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CONCEPT OF PRODUCT DEVELOPMENT SIMULATOR FOR AN EXCAVATOR USING A HAPTIC DEVICE

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ABSTRACT

The significance of Virtual reality (VR) tools lies on its capability to simulate physical presence. Dealing with 3D model in VR Systems is less expensive, less dangerous and easier to make modifications than dealing with real objects. Haptic devices are used because of their ability to generate and provide force feedback to the user during the real-time simulation. With this extra information, the user has gain more understanding of the model and makes it more real.

In this paper we present a new concept for using VR-environment, real-time simulation model of the excavator and haptic device to sense power consumption. Force signal generated by the haptic device is used on reflecting power consumption of a diesel engine. Such method can be used to evaluate how excavator mechanism and fluid power line works together when excavator accomplishes different work cycles. This approach gives a physical feedback of behavior of the main design property to a human test user. Haptic feedback together with 3D visualization enriches human understanding on nature of the entity and enables human creativity to be involved in design process.

Keywords: virtual reality, computational design synthesis, human behaviour in design

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1 INTRODUCTION

For many years, researchers have explored the potential and importance of Virtual Reality (VR) Systems in many different fields. The significance of VR lies on simulating physical presence in places in the real world, as well as in imaginary worlds. Dealing with a 3D model in VR Systems is faster, easier to make modifications, less expensive and less dangerous than dealing with real objects. One of the major advances of VR Systems is that the model can be imported from any 3D CAD software. Haptic devices are used because of their ability to generate and provide force feedback to the user during the real-time simulation. With this extra information, the user has gained more understanding of the model and made it more real. The force feedback makes interaction between the user and the 3D model easier. Applications of haptic devices and VR Systems have been presented in many studies in the fields of Robotics, Medicine as in Florian Gosselin, Sylvain Bouchigny, Christine Mégard, Farid Taha, Pascal Delcampe, Cédric d'Hauthuille (2012), Arts in Charles Nichols, as well as in Engineering Design. Designers and modelers may use haptic devices that give touch feedback relating to the surface they are sculpting or creating. This will allow a faster and more natural workflow than traditional methods in designing. This paper demonstrates one of the applications in the field of mobile work machinery.

The design of a heavy mechanism is complicated because the mechanism, first of all, needs to be able to execute the designed movements and, secondly, the power line moving the mechanism should provide smooth movements with high efficiency. Usually, several simulations need to be done to find suitable designs for the mechanism and power line.

In this paper, we present a new concept for using the VR environment and a haptic device to sense the power consumption of an excavator. The force signal generated by the haptic device is used when considering the power consumption of a diesel engine. Such a method can be used to evaluate how a well-designed excavator mechanism and a fluid power line work together. This approach gives indication of behavior of the main design property to a human user and it enables human creativity to be involved in such a design process.

1.1 Related Technologies

Innovations in the use of haptic devices show various ways of using these devices (José-Luis Rodríguez and Ramiro Velázquez (2012), Aude Bolopion, Barthélemy Cagneau, Stephane Redon and Stéphane Régnier (2010), and Andrew M. Wollacott and Kenneth M. Merz Jr. (2007). Generally, the ability of the haptic device in driving, controlling or interfacing with different kinds of robots remotely has been presented in many papers as an application of robotics teleoperation, Human-Robot (Huanran Wang and Xiaoping P. Liu, 2010), mobile robot (Otto J. Rosch, Klaus Schilling, and Hubert Roth, 2002), industrial robots (Glamnik and R. Šafarič, 2002). Very similar methods, like the one used in this paper were followed in a previous study to control a real robot (KUKA KR5) with a haptic device as in Glamnik and R. Šafarič (2002). A UDP (User Datagram Protocol) was used in the paper to send the information from the haptic device to the 3D model of an excavator.

Reaching a systematic way for teaching certain task to the user is one of the targets of using haptic devices in many studies such as Younhee Kim, Zoran Duric, Naomi Lynn Gerber, Arthur R. Palsbo, and Susan E. Palsbo (2009) as well as in this paper. There are two main challenges when controlling a large robot manipulator by means of a small haptic device studied in P. Chotiprayanakul and D.K. Liu; the mapping of a robot arm workspace to the workspace of the haptic device, and accurate and safe control of the movement of the robot arm.

However, the difference between this paper and the previous studies is that the aim of using the haptic device was not only to control the robot remotely, but also to utilize the information from the force feedback to sense the properties of the robot, such as power consumption.

