Design of Virtual Reality Prototyping System and Hand-Held Haptic Controller

G. Ko, S. Ryu, S. Nam, J. Lee, and K. Suh

***Abstract*—This paper proposed virtual reality prototyping system using a hand-held controller with haptic feedback. The prototyping process enables a company to extract user requirement effectively. However, repetitive process takes time and costs to creating mockups and testing space. The proposed system are designed and constructed to support prototyping process by creating, checking and manipulating a virtual product in a virtual environment. A haptic device provides physical interaction between virtual objects and the user in a virtual prototyping. The design of controller capable of five-finger haptic interaction is also proposed. The virtual hand interface is designed to be visually co-located with the hand-held controller.**

***Index Terms*—Haptic controller, product development, virtual prototyping, virtual reality.**

I. Introduction

Prototyping is an effective approach that simplifies a design process by allowing users to experience a prototype of a product [1]. Traditional prototyping process can be simplified as collecting requirements, designing prototypes, developing prototype mockups, and getting feedback from customers. The company repeats this process and produces a complete product. Such prototyping method are effective for extracting user requirements. In customer evaluation stage, potential customers are invited to the testing space to be observed and interviewed. However, when repetitive process take place, creating physical mockups and setting testing space increase costs and the time. Most product design is developed in 3D CAD software. This shorten the produce development period, reduces cost, and improves quality by validating designs through simulations in which products are assembled or operated in a virtual environment, without requiring physical assembly in the design stage.

Virtual Reality (VR) technology is being increasingly applied to product design, prototyping and manufacturing [2]-[4]. By combining virtual reality technology with 3D CAD software, a designer can use CAVE and Head Mounted Display (HMD) to visualize prototypes in virtual environments and evaluate on materials, colors and craftmanship as well as aesthetics, packaging and ergonomics under design. Ford designers, engineers and researchers are creating vehicles using virtual reality technology. Ford ergonomics and variation lab focuses on motion capture, 3D printing and virtual reality to design most efficient and safe assembly line [5]. Collaborative VR improves global collaboration between people and companies. Large organizations such as NASA, Volkswagen and Nvidia are already exploring and creating collaborative VR platforms [6], [7]. Because VR technology provides a realistic experience in an immersive environment, manipulating, arranging, disassembling, and assembling virtual products via spatial interaction are suitable as shown in Fig. 1.

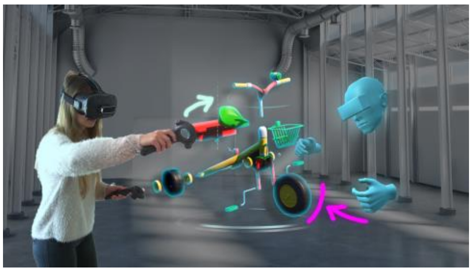

Fig. 1. Concept of virtual prototyping.

In VR design and prototyping of product, a haptic display provides realistic feeling by giving force feedback, vibration, and temperature. A haptic device provides the user with the sense of touch by simulating the physical interaction between virtual objects and the user in a virtual environment [8]. Because a self-grounded haptic device is more effective to provide freedom of motion in virtual environment than a world-grounded haptic device, most VR controllers are designed and manufactured as hand-held types [9]. The rest of this paper is organized as follows: In the next chapter, the design and implementation of the VR prototyping system are described and, in chapter 3, the design of a hand-held VR controller are explained. Finally, conclusion is made for the proposed system, and new research topics and directions.

II. VR Service Design Prototyping System

VR prototyping involves a series of processes related to the product design stage and has the advantages of lower costs and time consumption. As shown in Fig. 2, the proposed system comprises an experimenter computer with an HMD (HTC Vive), an operator computer, an observation computer, and a network server. Prototypes of various models are being evaluated with respect to their design and

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functionality via software that creates a virtual experiment environment for users to modify the materials and colors of the virtual products and to manipulate them in the system.

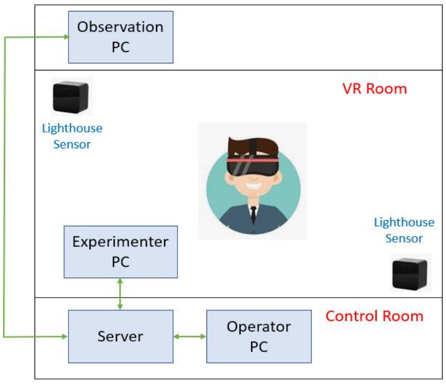


Fig. 2. Virtual reality prototyping system.

The subject and experimenter are in separate physical spaces like in traditional service design prototyping. The experimenter can see the state of the subject's behavior through special glass. The experimenter controls the experimental environment over the network. The network server delivers voice over the network; thus, the operator can instruct the subject manually. The operator computer has functions to select the product, environment, and material texture and color. The operator sets the product and environment to be used in the experiment. When the subjects wear the HMD connected to the experimenter computer, they can observe the virtual prototype and environment set by the operator with stereoscopic display. The proposed system includes a function that allows the subject to manipulate the virtual product. Ways of manipulating the virtual product are to grab part of it, move or rotate it, and disassemble or reassemble it.

