THE VIRTUAL ENVIRONMENT FOR FORCE-FEEDBACK EXPERIMENT OF EXCAVATOR USING A NOVEL DESIGNED HAPTIC DEVICE

Kyeong Won Oh[1], Dongnam Kim[1], Nam Hoon Kim[1] and Daehie Hong[2]*

[1] *Graduate School of Division of Mechanical Engineering, Korea University, Seoul, Korea*
[2] *Division of Mechanical Engineering, Korea University, Seoul, Korea*
** Corresponding author (dhhong@korea.ac.kr)*

ABSTRACT: This paper describes an approach force-feedback of excavator which is considered for tele-operation using a novel designed haptic device in virtual environment. This study has two main themes, the newly designed haptic device and force-feedback algorithm in virtual environment for excavator. The device can be controlled by human arm joint. Using the device, motion of boom, arm and bucket is controlled by operator’s elbow, wrist and metacarpophalangeal(MCP) joint. The motion of a novel haptic device is very similar to excavator. So, it is very intuitive and operator can control the device easily, even if they use it for the first time. It is a marked contrast between commercial haptics and this device. And then, 3D virtual environment is modeled for the force-feedback experiment using OpenGL program and 3D graphical simulations are extensively performed. The haptic offer force-feedback to operator exerted on each link of excavator during the performing various operation with DC motors. In this case, the force, which is forced by DC motor for feedback, is different as purpose of excavator and type of working. In order to increase the efficiency of operation and the protection of equipment, it is necessary to detect the reaction forces.

***Keywords**: Haptic Device, Virtual Environment, Excavator*

1. INTRODUCTION

Being a kind of construction machinery, hydraulic excavators are used in construction and dismantling sites for conducting various tasks such as digging, crushing. During the operation is processed, operator is exposed to unexpected dangerous situations. So, there have been many researches about remote control or tele-operating systems for excavator [1], [2], [3]. These topics have been a very attractive study that cannot be performed directly by human because of difficulties in accessing the operating positions and safe manner. Therefore, it is very necessary that increase operational efficiency and protect human health and safety from hazardous tasks.

In this study, a novel designed haptic device and virtual environment system for motion control of excavator using the proposed device is mainly considered. This paper is organized as follows. Chapter 2 deals with the newly designed haptic device for excavator. In Chapter 3, the virtual environment system is referred. Chapter 4 and chapter 5 present experimental results using haptic device. Finally, in chapter 6, conclusions are addressed.

2. A NOVEL DESIGNED HAPTIC DEVICE

In this study, the haptic device is newly designed for remote control of excavator. Fig. 1 shows the 3D drawings of haptic device and coordinate system. In the figure,