2 HAPTIC SYSTEM

Phantom Omni, by SensAble Technologies, was used in this study, the same way in many other studies such as Alida Mazzoli, Michele Germani, and Roberto Raffaeli (2009) and Eduardo Veras, Karan Khokar, Redwan Alqasemi, Rajiv Dubey (2012). This haptic device can provide the force feedback in three axes (x, y, z) in a workspace of the following dimensions: 160 (W) x 120 (H) x 70 (D) mm.

Two different programming languages were used to build the model in this study, C++ and Python. For better performance and to avoid delays in the system, two computers were used. In one computer, Visual Studio was used as a platform to program the haptic device, to write the inverse kinematics for the excavator, and to calculate the feedback forces applied by the haptic device for the user according to the different situation. The other computer was used to simulate the 3D model of the excavator in the 3D simulation program (Hydra). UDP codes were written to send the joints values calculated by the inverse kinematics equations to the 3D model in Hydra. The input parameters to the system are the positions and the orientations of the end-tool of the haptic device, which will be controlled by the user. By using the inverse kinematics equations for the given excavator, each position and orientation of the end-tool of the haptic device will give a certain position and orientation for the end-effector (the bucket) of the excavator.

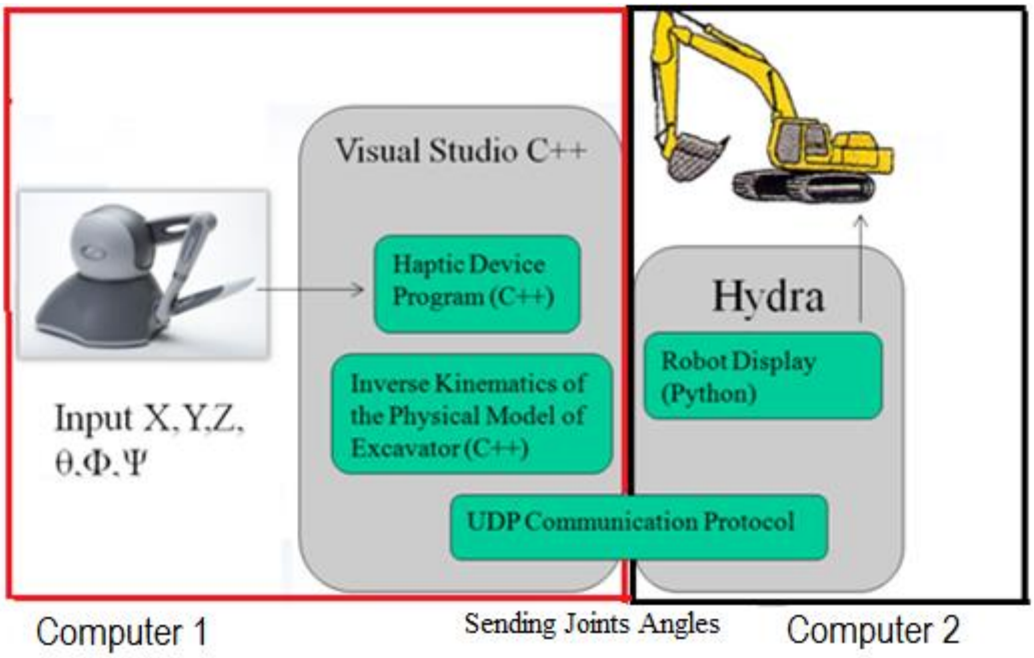


Figure 1. System diagram

Phantom Omni was programmed to control the excavator with the Absolute Position Method (called this by the designer). In other words, the workspace of the haptic device was scaled up to cover the workspace of the excavator, as shown in Figure 2.

