

# SimMechanics SimHydraulic을 이용한 가상 굴삭기 개발 Development of a Virtual Excavator using SimMechanics and SimHydraulic

레광환<sup>1</sup> · 정영만<sup>1</sup> · 웬치탄<sup>1</sup> · 양순용<sup>2\*</sup>

Q. H. Le, Y. M. Jeong, C. T. Nguyen and S. Y. Yang

Received: 16 Nov. 2012, Revised: 25 Feb. 2013, Accepted: 27 Feb. 2013

**Key Words** : Hydraulic System (유압 시스템), Virtual Excavator (가상 굴삭기), Control(제어), Dynamics (동역학), Simulation (시뮬레이션)

**Abstract:** Excavation is an important work in mining, earth removal and general earthworks. Nowadays, automation in excavator has been studied by several researchers. In the excavator research methods, simulation is one of the low cost methods for applied to test safely. In this paper, designed a virtual hydraulic excavator that with the control and the dynamic. At first, the simulation of hydraulic system for excavator's attachment such as boom, arm and bucket using Matlab/Simhydraulic is presented. Second, the dynamic model of excavator is distributed to combine with the hydraulic system. For controlling this system, electric joysticks are used to operate the orifice open areas in Main Control Valve. The simulation result is described to analysis the performance of this virtual excavator.

## 기호 설명

and the environment during the digging operation

- $\theta = [\theta_1 \theta_2 \theta_3 \theta_4]$  : measured joint angles
- $D_\alpha(\theta)$  : inertia
- $C_\alpha(\theta, \dot{\theta})$  : Coriolis and centripetal effects
- $G_\alpha(\theta)$  : gravity forces
- $B_\alpha(\dot{\theta})$  : friction
- $\tau$  : corresponding input matrix
- $\tau_\alpha = [\tau_1 \tau_2 \tau_3 \tau_4]^T$  : specifies the torques acting on the shafts
- $F_L$  : interactive torques between the bucket

## 1. Introduction

In the construction, mining, agriculture and wasted disposal fields, no other tool has been more versatile than the excavator.

A large amount of these machines, whose design has remained hugely unchanged for decades, are currently in service worldwide. Simplicity and reliability are key factors contributing to success of this design. However, contrary to this expected increase in equipment demand, the abundance of skilled operators is declining because it usually requires 3~5 years of handling experience to become a skilled excavator operator and the working conditions at construction sites are poor. To solve these problems, much research on automating excavator operations is being conducted [1-4]. In addition to

\* Corresponding author: [soonyy@ulsan.ac.kr](mailto:soonyy@ulsan.ac.kr)  
 1 Department Mechanical Automotive Engineering Graduate School of University of Ulsan, Ulsan, 680-749, Korea  
 2 Department of Mechanical and Automotive Engineering, University of Ulsan, Korea.  
 Copyright © 2013, KSFC

This is an Open-Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

automation of the hydraulic excavator, there is also research being conducted on its modeling. A dynamic model of the excavator can be used for development of an automation algorithm and the subsequent testing of this algorithm without incurring high costs [2, 5]. The model can also be applied to various situations such as simulation training for excavator operators [6] or estimation and analysis of systems' characteristics. However, these studies [1-6] have not been progressed considerably. Specially, the model combined hydraulic system and mechanical system of the excavator. In this paper, a virtual excavator included the hydraulic system and dynamic model was contributed and developed using SimMechanics and SimHydraulic of Matlab/Simulink software. In this study, the performance of the virtual excavator's attachment such as boom and arm and bucket will be described. In addition, user can visualize and verify dynamic system behavior of virtual excavator in a virtual reality environment through the user interface.

## 2. Virtual Excavator

The virtual excavator can be considered as a subsystem that includes dynamic system and hydraulic system. Also the virtual excavator includes the operation signal and 3D graphics monitor interface. In this study, the system is modeled to approach of the 1.5 tons excavator class of D company such as mechanical parameters, hydraulic circuit and components etc.

