

Graphical Simulation System for Planning and Visualizing Construction Processes

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Abstract: Three-dimensional graphical simulation is very useful for construction planning with its geometric analysis and visualization capability. This technique can further contribute to the improvement of construction planning processes by visualizing the numerically expressed results of process simulation (discrete-event simulation). This paper describes a graphical simulation system that has links to construction process simulation based on mathematical/statistical models. By fusing the visualization capability of the graphical simulation and the analytical superiority of construction process simulation in determining resource requirements and process optimization, the system proposed in this paper can overcome the limitations of the two different types of simulation. Earthmoving operation was selected as a case study to demonstrate the usefulness of the proposed research work.

Keywords: Construction graphical simulation, Visualization, Virtual Reality, Discrete-event simulation

1. INTRODUCTION

Although the usefulness of 3-dimensional graphical simulation for construction planning has been verified [1, 2], it is restricted by kinds of equipment and work to apply this technology to the practice.

In the case of the construction processes of Pick-and-Place method (Picking an object with a fixed form at a certain location and move it to the new place with equipment such as cranes), the geometric analysis with the graphical models can help planners make decisions such as the location, the types and the number of cranes, etc. Graphical simulation can also perform interference checking and constructability analysis for constructing a large number of elements in a small space such as the pipe work in plant construction sites to eventually determine the equipment configurations and construction sequences.

However, the application of graphical simulation has a limitation in dealing with objects without fixed form like earthmoving process. For earthmoving processes, only the approximate visualization might be possible by modifying the graphical models of terrain. However, the amount of earthmoving evaluated by graphical models is not accurate enough if we consider the complicated interaction between the soil condition with large amount of changes and equipment. In this case, the process simulation with

mathematical/statistical models about the productivity of the earthmoving processes based on the numerical data of working time, waiting time and working capacity of using equipment becomes effective by performing the resource requirement analysis and the process optimization. The process simulation with mathematical/statistical models (discrete-event simulation) is not fully utilized in the field of construction due to the difficulties of creating models. Therefore, the research for making the modeling processes less difficult has been conducted [3, 4, 5]. In addition, it's also very difficult to make the decision makers of construction trust the numerically expressed results of computer simulation. In order to overcome this problem, Huang attempted to visually prove by differentiating each node of process model in accordance with the change of time and working condition [3]. If the numerically expressed results of the construction process simulation can be visualized with the movement of equipment and materials by using 3D animation, it's not only the expansion of graphical simulation function but also the reinforcement of the process simulation. Kamat and Martinez [6] investigated this topic and developed a 3-D visualization system for construction process simulation.

Another drawback of construction graphical simulation is the lack of the connection with the physical models of the construction equipment and material. The complete description of construction

operations through graphical simulation needs analysis on the physical properties such as the weights, velocity, acceleration of the equipment and material. Hendrikson and Rehak [7] suggested the needs of the physical models for VR (Virtual Reality) -type construction simulation. Beliveau and Dal [8] worked on the theoretical framework to incorporate the physical model into the construction equipment simulation. However, the consideration of the physical phenomena such as equipment's deformation, supporting soil condition, and wind condition requires complex and time consuming modeling process, and real-time analysis is not often possible, which make the incorporation of the physical modeling into graphical simulation unrealistic. Even with the difficulties involved in physical modeling discussed above, certain construction processes such as crane operation require physical modeling to be able to rationally modeled and simulated by construction graphical simulation. The oscillation of the crane's cable and the lifted material that should be considered for improving constructability and safety of the operation is a good example. Current construction graphical simulation systems do not support such physical analysis.

Construction Technology Laboratory at Hanyang University is conducting a research project to enhance the functionality of construction graphical simulation systems. The objective of the research project is to overcome the above-discussed limitations of construction graphical simulation as shown in Figure 1. This paper describes the initial efforts made so far for the visualization of the construction process simulation.