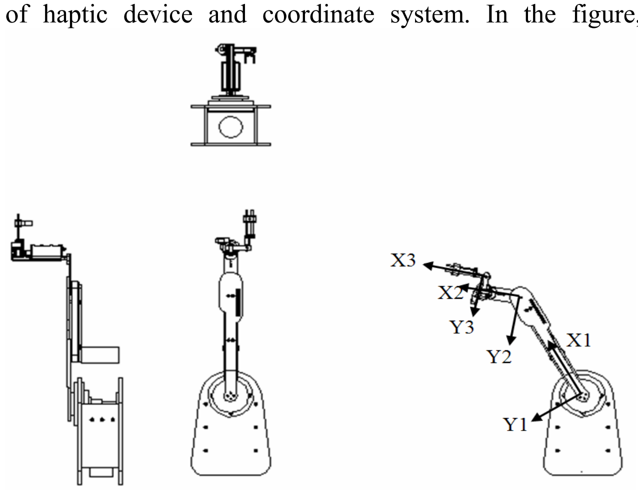

Fig. 1 3D drawings and coordinate system of haptic device

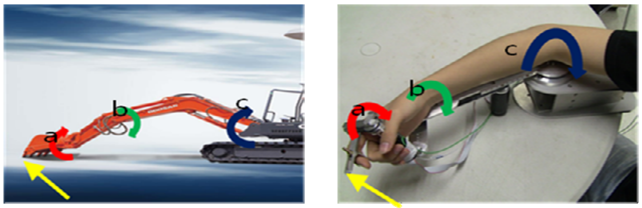

Fig. 2 Relationships between excavator and haptic joint

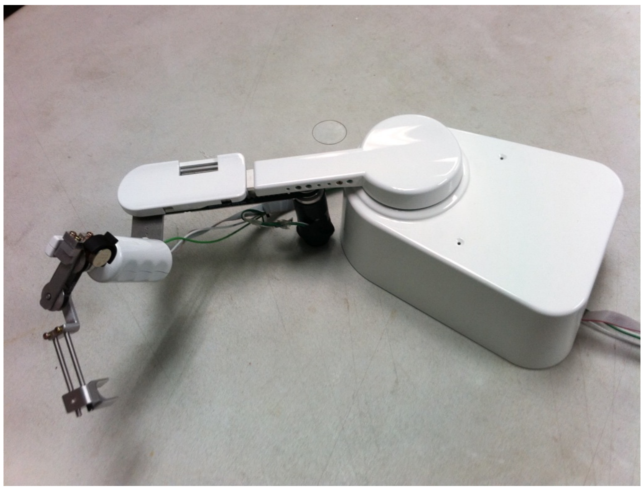
Fig. 3 A novel designed haptic device

having 3 degrees of freedom, the haptic device can control 3 basic motions of excavator, boom, arm and bucket, except for swing motion. Haptic device, that has 3-DOF motion, is controlled by elbow, wrist and finger of operator and relationship of each joint between excavator and haptic device as shown in Fig. 2. The suggested haptic device is considered only 2D motion, boom, arm, and bucket, because of controlling swing motion separately to the others in actual working process. As manufactured apparatus actually realized in this research shown in Fig. 3, the actuator is installed at each joint of haptic device to infer generating force exerted on excavator to operator. While at work, more efficient operation can be preceded by attached actuators through providing working conditions. In this research, two kinds of haptic control method are considered; rate control and position control. Rate control method is the same type of commercial joystick which is operated by difference between neutral position and current position of device. On the other hands, position control method is controlled by encoder value which is attached to each joint of haptic device. Each control method will be explained in the following chapter 4.

3. SIMULATION ENVIRONMENTS

Though excavator can operate various working process, actually dismantling process is considered in this research. Using OpenGL and Mircosoft Visual C++ program, the virtual environment is configured but also, excavator and building wall. Fig. 4 shows the flowchart of program for simulation. After windows timer starting, in the first step, current positions of haptic joint are collated. In the second step, using kinematics analysis joint angle and bucket tip of excavator in virtual environment are calculated by each control method algorithm[4]. And then, if the force is detected exerted on excavator in virtual, motor generate current which corresponds to the force. In this case, interactions between virtual wall and human or wall and excavator have to be considered because the force feedback which is generated in virtual environment has different properties as per connections between virtual wall and human/excavator. According to interaction between human and wall, being uncrushable rigid body, wall has very high spring constant and very low damping ratio. The wall is the broken object, however, it has low spring constant and high damping ratio considering relation between wall and excavator. Fig. 5 shows virtual environment system with excavator and wall. Operators can adjust haptic workspace privately through self test. And, in this program, operators are able to get information of each joint such as encoder value, current value also bucket tip's position of excavator.

