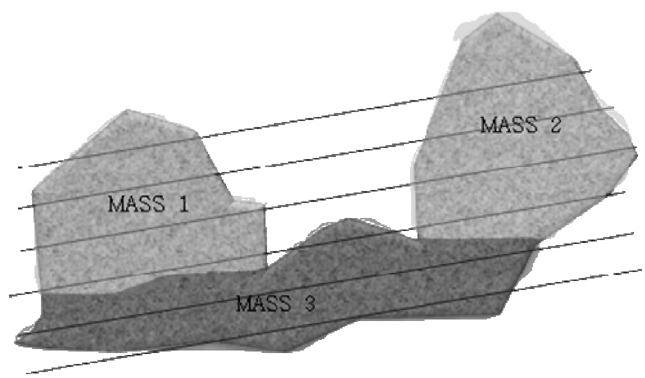

Figure 6. Mass Unit Area Designation

4.1.3 Vertical Division

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.

4.2 Designation of Unit Work Area

Unit Work Area is designated by considering the working direction and continuity for the work object layer created through global area division. A skilled operator of the excavator performs continuously with a certain direction until backing is infeasible. This can simplify the work plan and can devise the efficient work plan through the minimization of the movement distance of the excavator and the direction changing. Also, operators perform the work backing the excavator so it becomes well-drained naturally by the gravity to treat the flowing groundwater and the surface water affects on excavating.

The operator decides the spot that has the minimum movement distance and that secures the safety as the next target spot even when moving the distance between the work areas. When designating Unit Work Area, considering obstacles is efficient when beginning the work in the distance place from the place to reduce the damage and to consider the difficult work degree, and enables the platform to be located by considering the corners, obstacles of the layer geographical feature.

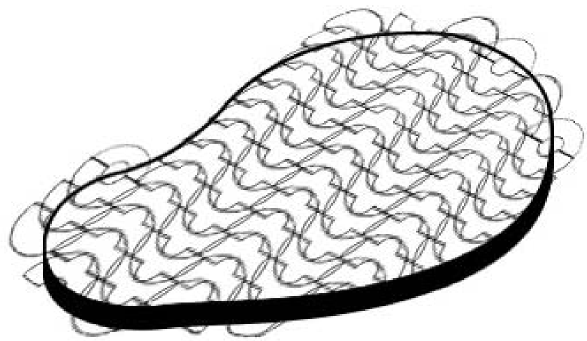

Figure 7. Unit Work Area Designation

4.3 Division of Local Area

This is the process to divide Unit Work Area into Local Area. Platform means the spot 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 90~110° 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° when loading the truck. When designing Local Area, the area for gathering the earth and securing the safety is set by having the spatial room of a certain radius. This can reduce the excavators' idle-time and can improve the work efficiency by preventing the inversion due to the loss of the track ground capability and by facilitating loading trucks.

Local Area is platform unit area divided by a certain rule considering the trajectory of bucket and kinematics. The designed geographical feature including each functional and each unit areas organizing Local Area is defined as Local Package. Local Package standards are affected by the specifications and other working environment conditions. Local Package Algorithm was developed by considering these conditions. Local Package Algorithm was made to calculate standards according to Algorithm if inputting variables being required respectively, and U.I (User Interface) for users' convenience was developed.

The inputted 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 U.I 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 U.I. The optimal horizontal excavation scope length (O.L) considering the excavating depth and the excavator's height by the inputted data, the radius of gathering the earth and the safety guarantee section length (S.L) are to be calculated. The horizontal excavation angle applies 180° 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.

4.4 Optimal Platform Location Setting

When arranging Local Area and Unit Work Area, the reiteration occurs because the shape of Local Area performs the excavation in the closed circular arc form according to the excavators' characteristics. It is possible to excavate efficiently and economically by removing the unnecessary excavating plan. The number of platforms for the soil- cutting area is decreased by reducing the unnecessary movements and direction changes only when creating the optimal platform location where the reiterations are minimized on the vertical and horizontal way. Also, Local Area standards are changed according to the excavator dimension, the quantified algorithm type is required for an Intelligent TPS to decide automatically the platform location. Algorithm has been developed to calculate the optimal platform location, and verified the minimization of the reiteration by applying AutoCAD.