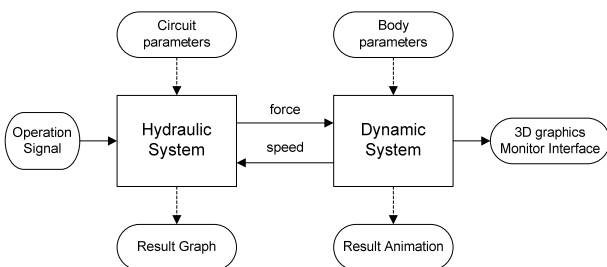


Fig. 1 Structure of virtual excavator

The structure of the virtual excavator is shown in figure 1. The dynamic system and the

hydraulic system are modeled by using the Simcapse toolbox of Matlab/Simulink software. In addition, 3D graphics for monitor interface shown in figure 2 is contributed by using 3D animation toolbox. These toolboxes are from Matlab/Simulink software so it is very compatible and convenient to connect and collect data between the subsystems.



Fig. 2 3D graphics for monitor interface

## 3. Dynamic model of virtual excavator

The dynamic model of excavator can be expressed concisely using the form of the well-known rigid-link manipulator equations of motion:

$$D_a(\theta)\ddot{\theta}_{a+c_a}(\theta, \dot{\theta}) + G_a(\theta) + B_a(\dot{\theta}) = \Gamma\tau_{a-F_L} \quad (1)$$

In this paper, the dynamic model of the excavator is designed by using the SimMechanics software. At first, the 3D CAD model is created by Solidworks software. Second, the SimMechanics model is built by translate from the 3D CAD model.

### 3.1 3D CAD model of excavator

The 3D model of 1.5 ton excavator class of D company is distributed by using CAD software is shown in figure 3. In this model, the parameters applied real excavator parameters such as mass and the length of parts and inertia moment. And revolute joints are used to connect of each module such as lower-base and upper-base and boom and arm and bucket.



Fig. 3 3D model of excavator

### 3.2 3D CAD model of SimMechanics model

The first translation step is to use the SimMechanics link exporter to create an intermediate physical modeling XML file from a CAD assembly. The second translation step is to import the physical modeling XML to generate the SimMechanics model then use that model together with the body geometry graphics files to simulate and visualize the original mechanical system. The process is described in figure 4.

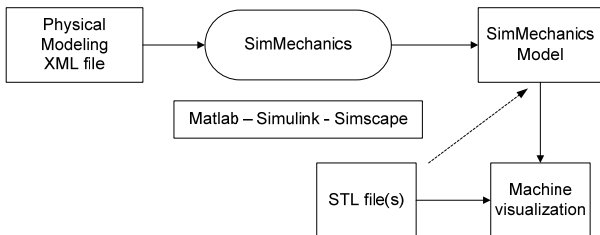


Fig. 4 Physical Modeling XML to Visualizable SimMechanics Model

When the model is imported completely, the Simechanics model will appear in the Simulink windows.

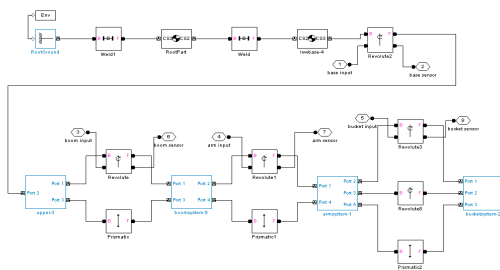


Fig. 5 SimMechanics model of excavator

The figure 5 is shown the result of excavator model. In this excavator, the kinds of joint are

revolute joint and prismatic joint. The revolute joints connect the upper-base, lower-base, boom system, arm system and bucket system likely an arm robot. The prismatic joints represent the connection of between the rod and the tube of each cylinder attached to boom arm and bucket.

## 4. Hydraulic model of the virtual excavator using SimHydraulic

### 4.1 Main Control Valve (MCV)

The MCV consists of various valves for boom, arm, bucket, travel motor, dozer and swing etc. Only the valves of boom, arm and bucket are considered in this paper. These valves are 6 ports 3 position types including bypass circuits. An example of modeling for boom 6/3 directional valve is presented below.