In virtual reality prototyping, VR controllers are visualized using human hands, where the hand shape changes as the subject presses the buttons on the controller as shown in Fig. 3. This system is designed to support HTC VIVE controller and the VR haptic controller proposed in the paper. For the HTC VIVE controller, the thumb is connected to the touch pad and the other four fingers are connected to the trigger button. The virtual hand is visualized as stretched if the subject does not press the trigger button and touchpad as shown in Fig. 3. For the proposed haptic controller, virtual hand shape changes according to the fingers pressing the haptic controller. When the trigger button and touchpad are pressed together, the virtual hand represents the shape of a hand making a fist. Because humans tend to use their fingers and thumb together to hold objects, we defined it as grab interface.

The prototyping system was implemented in the Unity game engine. physics simulation is applied during operation of the product, which realizes various physics simulations, such as gravity and collision as shown in Fig. 4. If the subject moves the hand to a part of the product with grip interface, the part can be held in their hand. In addition, when the subject moves their hand in the space, the part moves with the hand. When the subject releases the trigger and touchpad buttons, the part is released from the virtual hand.

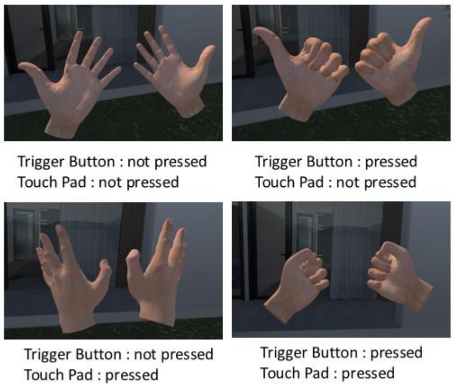
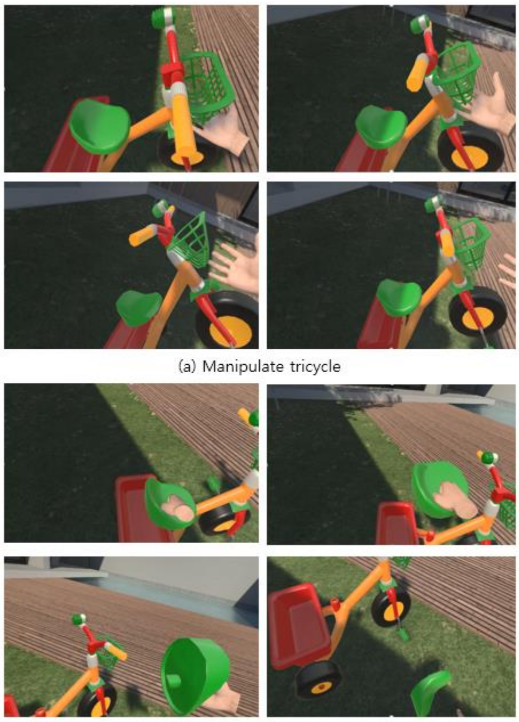


Fig. 3. Hand interface based on the haptic controller.



(a) Manipulate tricycle

(b) Grab a part of tricycle

Fig. 4. Physics simulation of virtual prototyping system.

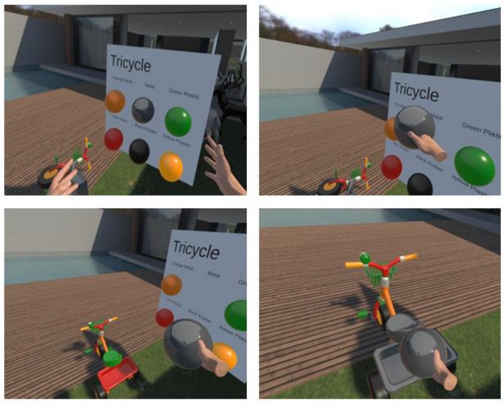


Fig. 5. Change material of virtual product from menu plate.

The menu option allows the user to select and change the virtual product's material. When the subject presses the menu button, a menu panel appears in the virtual environment. The subject can select desired material from the menu panel by grasping it and moving a handheld material ball to the part of product they wish to change as shown in Fig. 5.

The experimenter computer observes subjects from the first-person point of view. The observation computer allows the experimenter to observe the subject's movement and manipulation of the virtual product by visualizing the virtual environment. The experimenter can freely change the viewpoint of the camera to observe the subject as shown in Fig. 6.