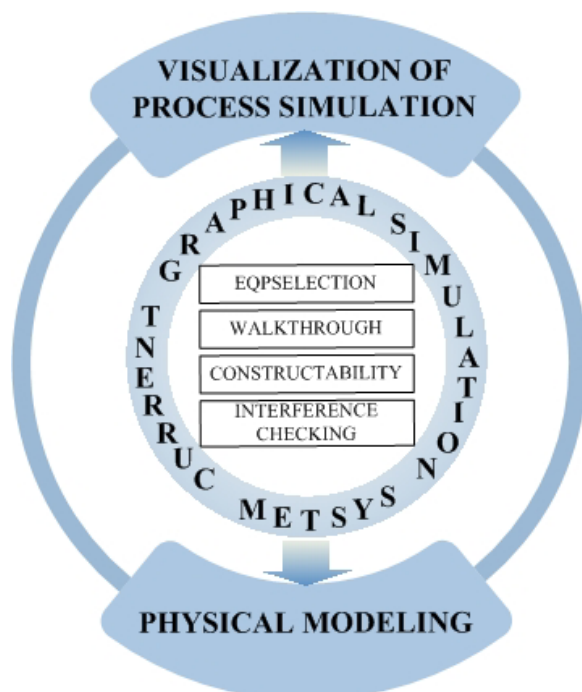


Figure 1. Expansion of Functionality of Construction Graphical Simulation

2. DEVELOPMENT ENVIRONMENT FOR VISUALIZING PROCESS SIMULATION RESULTS

The visualization of construction process simulation was achieved through the links between a commercial discrete-event simulation program SIGMA and a virtual reality program development environment World UP®. World UP® (EAI-Sense8 Products) has been selected as the graphical simulation engine, because of its complete software development and delivery environment for building 3D/VR applications. It also provides an easy-to-use graphical user interface from which creating and/or importing graphical objects and designing simulations. The behaviors of objects were added by writing task scripts using Basicscript language. The task script was written so that the output of the selected process simulation program (SIGMA) could be incorporated for visualization.

3. PROCESS SIMULATION OF EARTHMOVING OPERATION

As a pilot study, the selected construction operation for visualizing the results of the process simulation is earthmoving operation. To get results of construction process simulation for earthmoving process, a model was built using SIGMA. SIGMA, the Simulation Graphical Modeling and Analysis system, is an interactive approach to building, testing and experimenting with discrete-event simulations [9]. The discrete-event simulation model for the earthmoving process has been built through the following procedure.

- 1) Identify entities and attributes
- 2) Identify state variables
- 3) Identify events
- 4) Specify the relationship among the events

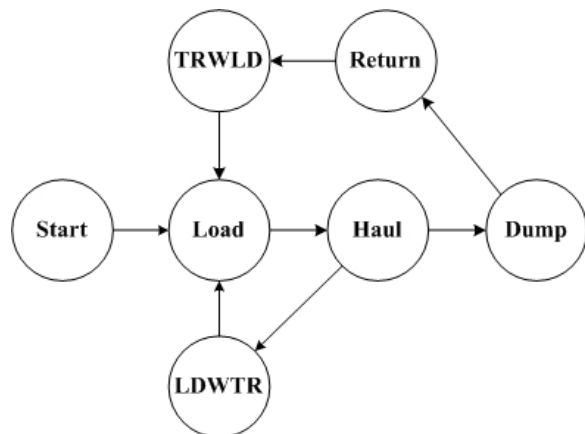


Figure 2. Simplified simulation model for earthmoving in SIGMA

Figure 2 shows the simplified simulation model built through this procedure for the earthmoving process. The following sections describe the details of the modeling procedure for earthmoving operation.

3.1 Earthmoving

Earthmoving is a specialized construction field where large amount of objects without fixed forms are moved from one location, to another location. Earthmoving process can be divided into four tasks, namely, load, haul, dump, and return.

3.2 Identify entities and attributes

The resident and transient entities in the system and their attributes are as follows.

- Loader: Working time, status variable, capacity
- Trucks: Working time at each state, status variable, working capacity

3.3 Identify state variables

The state variable names to the attributes are as follows.

- Status of the loader (Loader: 0/1=busy/idle)
- Number of trucks waiting for the loader to available (Truck)

3.4 Identify events

The changes in the state are called events, and the following events are involved in the earthmoving operation.