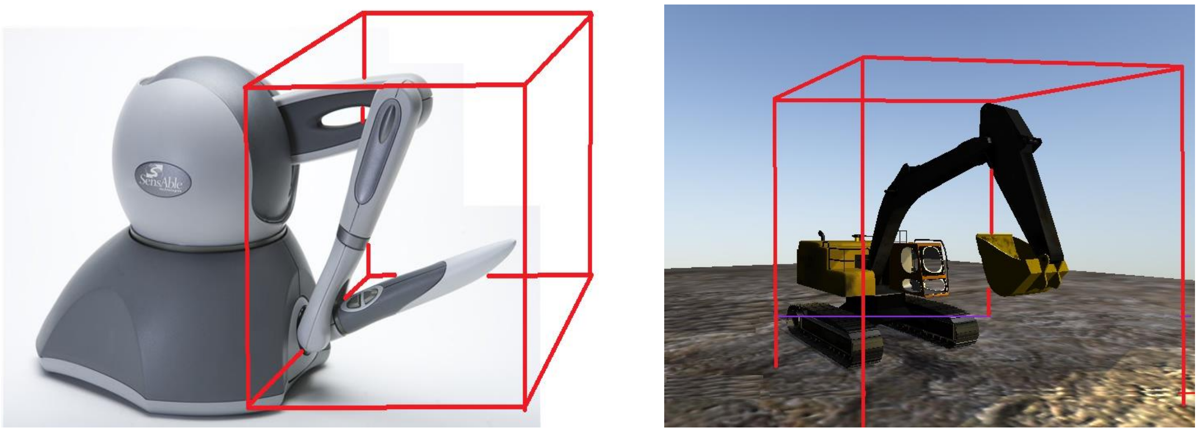


Figure 2. Workspace of the Phantom Omni and the excavator 3D model (in Hydra simulation program)

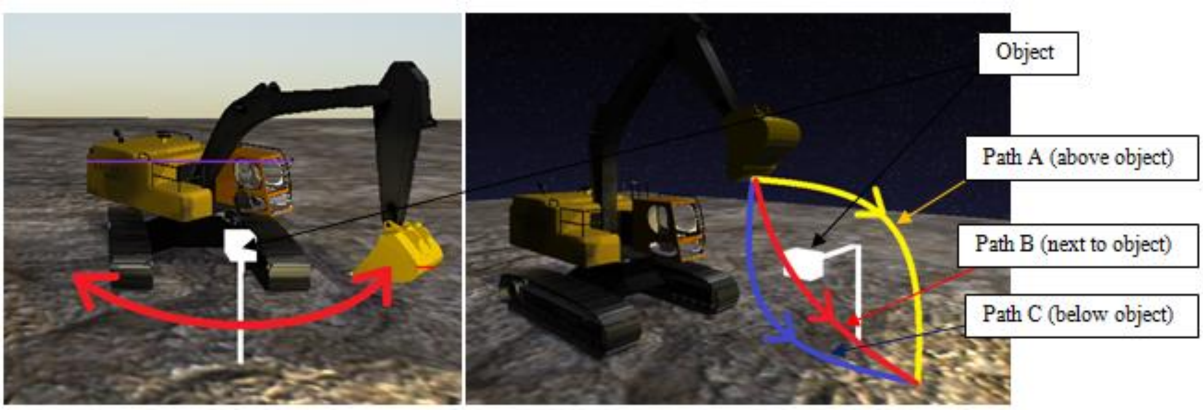
The haptic device has 6 DOF, whereas the excavator has 4 DOF. Therefore, in this project, only one of the revolute joints in the haptic device (Φ) was used to control the bucket of the excavator. When another excavator design is used in this system, the parameters of the design (length and weight of the links) must be entered in the program; then the force feedback will be calculated according to the new dimensions.

2.1 Force Modeling

By using some provided API with the Phantom Omni, a simplified model that calculates the mechanism power consumption and converts it into force feedback, scaled to fit the force range of the haptic device, was built from different sources while controlling the excavator:

- **The resistance force from the rotation speed of the joints**
  For simplicity, because of the limited force provided by the Phantom Omni, Hooke's Law is used: $F=-kx$. The method to find this force is to calculate the difference between the current position of the end-effector of the excavator model and the previous one. Then, multiply the difference with a scale factor, determined by the designer, which represents stiffness. This function that calculates the force is called by the haptic device every 100Hz. Therefore, the time interval used to calculate the speed in every loop is Δt=1/100 seconds. In Figure 3 (a), which shows a front view of the excavator model, if the user moves the haptic device in a swing motion like the one shown in the figure, with different speed, the user will feel different degrees of force resistance from the haptic device.

- **The torque acting on the links due to gravity**
  Because of the mass of each link, the gravity force will pull the links of the excavator to the ground. Equations that calculate the torque on each joint were used. Again, for simplicity, only the torque caused by gravity was calculated. Figure 3 (b) shows three different paths between two points. Each path will cause different force feedback to the user hand.