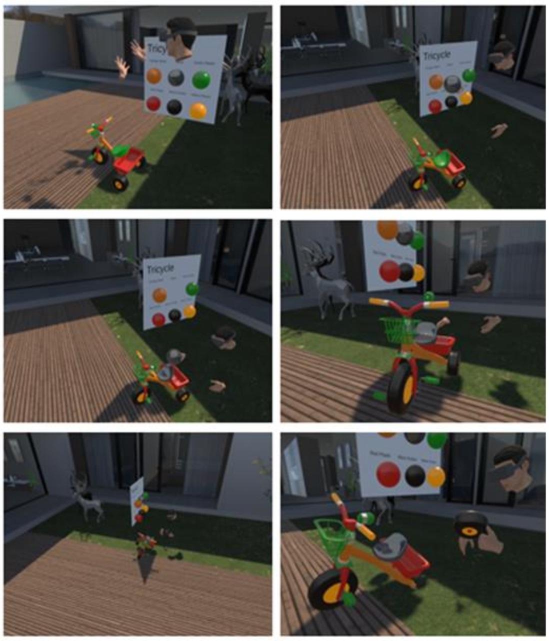


Fig. 6. Observation of subject's behavior in observation computer.

III. Hardware Controller

There are many types of hand-held input device; non-tracked hand-held controller (joysticks), tracked handheld controllers (HTC VIVE Controllers, Oculus Touch Controllers), hand-worn device (data glove), and bare hand device (leap motion). As more advanced types, some controllers have other functions to provide more realistic interaction. For example, DextaRobotics and HaptX made exoskeletal devices [10], [11]. Force feedback interaction is important effect for VR prototyping, an exoskeleton-type controller has the disadvantages of being heavy and difficult to use without help. The Knuckle controller of Valve has object manipulation function in finger level [12]. Therefore, this study also focused on a handheld controller, by which it is possible to integrate sensors and motors inside the handle of the controller. Moreover, the user's thumb is able to move freely, so additional necessary operations, such as pushing a button, can be performed.

In addition, the controller has the form of a handgrip to measure the pressure of each finger, a linear motor corresponding to the five fingers on one hand to give force feedback, and a network module to communicate with the operating computer as shown in Fig. 7. The controller's processor sends five fingers' pressure to the prototyping controller module. The prototyping controller module is developed in C++ and connected to the Unity and Unreal game engines through plug-in modules. The displacement of the linear motors of the controller is calculated by the physics engine based on the pressure of the hand holding virtual object and physical property of the object, and is transmitted to the controller.

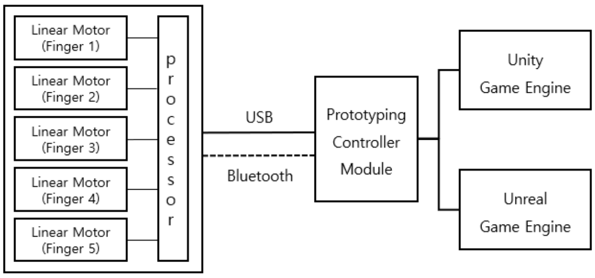


Fig. 7. Communication between controller and game engine.

The mockup of the controller is made from clay. According to the design evaluations of engineers and designers, the external design of a haptic controller was derived. First design of the haptic controller are designed as shown in Fig. 8.

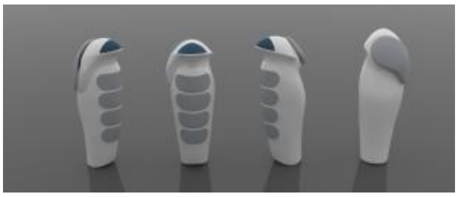


Fig. 8. First design of a haptic controller.

We used the first design of a haptic controller to create mockup as shown in Fig. 9. The controller was separated into left and right models. Both parts of controller were output using a 3D printer. We performed the process of checking and selecting the 3D printer output and combined the output in three steps to produce the external shape of the haptic controller.

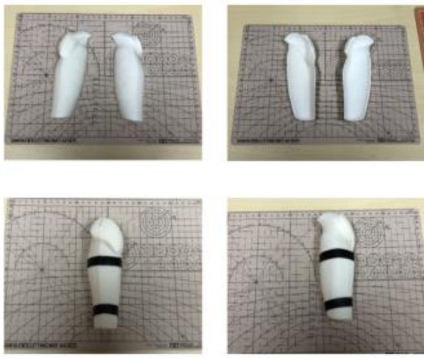


Fig. 9. Mockup of a haptic controller.

Fig. 10. Final design of a haptic controller.

An additional part along the back of the hand is added to tackle a potential drawback of the controller's being too large to be uncomfortable when too many parts are integrated inside the handle, i.e., other parts, such as the battery and inertial measurement unit (IMU), are contained within the handle. The final design of the controller in Fig. 10 is derived from a grip test with an initial mockup produced by a 3D printer.

IV. Conclusion

This study examined a prototyping system using VR technology for solving the constraints of existing service design prototyping systems. The proposed VR prototyping are designed and implemented. The system makes it possible to change the pose and material of a virtual product, as well as assemble, disassemble, and manipulate the target product. In addition, research is underway to develop a VR haptic controller suitable for manipulating a virtual product with all five fingers in the proposed prototyping system. The Hand Interface are designed for a haptic controller. The exterior design of a controller are performed. However, the proposed haptic controller has yet to be integrated into the system. In the future, we plan to integrate the controller into the virtual prototyping system and perform a usability test.

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