The figure 6 is shown a circuit diagram of a boom valve. When spool is in neutral, the bypass line is completely open. If pilot pressure act to one side of a valve selectively, spool is moved in accordance with the pressure. Then the open-area shows a non-linear relation with spool displacement as same to the figure 7.

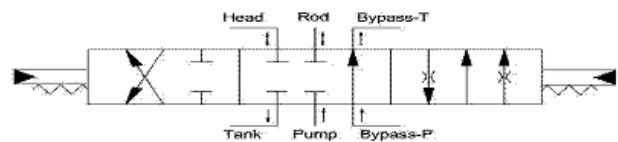


Fig. 6 Circuit diagram of the boom valve

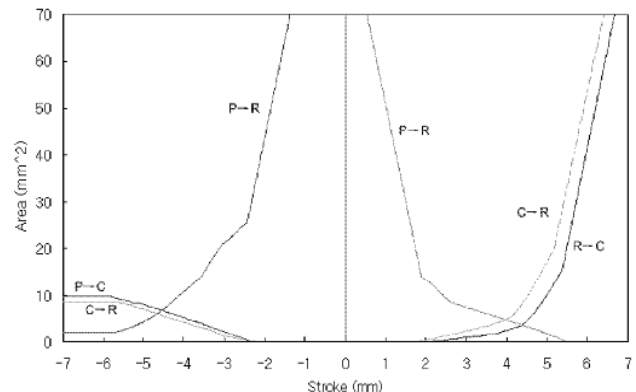


Fig. 7 Stroke Open area characteristics of the boom valve

The boom valve is designed in order to include the direction of spool and non-linear open-area using the SimHydraulic as shown in figure 8.

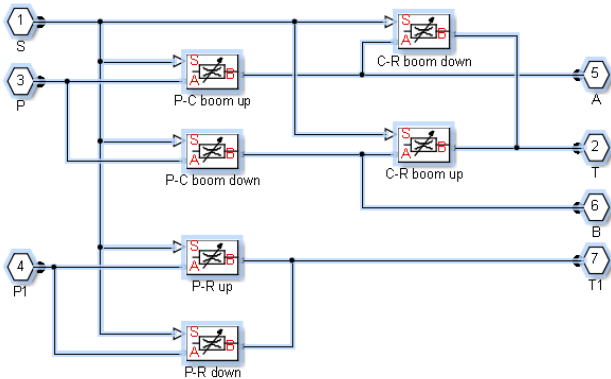


Fig. 8 Model of the boom valve using SimHydraulic

#### 4.2 Pump

An applied field robot has got three hydraulic pumps. The pump is used to control pilot pressure. The orders are fixed capacity type each flowing out 5.1cc/rev. A pump mainly takes charge of the movement of the arm. And a pump 2 usually concern with motion of boom and bucket. When the cylinder need much flow rate, pump 2 can concern with the operation through a check valve.

#### 4.3 Cylinder

Attachment is moved by stroke variation of three cylinders. The specification of cylinders is shown in the Table 1. In this study, the weight of cylinders has been ignored.

Table 1 Specification of cylinders

	Cylinder		
	Boom	Arm	Bucket
Piston diameter	55mm	55mm	55mm
Rod diameter	30mm	30mm	30mm
Length of stroke	250mm	390mm	245mm

#### 4.4 Modeling of the hydraulic system

The hydraulic system is made completely and described in figure 9. The hydraulic simulator system for field robot is completed by assembly of each component. The models of the attachment and valves are setting up to each separate super component.