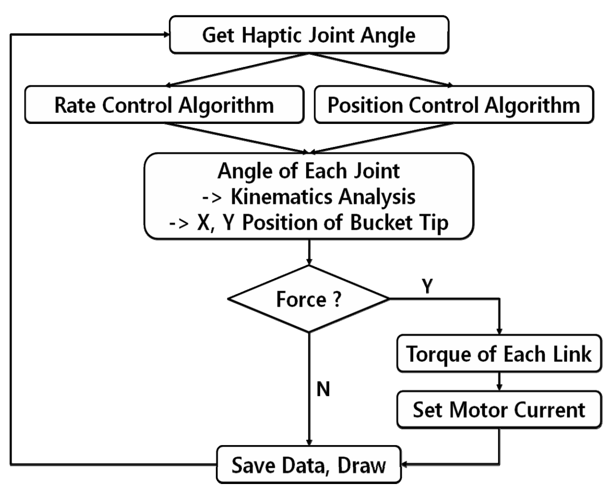

Fig. 4 The flowchart of program for simulation

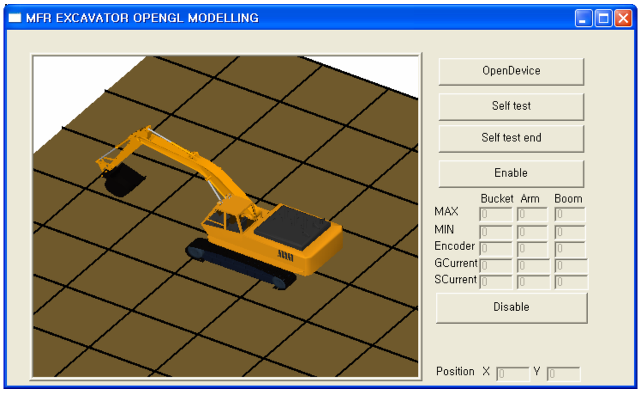

Fig. 5 Virtual environment system for dismantling process using haptic device

4. SIMULATION OF EACH CONTROL METHOD

In this chapter, operating simulation of the designed haptic device is progressed in virtual environment to evaluate each control method.

4.1 RATE CONTROL

Rate control method is the same type of commercial joystick which is operated by difference between neutral position and current position of device. The advantage of rate control method is providing comfort to the driver because of adjusted same control type of existing joystick. Furthermore, driver can operate easily by way of just slight movement of human arm not only spacious workspace of excavator but also fine control. Operator has to set the suitable neutral position for him, deadband, of haptic device before using rate control method. The equation of rate control follows as

$$F = K_s \times \left| Motor\_Position - Stop\_Position\_Max, Min \right| \quad (4.1)$$

Fig. 6 shows the boom control simulation result of rate control. At the beginning neutral position, in section A and section B, we can conform the changing of boom angle through difference between deadband and boom joint angle of haptic. In this case, section A and B has different velocity, which is the changing degree, as per boom joint angle of haptic device. The other way, in section C and section D, though in section D with small errors, position of haptic joint is placed inside the range of deadband so the