- Load: Since the initial status is that the trucks wait for loading by loader, the loader begins loading soil into one of the waiting trucks.
- Haul: The loaded truck departs to haul the soil.
- LDWTR: After the completion of loading, the loader begins to idle.
- Dump: The truck begins to dump in the dump area.
- Return: After the completion of dump, the truck returns to the load area.
- TRWLD: The truck arrives and waits for the loader to be available

3.5 Specify the relationship among the events

This step requires the identification of the dynamic attributes and the state that cause their values to change.

- Load:
Status of the loader, Loader=0.
Number of trucks waiting for the loader to be available, Truck=Truck-1.
Schedule the "Haul" event in the loading time unit.
- Haul:
Schedule the "Dump" event in the hauling time unit.
- LDWTR:
Loader=1

If Truck>0, schedule "Load" event immediately.

- Dump:
Schedule the "Return" event in the dumping time unit.
- Return
Schedule the "TRWLD" event in returning operation time unit.
- TRWLD
Truck=Truck+1
If Loader>0, schedule "Load" event.

4. VISUALIZATION OF SIMULATED EARTHMOVING OPERATION

4.1 The objects-oriented model

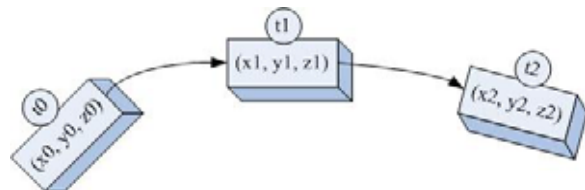
Object-oriented models for equipment, material and work environments for earthmoving operation were devised to effectively visualize the numerical simulation results of the working time, the queuing time as well as the amount resources etc. The interaction between each component of equipment was modeled efficiently, as the equipment behaviors interact with its sub-components (e.g. when the arm of loader is moved up, its bucket should be moved up together) as well as materials that are dealt by the equipment. The same type of equipment can also easily be created with the model hierarchy.

4.2 Link to process simulation

Working time was calculated from the process simulation results such as the start time of load, haul, dump and return. The calculated working time was saved in a text file which becomes the input source to the scripts defining the behaviors of each graphical object.

4.3 Working with task scripts

The behaviors of graphic objects were defined using Basicscript language in World UP program. In order to transport an object in a working time, location and duration information must be defined.



Following pseudo code shows an example of transport an object from location (x0, y0, z0) to location (x2, y2, z2) in end time t2.

```
T= SimulationTime
set obj = Truck1
dim pos as vect3d ...
```

```

If T<=(t1-t0) then
  obj.gettranslation pos
  pos.x = x0+(x1-x0)/(t1-t0)*T
  pos.y = y0+(y1-y0)/(t1-t0)*T
  pos.z = z0+(z1-z0)/(t1-t0)*T
  obj.settranslation pos
End if
If (t1-t0)<T<=(t2-t0)
  obj.gettranslation pos
  pos.x = x1+(x2-x1)/(t2-t1)*(T-t1)
  pos.y = y1+(y2-y1)/(t2-t1)*(T-t1)
  pos.z = z1+(z2-z1)/(t2-t1)*(T-t1)
  obj.settranslation pos
end if
...

```

Here, T, t0, t2 are the system clock, time to start an event, time to finish the event or time to start a

subsequent event, respectively. t1 is the time that the object's location would occur at the intermediate point (x1,y1,z1) between the starting and the ending location. The horizontal orientation of the equipment is also continuously updated based on the similar approach shown above. The pitch and roll of the truck should also be updated based on the terrain shape. The algorithm for this process is currently being developed. The scripts for truck, loader, and soil were implemented to visualize the dynamic earthmoving process based on the result of the process simulation. Figure 3 shows the overall hierarchy of the graphical simulation system for earthmoving process, and Figure 4 shows a scene of the earthmoving process visualized by the developed system.