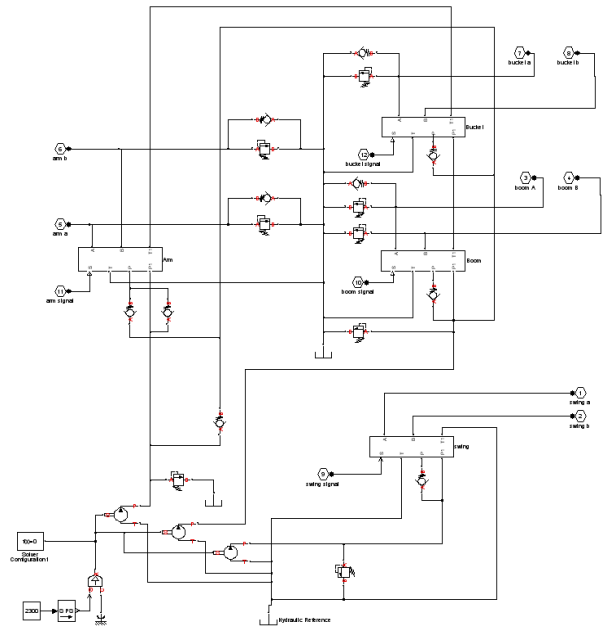


Fig. 9 The hydraulic system Model

This simulator system works according to input signals having range of -7 mm to 7 mm which they move valve spools. Relief valves set up the maximum pressure in the system to 210 bar. Two pumps turn to the same speed because they are connected with the only engine. And the flow rates are also same.

### 5. The performance of the virtual excavator

The virtual excavator is built the hydraulic and dynamics system completely is described in the previous chapters. In this chapter, the performance of the virtual excavator is presented with some simulation result. The modeling of the system includes the control; hydraulic and dynamics subsystem was shown in figure 10.

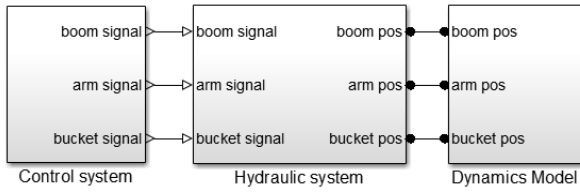
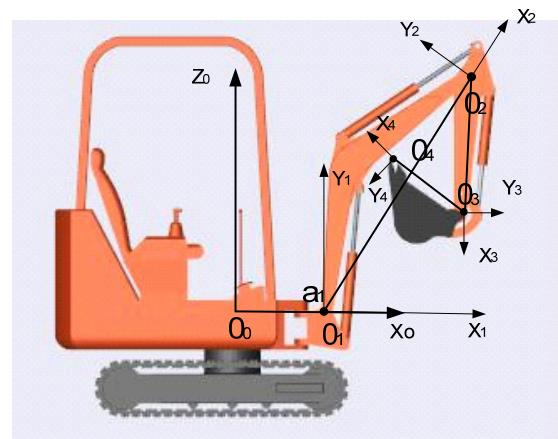


Fig. 10 The modeling of the system

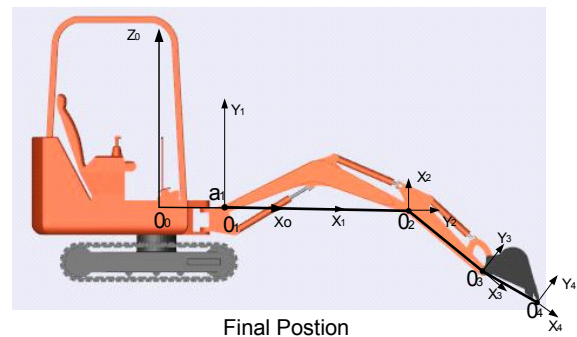
In this simulation, the performance of the virtual excavator is verified through analysis the flow rate and the pressure of cylinders. Besides, there is only consisting the movement of the attachment so the collaborative between the hydraulic system and dynamic model would be concentrated to verify the operating of virtual excavator. In addition, this study ignores the joint friction and the interactive force between the bucket and the soil ground so the elements include inertia and Coriolis and centripetal effects and gravity forces are considered during the operating of the virtual excavator. Therefore, for testing this system, the task design is not a complex movement of attachment for common excavator working as digging or lifting etc. In this case, the task is only designed to test the hydraulic system under the effects of the dynamic system. Specifically, a task which cylinder runs full length of stroke from the initial position to finally position to verify the state as start and moving and stop should be designed. At first, the input signals of the joysticks are set to operate the orifice open areas in MCV. Second, the stroke cylinder position and pressure and flow rate of the head and rod of cylinder are verified that the responds of them are suitable or not from the change of MCV.