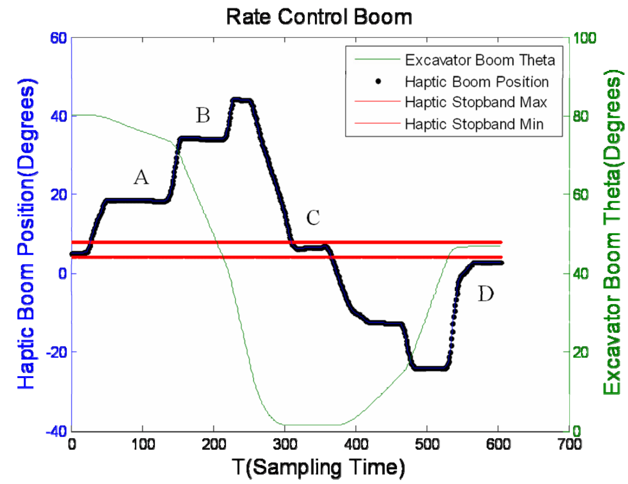

Fig. 6 Boom angle control with rate control

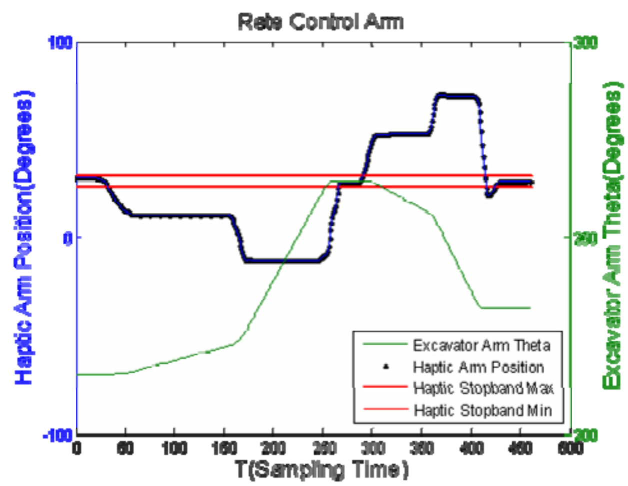

Fig. 7 Arm angle control with rate control method

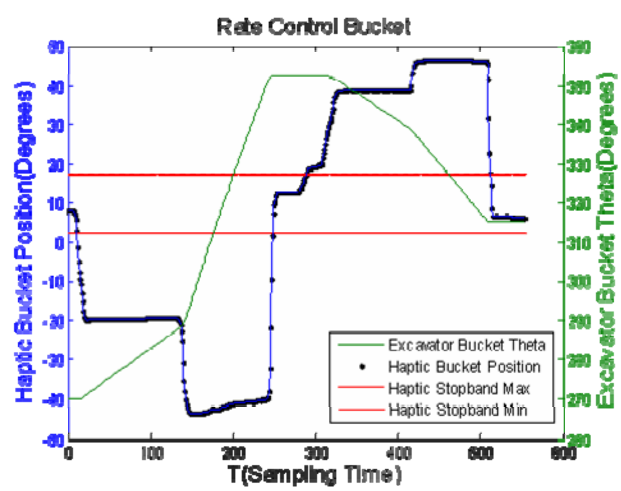

Fig. 8 Bucket angle control with rate control method

boom angle of excavator keep the position. The simulation results of arm and bucket angle control are represented as shown in Fig.7 and Fig. 8. Because the rate control method uses proportional-control when the haptic device moves into neutral position, the notable point is section E that is an overshot point shown as Fig. 7. However, an overshot is generated by p-control in an instant we can find that haptic position moves into neutral position because of spring-damping ratio between haptic device and operators.

4.2 POSITION CONTROL

In position control, each joint of excavator is controlled by changing angle of remote controller. Being very similar to digging motion of excavator, controlling motion of haptic device is easy to operator, even though it is operator's first experience. However, workspace of excavator is larger than haptic's, so fine control of excavator is difficult and operator can feel tired soon. Simulation result of each joint control, boom, arm and bucket, with designed haptic device is as shown in Fig. 9-11. We can verify as per changing angle of haptic joint, joint angle of excavator can be operated. When operator uses the position control method, like the preceding in rate control method, operator has to set the suitable workspace of haptic device for him. Figures show that each joint angle of excavator, boom, arm and bucket, follows actuator's value of haptic device. There are three sections that the reference and bucket position degree are 0 at the same time in Fig. 11. We can make certain whether to operate or not as limit of workspace, in this case, human arm workspace passes over workspace of haptic device which is initial set in this case.