5. Inspection of TPS with VR Simulation

So far, this paper has explained the modules of TPS, and heuristics applied to organizing the modules. Each module performs its role in series or in parallel and displays its function having an organic relationship mutually, not being

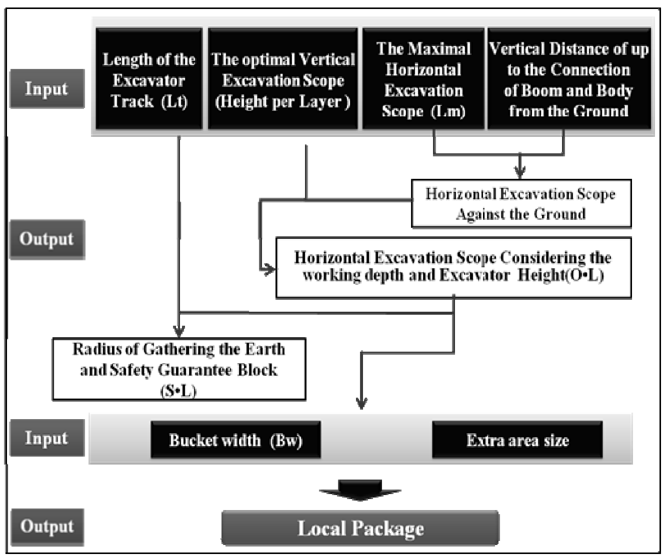

Figure 8 Local Package Algorithm

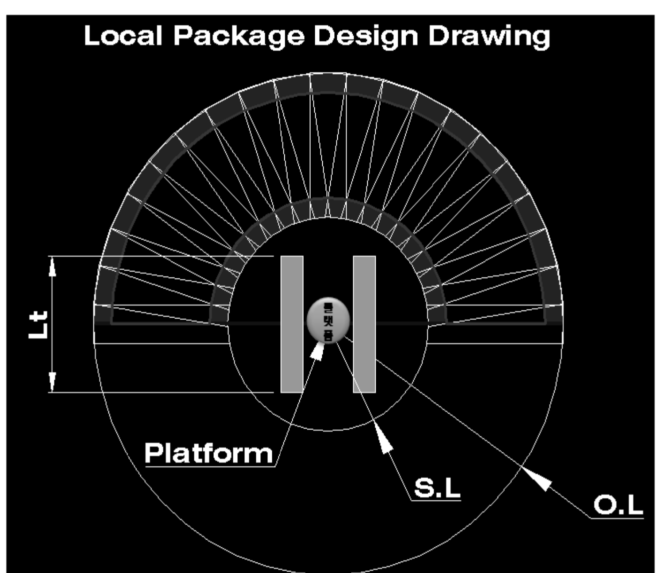

Figure 9. Local Package Design Drawing

independent. Through the area division practically, the sequential creation of works is created naturally. This affects on even the path planning of the excavator bucket and the excavation control. The designated platform supplies the creation and the path plan, and the location for the excavator. Also, the area division process for each bucket supplied the specific unit for the optimal excavation by being designed after reflecting the optimal excavating plan.

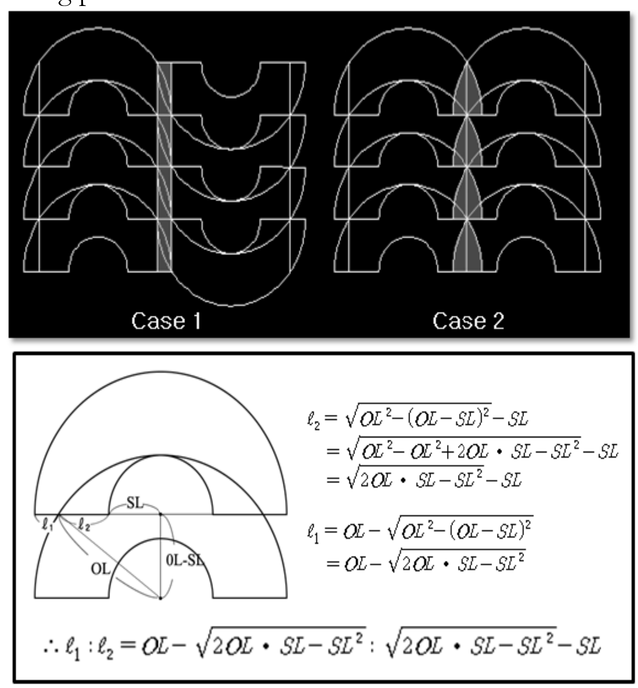

Figure 10. Platform arrangement and reiteration spot calculation considering the minimization of reiteration

The simulation was performed by applying task planning simulator for checking the contents of each module function organizing the intelligent TPS with the system configuration.

First of all, after acquiring the geographic data to be the simulation object, it was changed into solid model without material parameters considering the capacity of the data flow.