A simulation is designed with the input value that has set from 0 mm to -7 mm. This value means the stroke's displacement of MCV and the displacement set from 0 mm to 7mm and the direction movement which marks by minus symbol. This means cylinder retraction. The cylinders of boom, arm and bucket retracted completely from the maximum extended positions shown in figure 11. This means the cylinders

move full length of their stroke displacement.



Initial Position



Final Position

Fig. 11 The excavator's attachment initial point and final point

The results included the displacement and flow rate and pressure of the cylinders of boom and arm and bucket are shown from figure 12 to figure 14.

In this simulation, which the input signal for each cylinder is designed, the cylinders of boom, arm and bucket are retracted completely from the initial position which they are extended maximum. Therefore, the displacement of each cylinder's tip means full length of the stroke that shown in the figure 12-14. Compare with the specification of cylinder in table 1, the results describe exactly the movement of the cylinders.

Following these figures, at the initial state, cylinder start moving, all flow rate value is 0 l/min but the initial pressure of each cylinder is different because of the mass of the links. At the movement state, with the signal increases from 0 to 7 following the retract direction, the pressure

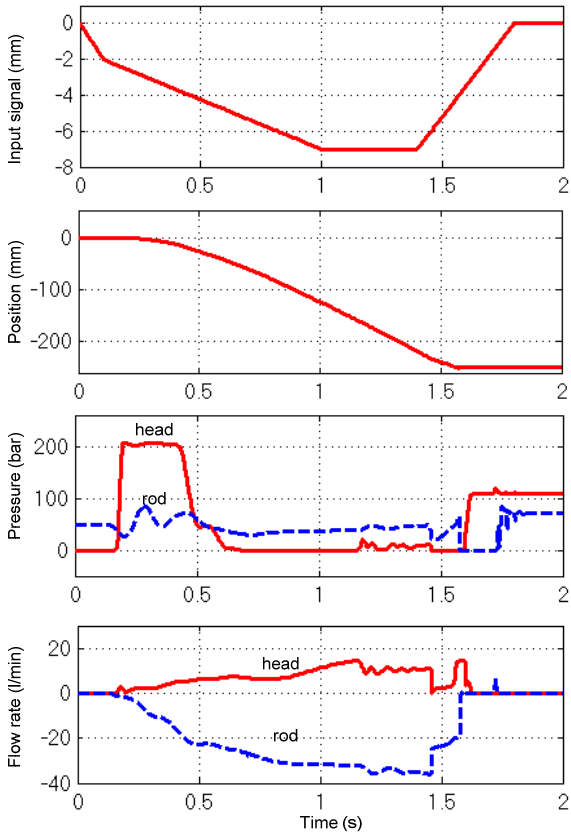


Fig. 12 Simulation result of boom cylinder

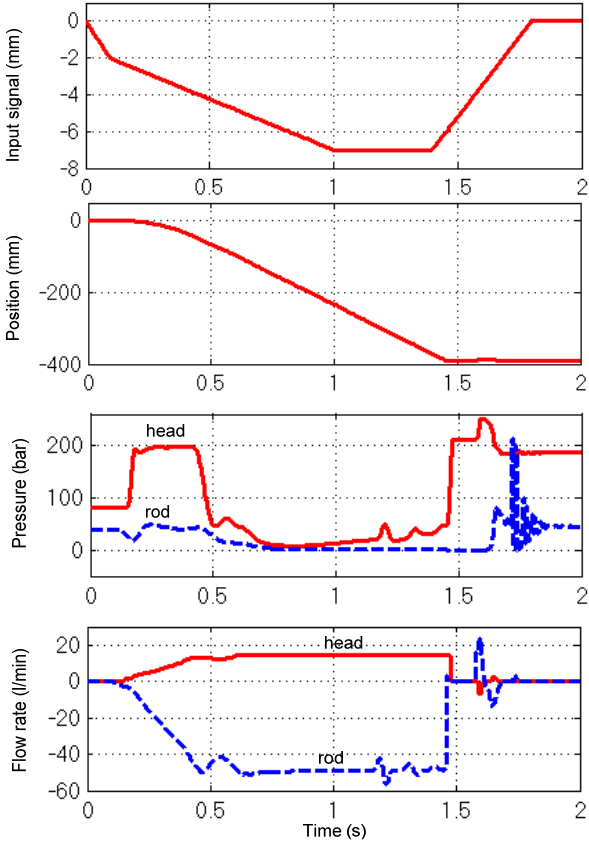


Fig. 13 Simulation result of arm cylinder