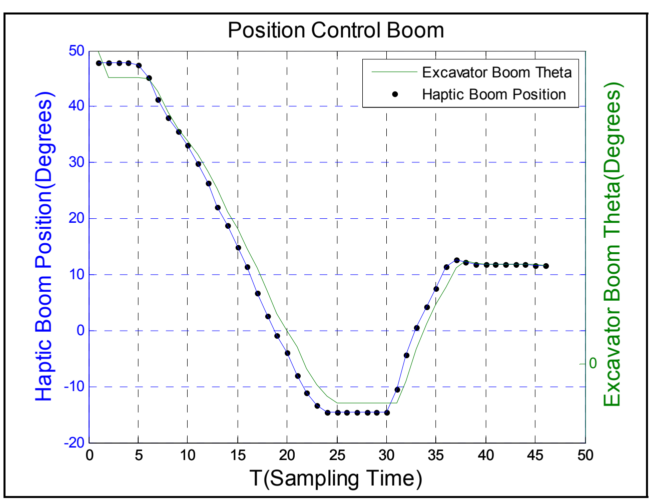

Fig. 9 Boom angle control with position control method

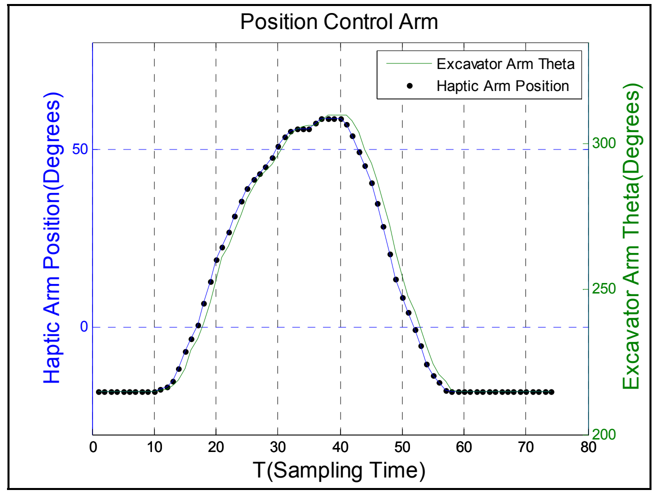

Fig. 10 Arm angle control with position control method

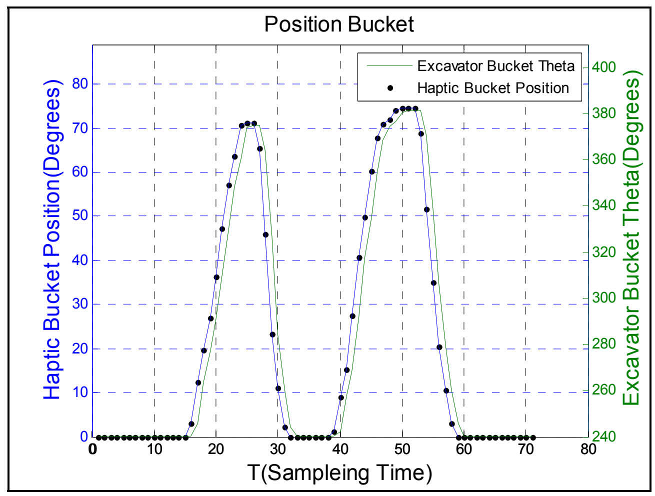

Fig. 11 Bucket angle control with position control method

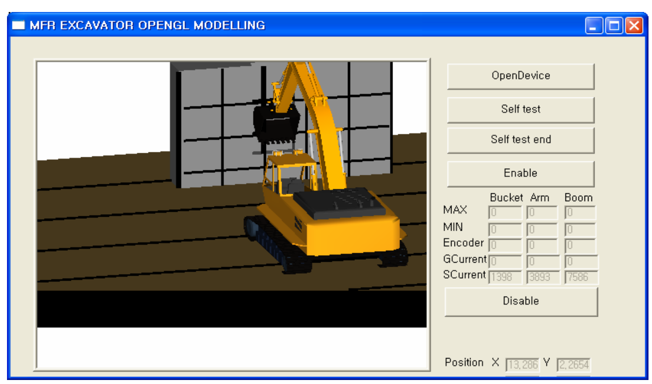

Fig. 12 Simulation view point and environment with wall

5. FORCE FEEDBACK EXPERIMENT AND RESULT

In this session, we consider force feedback experiment both ways using designed haptic device in virtual environment. When the wall and human collides, the wall is modeled on rigid body, which has large spring constant. However, this simulation is not that it is relation between wall and human but that it is relation between wall and excavator. So, from the point of view of the excavator, the wall should have small spring constant and damping ratio. The virtual environment is based on this property. Breaking after digging into certain distance, the wall is dismantled. Operator view point is offered during the simulation as shown in Fig. 12.