(a) *(b)*

Figure 3. a) Front view of the excavator, with swing path. b) Side view of the excavator with three paths of motion

3 USER TEST

In order to test the usability and concept of using the haptic device to sense the power consumption by the excavator while driving on different paths at different speeds, 12 male Master students in the Automation Engineering Programme from Seinäjoki University of Applied Sciences volunteered to make the user test. In this test, the students were asked to control the excavator between two points at different speeds in the workspace of the excavator, avoiding an object located in the middle of these two points (white box) as can be seen in Figure 3 (b). The idea is to choose the most comfort path for the user based on the force feedback, and three paths (A, B, and C) were given to the user. Each student was using the haptic device for approximately three minutes.

The following table summarized the results from the students and their opinions about this idea in general.

Table 1. Summary of the user test from 12-students

The Question	The Answer (Number of Students)
1. Does this test help you feel different force feedback by moving in different paths?	•Yes(12) •No(ZERO) •Not Clear(ZERO)
2. Which path do you think is the best for less power consumption, from Figure 3?	•Path A(1) •Path B(2) •Path C(9)
3. Do you feel different force feedback by moving the excavator bucket with different speed?	•Yes(12) •No(ZERO) •Not Clear(ZERO)
4. Does it limit your driving speed in certain range?	•Yes(9) •No(1) •Not Clear(2)
5. Do you think the idea of driving the excavator and measuring the power consumption using the haptic device is useful in this paper?	•Very useful(ZERO) •Useful(11) •Not Useful(1) •Very Not Useful(ZERO)
6. Do you think the concept of sensing the power consumption with haptic devices will be useful in the future in general?	•Very useful(3) •Useful(9) •Not Useful(ZERO) •Very Not Useful(ZERO)

In general, as can be seen from Table 1, all the students find this test is useful and they felt clearly the different level of power consumptions for different excavator movements. Most of the students limited their controlling speed because of the feedback force from the haptic device. Most of the students who selected Path C (below the object) mentioned that it was the easier path to follow because of the low force reflected in the haptic device. The student who selected path A (above the object) mentioned that it was easier in general to move in this arc motion and Path C was the most difficult for him because he needed a lot of power to move the haptic device in the second half of the motion, see Figure 5. The two students who selected path B they said they were more comfortable with that path in general. It is important to mention that most of the students found some difficulties in controlling the excavator with very accurate movements during the first minute. However, it became much easier with more practice.

Figure 4, is a sample points from one of the users, shows the net force applied by the haptic device into the user hand while doing he swing motion that is shown in Figure 3 (a) by two different speeds.

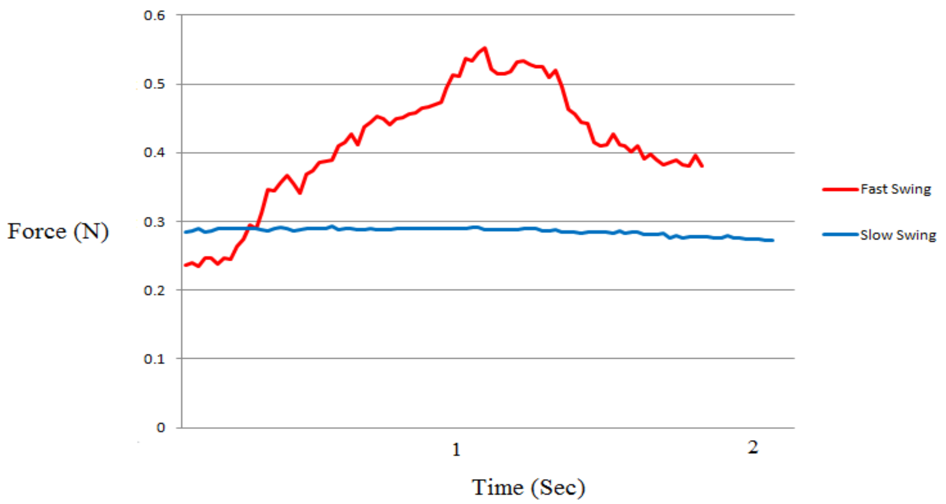


Figure 4.The force feedback (N) with the time (during 2 seconds) for two swing motions (fast, slow)

Figure 5 shows the average force feedback from the 12 students when they were moving the excavator between two points on three different paths (A, B, and C), as shown in Figure 3 (b). All the students were asked to move between the two points within approximately 5 seconds, so that the average force feedback can be calculated accurately, as shown in Figure 5.