at first increase because of the initial moment of the links then reducing when cylinder gets the steady velocity. Besides, the flow rate increased from the 0 l/min by the input signal. At the final state, when the cylinders stop, all flow rates are reduced to 0 l/min and the pressures get the value base on the movement of the input signal. In addition, when both control signals and the cylinder displacements are 0 value, all pressure and flow rate value keep the currently value. This result shows that the hydraulic system and dynamics system curves simultaneously and the collaborative relation between the control system, hydraulic model and dynamics model of virtual excavator can be verified through the below analysis.

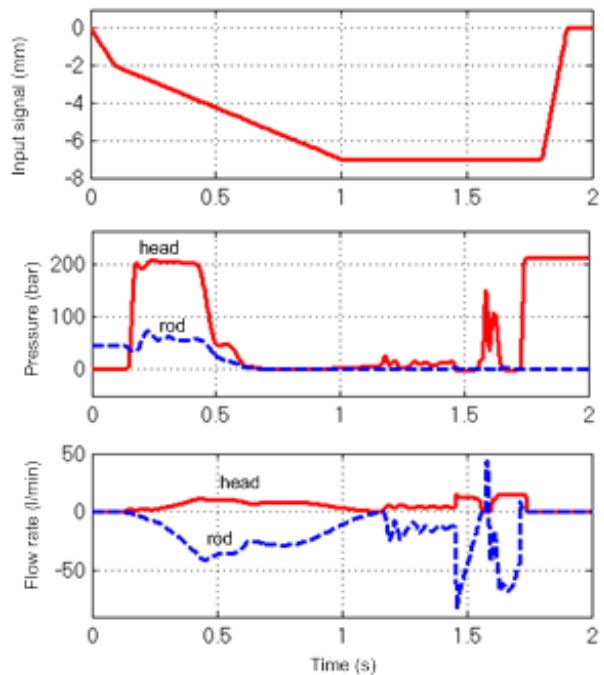


Fig. 14 Simulation result of bucket cylinder

## 6. Virtual reality user interface

User can observe the operating of the virtual excavator through a virtual reality user interface (VRUI). In this paper, Simulink 3D animation software was used to contribute the VRUI. The virtual reality environment was shown in the figure 15.

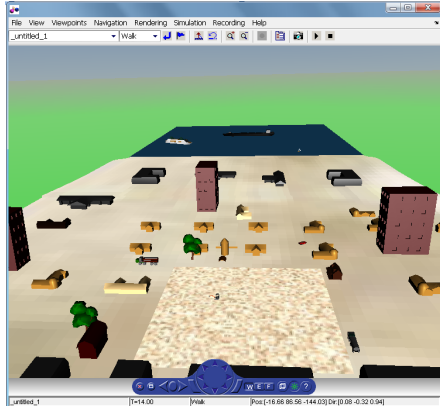


Fig. 15 Virtual reality environment

User can be able to choose the viewer to verify dynamics system behavior of the system. Four viewpoints were designed overview and working viewpoint and cabin viewpoint and exterior viewpoint.



Fig. 16 Overview view point

The position of the virtual excavator among the working environment could be surveyed through the overview view point have shown in figure 16.



Fig. 17 Exterior viewpoint

The exterior viewpoint shown in figure 17 allows the user observe the virtual excavator as standing outside of this system.



Fig. 18 Working viewpoint

The other viewpoints give the operator have an intuitive interface as sitting in the cabin of excavator. With working viewpoint in figure 18, user can be able to monitor the interaction between the tip of bucket and the working area. Besides, the cabin viewpoint gives the user feeling sitting in the cabin. This viewpoint described in figure 19 is useful when operator wants to drive the virtual excavator.