5. 1 RESULT OF RATE CONTROL

Fig. 13 and Fig. 14 shows simulation result of rate control method. Difference between X-position of reference value which is operated by haptic and endpoint of bucket tip in virtual environment is represented, as shown in Fig. 13.

During the experiment processed, operator issue orders that bucket moves to only X-direction forward. Each joint torque in haptic controller is calculated by the mutual force of virtual excavator and the wall. And then we can get each joint motor's electric current value by using joint torque equation [6], [7]. [8]. In some cases, force generates electric current and neutral positioning joint electric currents canceling each other. In that case, there is no joint torque. To improve this problem, after bucket collision about at 480ms, we vibrate the haptic device in order to notice the user that there is wall in front of bucket.

5. 2 RESULT OF POSITION CONTROL

Fig. 15 and Fig. 16 shows simulation result of position control method using haptic. The end point of bucket tip's

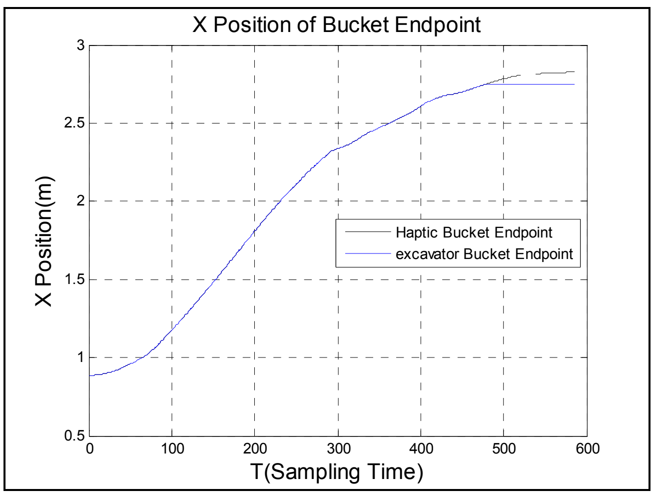

Fig. 13 X position of bucket endpoint of rate control

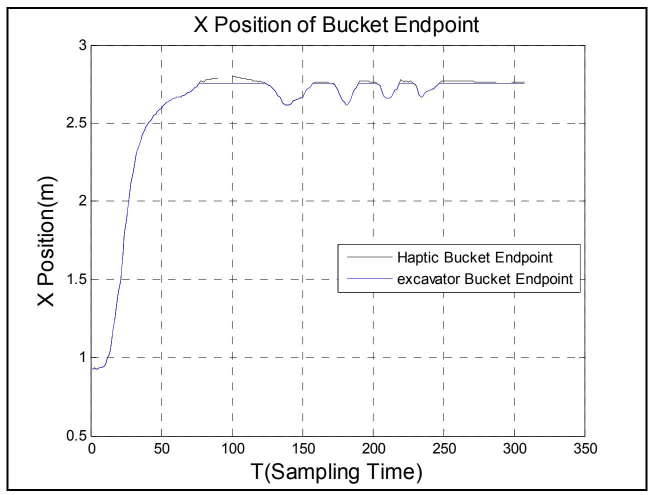

Fig. 15 X position of bucket endpoint of position control

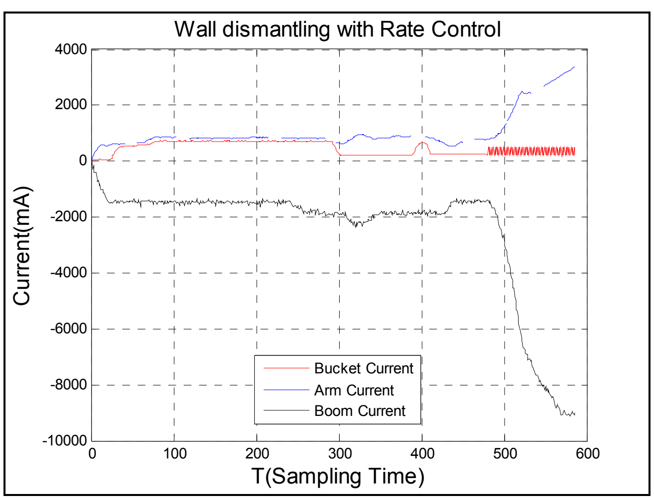

Fig. 14 Wall dismantling simulation with rate control

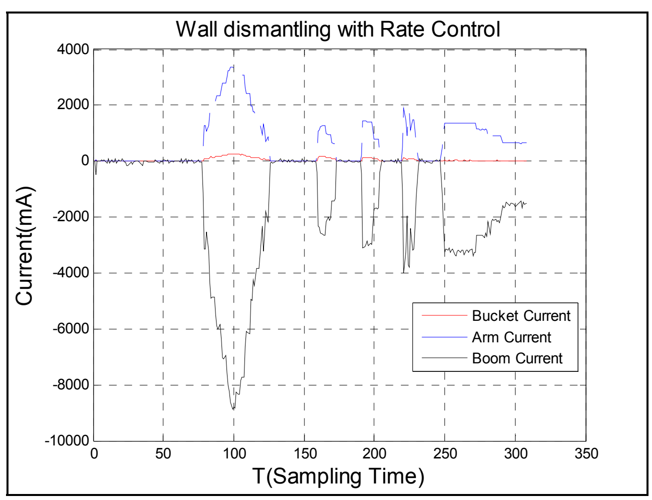

Fig. 16 Wall dismantling simulation with position control

X-axis position is represented as shown in Fig. 15. After collision with the wall, force is generated by difference between bucket tip's position, where is the operator wanted, and the real position as shown in Fig. 16.

6. CONCLUSION

In this research, we developed a novel designed haptic device which operates hydraulic excavator with force feedback mechanism. The motion of a novel haptic device is very similar to excavator. So, it is very intuitive and operator can control the device easily, even if they use it for the first time. It is a marked contrast between commercial haptics and this device. And then, 3D virtual environment is modeled for the force-feedback experiment using OpenGL program and 3D graphical simulations are extensively performed.