Task planning simulator creates Local Package standards by inputting the data necessary in designing Local Package. The depth of the horizontal area division was determined 2.5m, and a layer was created by the horizontal division module. The created layers were changed into solid object models respectively through mesh configuration, and it was designated as Unit work Area creation object after selecting the highest layer. The layer was divided based on the object local model of the calculated 3D solid, and this aims at the changes of the geographic data in three dimensions according to the practical operation of robotic excavator. The location of robotic excavator is displayed on the map after being transmitted through GPS data. The changes of the geographic data through the operation progress are updated on the global geographic data by receiving the formation of the geographical feature changes through the local sensing, and form the condition similar to the figures of the real field by being applied to the virtual simulation of TPS.

In the progress of the simulator, as the operations of the upper layers are progressed, the operation plan was devised simply as the geographical feature became gentle. Also, because the robotic excavator has difficulties in working with a certain direction and continuity if arranging after finding a positionable location by considering the shape of the geographic data when designating the platform location in case of the designation of unit work, the operation plan considering the presence or not of the evenness and the hardening operation possibility of the expected platform spot will be created.

6. Conclusions

Though each country all over the world has performed incessant research and development for the automation of the construction industry, it has run into numerous brick walls such as the continuation of non-repetitive operations, the lasting occurrences of uncertain incidents, the subjugation of the natural environment, the necessary elements, technological shortage, compared to other industries. To solve these

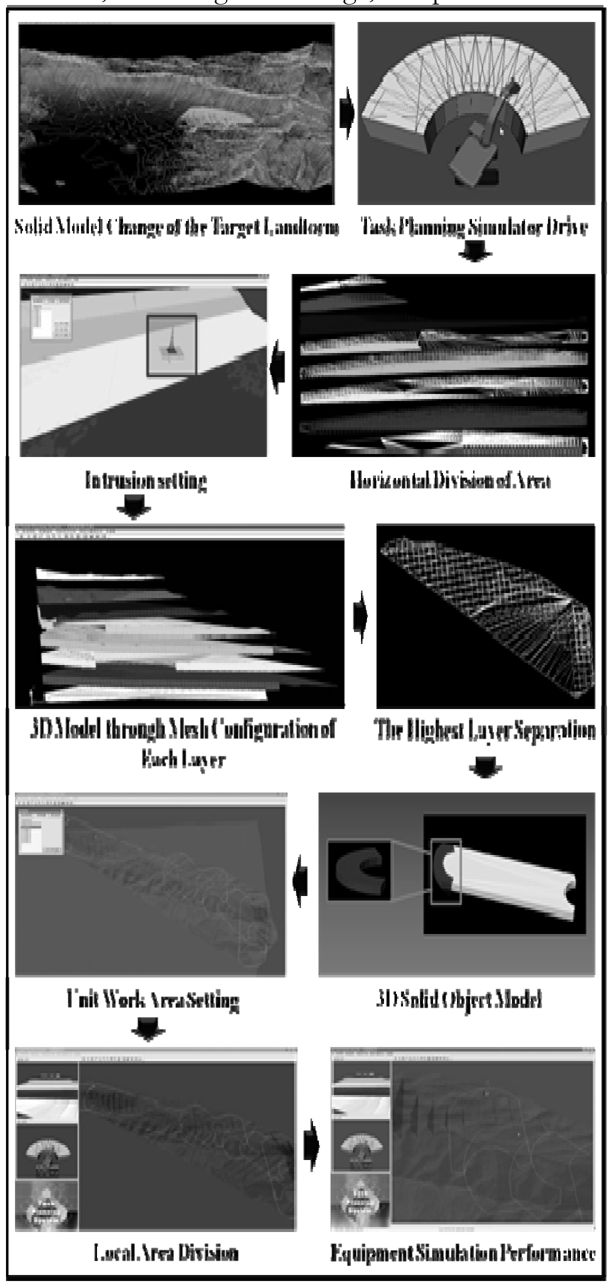

Figure 11. Task Planning Simulator

problems, it should be equipped with the necessary element technologies such as the development of the equipment corresponding to the purpose of the automation, and more exact and rapid sensing, and computer technology. All these things such as the experiential knowledge, the plans to cope with dangerous incidents, the past's successful data to improve the construction productivity for the skilled workers to perform more efficient operation in construction industry now are essential data. In particular, if granting it to the automation system after arranging the skilled workers' heuristics systematically and faithfully in the implementation of the automation through the development of construction machinery, it can bring about numerous profits such as the prevention against various disasters, efficient operations, the improvement in productivity and quality, and will be able to minimize the trials and errors accompanying in the process of achieving the automation. This research improved the efficiency and the safety by applying it to the module configuration through the algorithm development of each stage after arranging the skilled workers' and the superintendent's heuristics being required over the whole of TPS development which is an intelligent plan creation system among the IES development. It is necessary to seek the applications and the plans of various logics to grant artificial intelligence in the future, and the module that trials and errors are fewer and exquisite will be developed only when the development of close algorithm becomes a precondition.

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