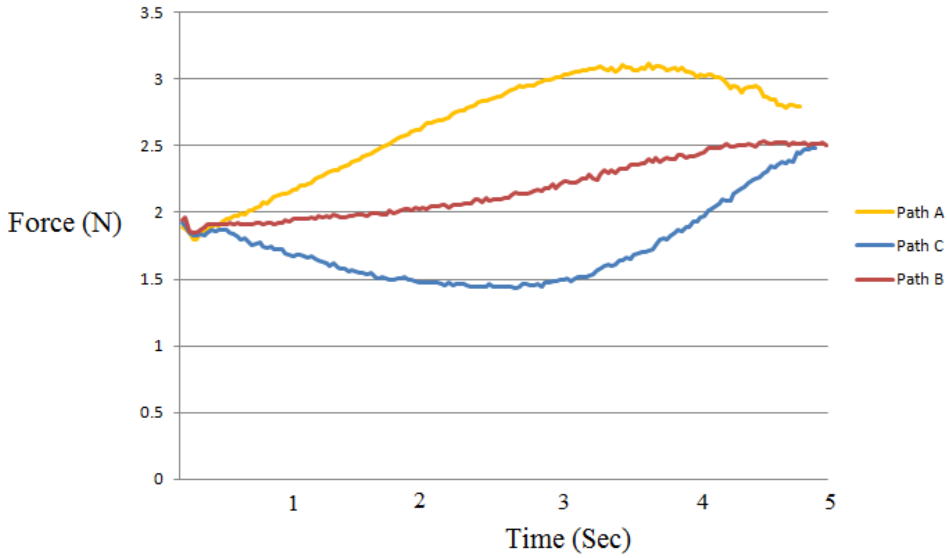


Figure 5.The average force feedback from 12 trials with the time for three different paths in Figure 3 (b).

4 DISCUSSION

From the results of Figure 5, it is obvious that the force feedback acting on the user hand is large when the user is trying to swing the bucket of the excavator at a faster angle speed. The result in Figure 5 shows that the force feedback generated by the haptic device is larger when the user tries to follow path A than the forces generated from path B and path C. This is in line with the results of the user test in Table 1. These tests provided an idea of how a user can study the properties of the machine based on the haptic feedback force when changing the path and speed in manipulating the machine model.

At beginning of this project, the haptic device program and the simulation program run in the same computer resulted in small jumps in the haptic device due to computational overload. In order to provide a smooth feeling of the force on the user hand, the haptic rendering needs to be done at least with a 100Hz frequency. This problem was solved using two computers communicating via a UDP socket. The first computer was responsible for running the haptic device program and the second computer for running the Hydra 3D simulation, respectively. Both computers were using the same address in the UDP code in order to send the joints values between them.

One point to mention is that Phantom Omni can apply limited force feedback. The Maximum execrable force at a nominal (orthogonal arms) position is 3.3 N and the stiffness values of Phantom Omni in X-axis, Y-axis and Z-axis are 1.26 N/mm, 2.31 N/mm and 1.02 N/mm, respectively. Therefore, it was not necessary to apply very complicated equations to calculate the power in different cases and then convert it into force applied to the user hand. The reason is that when forces of 0.5N and 0.4N are applied to the user hand by the haptic device during the experiment, the user will not be able to differentiate between these values. Therefore, we could use simplified equations to calculate the force without losing meaningful information.

Overall, the result from this project proved to be useful because it gives the user quite a good understanding of how to drive the 3D model of the excavator at a good speed. Because the haptic device successfully reflects on the user hand the force feedback generated by different factors, after some tests the user will be able determine some optimum paths to manipulate the excavator bucket, during work. By this way, the driver themselves will gain good understanding of the power consumed by the machine, which was hidden in the real-life application. With some practice with this 3D model, the user will be able to develop a method of manipulation to sense the estimated power needed as feedback force while carrying out the work.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we presented the idea of controlling the 3D model of an excavator using the Phantom Omni haptic device. This study gives the user a better understanding of how to manipulate the bucket of the excavator while moving in space, which can help them understand how required diesel power behaves while carrying out the work. The haptic device was a good tool to support the user's understanding of how different designs of the machine prototypes can result in different levels of power consumption because of the different link mechanisms. This can help in the design phase of any machine prototype in the future.

As future work in research, a better haptic device might be used in order to have a larger range for the force feedback. More user tests are needed to study how people perceive multimodal feedback and how it will support finding new ideas to accomplish a new type of boom mechanism and fluid power transmission line.

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