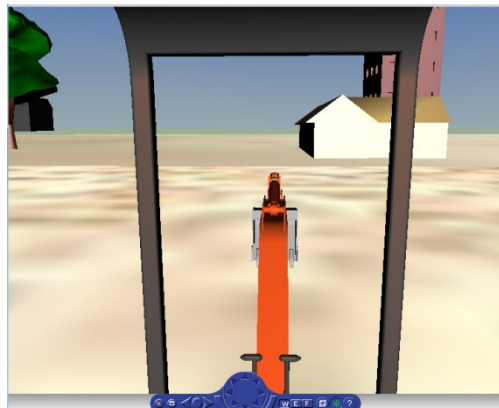


Fig. 19 Cabin viewpoint

## 7. Conclusion

In this study, the main features could be summarized with the following key messages:

- The virtual excavator which combined between the hydraulic model and dynamic model

is developed. Besides, Virtual Reality User Interface is designed to allow the operator control and monitor the system.

- The combined performance between the hydraulic power system and mechanical system of the virtual excavator is verified through some simulation results.

- After rectification and supplementation, it is expected that this virtual excavator could be apply to operator training, automation study, performance test of component design etc.

In the future work, this virtual excavator will be developed to run in real-time for testing in some HIL applications. Besides, this model can apply the interactive torques between the bucket and the environment during the task operation to get more valuable for this virtual excavator.

### Acknowledgement

This work was supported by 2012 special research fund of mechanical engineering at the university of ulsan.

### Reference

- 1) B. I. Kang and J. S. Lee, "Boom Energy Regeneration System of Hybrid Excavator Using Simulation Technique," J. of the Korean Society for Fluid Power and Construction Equipments, Vol.7, No.2, pp.12-18, 2010.
- 2) S. J. Lee and P. H. Chang, "Modeling of a Hydraulic Excavator based on Bond Graph Method and its Parameter Estimation", Journal of Mechanical Science and Technology, Vol. 26, No. 1, pp.195-204, 2012.
- 3) N. Sepehri, P. D. Lawrence, F. Sassani and R. Frenette, "Resolved-mode Teleoperated Control of Heavy-duty Hydraulic Machines", ASME Journal of Dynamic System, Measurement and Control, Vol. 116, No. 2, pp.232-240, 1994.
- 4) P. H. Chang and S. J. Lee, "A Straight-line Motion Tracking Control of Hydraulic Excavator System, Mechatronics, Vol. 12, No.1, pp.119-138, 2002.
- 5) L. D. Hanh, K. K. Ahn, B. B. Kha and W. K. Jo, "Trajectory Control of Electro-hydraulic Excavator using Fuzzy Self Tuning Algorithm with Neural Network", Journal of Mechanical Science and Technology, Vol. 23, No. 1, pp149-160, 2009.
- 6) T. Yoshimura and K. Etokoro, "A Simulation Study of Leveling Control by Hydraulic Shovels", Transactions of the Japan Society of Mechanical Engineers Part C, Vol. 58, No. 554, pp.161-167, 1992.
- 7) Y. Gonthier and E. Papadopoulos, "On the Development of a Real-time Simulator for an Electro-hydraulic Forestry Machine", Proc. of the IEEE International Conference on Robotics and Automation, pp. 127-132, 1998.
- 8) S. Y. Yang, S. M. Jin, and S. K. Kwon, "Remote Control System of Industrial Field Robot", 6th IEEE International Conference on Industrial Informatics, pp. 442-447, 2008.
- 9) S. K. Kwon, Y. S. Kim, C. D. Lee and S.Y. Yang, "Development and Evaluation of Simulator for Field robot", International Conference on Smart Manufacturing Application (ICSMA), pp. 419-423, 2008.
- 10) S. Y. Yang, M. C. Lee, M. H. Lee, Suguru Arimoto, "Measuring system for Development of Stroke-Sensing Cylinder for Autonomic Excavator", Vol. 45, No. 3, 1998.