ACKNOWLEDGEMENT

This research was supported by a grant (code#06-B04) from the Unified and Advanced Construction Technology Program that was funded by the Ministry of Land, Transport and Maritime Affairs of Korean government and Brain Korea 21.

REFERENCES

[1] Hirabayashi, T., Yamamoto, T., Hiroaki, Y. and Iwata, H., "Experiment on Teleoperation of Underwater Backhoe with Haptic Information", Proceedings 23rd Int. Sym. on Automation and Robotics in Construction, pp. 36 - 41, 2006.

[2] Sasaki, T., Nagai, T. and Kawashima, K., "Remote Control of Backhoe for Rescue Activities Using Pneumatic Robot System", Proceedings of the IEEE Int. Conf. on Robotics and Automation, pp. 3177 - 3182, 2006.

[3] Quang, N. H., "Robust Low Level Control of Robotic Excavation", Australian Centre for Field Robotics, A Thesis of Doctor of Philosophy, The University of Sydney.

[4] Frimpong, S. and Li, Y., "Virtual Prototype Simulation of Hydraulic Shovel Kinematics for Spatial Characterization in Surface Mining Operation", International Journal of Surface Mining, Reclamation and Environment, Vol. 19, No. 4, pp. 238 – 250, 2005.

[5] Joseph, G. F., "Development of a Haptic Backhoe Testbed", School of Mechanical Engineering, A thesis of Master of Science, Georgia Institute of Technology, 2004.

[6] P.K. Vaha, M.J. Skibniewski, "Dynamic model of an excavator", J. Aerosp. Eng. 6, pp. 148-158, 1993.

[7] A.J. Koivo, "Kinematics of excavators (backhoes) for transferring surface material", J. Aerosp. Eng. 7, pp. 17-31, 1994.

[8] A.J. Koivo, M. Thoma, E. Kocaoglan, J. Andrade-Cetto, "Modeling and control of excavator dynamics during digging operation", J. Aerosp. Eng. 9, pp. 10-18, 1996.