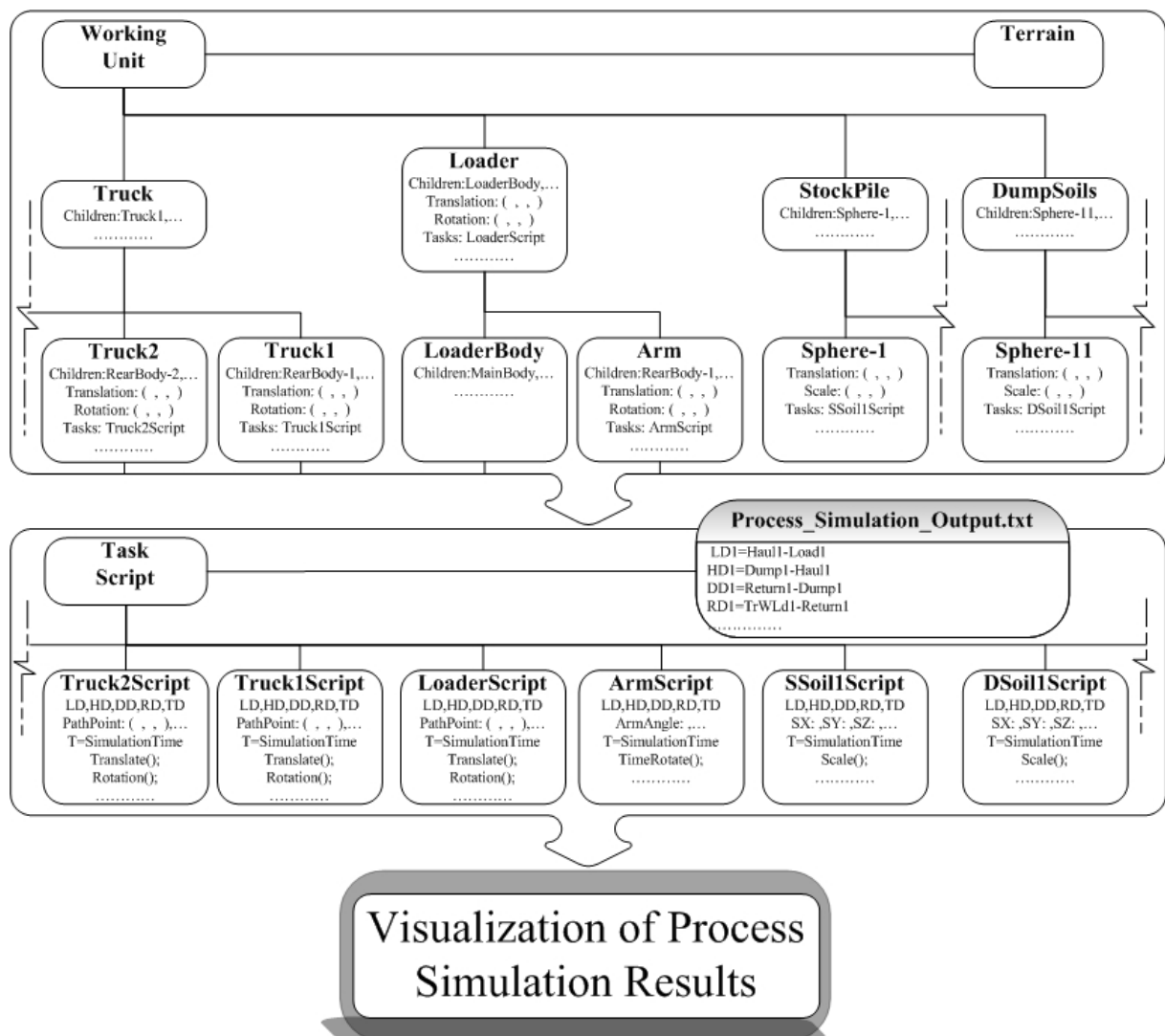


Figure 3 . Graphical simulation system for earthmoving process

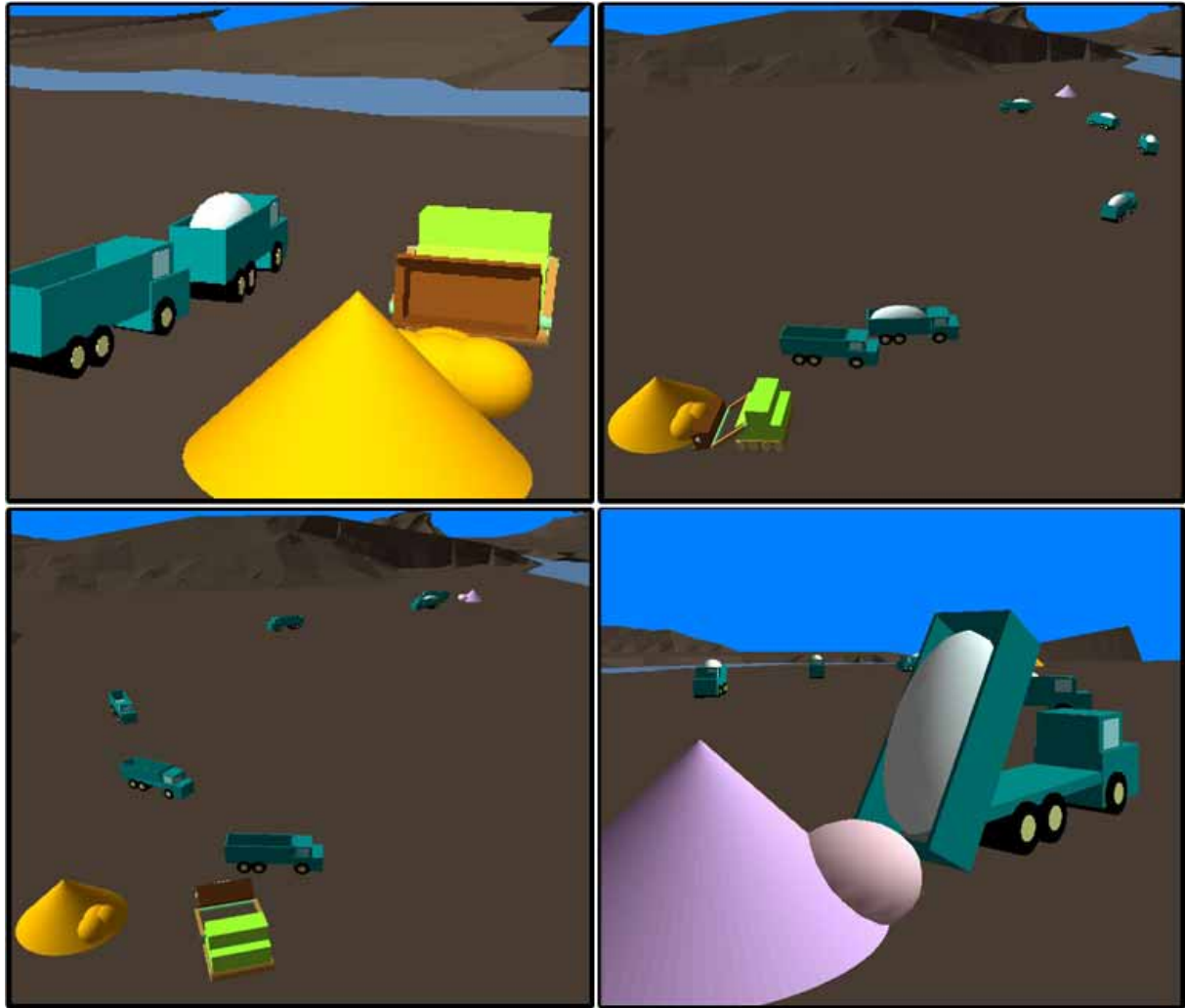


Figure 4. Scene of earthmoving process

5. CONCLUSIONS

The major objective of this study was to develop a graphical simulation system that can help the construction planner in the design and planning of construction processes. In order to meet major objective, the visualization of earthmoving process was achieved through the links to the discrete-event simulation system. The case study revealed that the credibility of the discrete-event simulation results could be improved with the realistically visualized construction operation.

Acknowledgments

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