

Augmented Reality Video See-through HMD Oriented to Product Design Assessment

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Abstract. Current state of the art technology offers various solutions for developing virtual prototyping applications that also allow the interaction with the real environment. In particular, Augmented Reality (AR) technologies include tracking systems, stereoscopic visualization systems, photorealistic rendering tools, hi-resolution video overlay systems that allow us to create various types of applications where the virtual prototype is contextualized within the real world. One application domain is product design: AR technologies allow designers to perform some evaluation tests on the virtual prototype of industrial products without the necessity to produce a physical prototype. This paper describes the development of a new Video See-Through Head Mounted Display (VST-HMD) that is high-performing and based on stereoscopic visualization. The developed display system overcomes some issues concerning the correct visualization of virtual objects that are close to the user's point of view. The paper also presents the results of some tests about an AR application developed for product design assessment.

Keywords: Augmented Reality, Head Mounted Display, Video See-Through HMD, Design Assessment.

1 Introduction

Today, the aesthetic impact of products is an important aspect that may contribute in making the difference in respect to products that are technologically similar and with same functionalities. The product development process of products includes a phase dedicated to the design assessment, which is a crucial phase where various experts cooperate in selecting the optimal product shape. Although computer graphics allows us to create very realistic virtual representations of the products, it is not uncommon that designers decide to build physical mock-ups of their newly conceived products because they need to physically interact with the prototype and also to evaluate the product within a plurality of real contexts.

Current state of the art technology offers various solutions for developing virtual prototyping applications that also allow the interaction with the real environment. In particular, Augmented Reality (AR) technologies include tracking systems, stereoscopic visualization systems, photorealistic rendering tools, hi-resolution video overlay systems that allow us to create various types of applications where the virtual prototype is contextualized within the real world.

In case of an AR application for supporting the assessment of designed products, it is very important that the designers are able to see the virtual object from different points of view, in a stereoscopic modality, and inserted within a real context. This can be achieved using a tracked Video See-Through Head Mounted Display (VST-HMD). This type of display system simulates the user's eyes viewing system. Although this solution allows a user to see the virtual objects in a stereoscopic modality, many problems arise when the user tries to see virtual objects that are near and far from the user's point of view. These problems are related to the cameras convergence angle. In most of the video see-through display systems the cameras position is fixed, while in order to solve convergence problems the angle between the two cameras should be accommodated according to the convergence value as our eyes do.

This paper describes a VST-HMD system that we have developed where cameras convergence issues have been addressed and solved. The VST-HMD system here presented is an initial prototype that has been developed in order to investigate issues regarding visual parameters and ergonomic aspects.

In addition we have implemented an AR application for product design assessment where users can interact with various 3D models of a product through the use of an input remote control with the aim of assessing the designs.

The paper is organized as follows. Section 2 includes an overview of related works. Section 3 describes the design and development of the HMD. In Section 4 we present the AR application developed for product design assessment that has been used for validating the design and performances of the HMD.

2 Related Works

The selection of a specific visual display technology for an AR application depends on various factors [1] including: the type of objects to see, activities to be carried out, the environment where the application is performed (internal or external workspace), role of the user, etc.. With regard to our design assessment application the most appropriate visualization technological solution is a kind of VST-HMD system where the user is able to see a three-dimensional representation of a Virtual Prototype (VP) of a product from different points of view and in a natural way. Commercial VST-HMD are rare [2] and are mostly dedicated to a specific application purpose, and in addition have several limitations. For this reason, many research groups have worked on the development of different types of VST-HMD oriented to their specific purposes.

One of the first examples of stereoscopic VST-HMD was developed by mounting small cameras onto a commercial Virtual Reality (VR) HMD [3]. This is a quick solution for the development of a VST-HMD and many research groups, including ours, are using this solution to create and evaluate AR applications with the aim of performing preliminary tests. Unfortunately, this solution does not guarantee high visual performances and the supported configuration involves several issues which must be addressed. The following reports some issues that may occur. The misalignment between the cameras and the user's eyes produces a parallax effect that leads to a spatial perception error [4] with the consequent feeling of incongruity especially at close distance [5]. The peripheral imagery does not match with the imagery inside the

display: this may confuse the user who needs to see, at the same time, the display and the external surrounding environment [6]. Fixed cameras position does not allow users to reconstruct correctly objects that are near and far from the users' point of view. Fixed displays position does not allow users, with different interpupillar distance (IPD), to see properly the acquired scene. The initial experimental VST-HMD prototypes have proposed various solutions for solving these issues.

Fuchs et al. [7] describe a VST-HMD prototype implementation of a three-dimensional visualization system to assist laparoscopic surgical procedures. This device has two "eye-pods" consisting of a compact display and a lipstick camera. Takagi et al. [8] describe the studies and the experiments which led to the development of the Canon-MR HMD System [9]. The optical system of this VST-HMD is based on two prisms with a particular geometry that, by defining a specific optical path, allow the development of a compact and light optical system without parallax effect. Unfortunately this configuration does not allow users to see correctly the objects that are near from the users' point of view [2].

A solution for improving the visualization of close objects is to modify the convergence angle between the cameras accordingly to the user's point of view. A first attempt based on this approach has been implemented is a teleoperation system including two motion-controlled cameras, which dynamically converge onto the target object [10]. In this system the output stereoscopic imagery are displayed on a monitor and the user wears active polarized goggles. Actually, this is not a VST-HMD device but the results obtained using this particular acquisition system are indeed very interesting.

A different solution was described in [11] where, instead of rotating the cameras physically for changing the convergence angle, the authors have developed a software algorithm that allows them to simulate cameras rotation. They used a VST-HMD whose video cameras have a much larger field of view (fov) than the display unit. On the basis of this prototype they have developed another VST-HMD using commercial components and a mount manufactured through rapid prototyping methods [2].

3 VST-HMD Development

In current VST-HMD state of the art there are many examples of experimental devices created for specific purpose but a commercial product that solves all of the visual issues discussed in the previous session doesn't exist. Consequently we have developed a VST-HMD device which supports our application for product design assessment and which solves the issue related to the visualization of objects closely. The proposed solution for solving the visualization issue is to control the convergence angle of the cameras by using two micro servos. The main objective of our research was to demonstrate the feasibility of such visualization system; for this reason we have developed a prototype based on commercial component. The real scene is acquired by two Logitech QuickCam® Pro for Notebooks webcams that have these specifications: resolution of 640X480 @ 30fps. The display system is based on two Liteye monocular Full Color OLED display with a resolution of 800X600. The two cameras are handled by two Dong Yang analog servos that, although having small dimensions (19.8mm X 8.0mm X 22.5mm) and weight of 4.4 g, allow us to provide a

torque of 0.8kg/cm and a speed of 0.12/60° values, which is more than enough for our purposes. All components were arranged on a light safety helmet by using a specific frame designed in order to provide all of degrees of freedom for a correct registration. Before physically making our device, we investigated some aspects in order to define the best layout of the components, and we performed a preliminary test in order to optimize the algorithm for the cameras control.

3.1 Cameras Control System

The geometrical studies discussed in [8] reveal that camera and display must be always aligned. However, like it has been demonstrated in [5], the human eye is able to adjust, in a short time, to small visual incongruities and consequently to reconstruct the three-dimensional image correctly. Starting from these assumptions we would like to demonstrate that the user can reconstruct a good three-dimensional image by using our system where the monocular displays are parallel while the cameras automatically converge toward the target object. This solution allows us to see far objects (parallel cameras and displays) and near objects (parallel displays and angled cameras) without the need of a manual registration.

The value of the convergence angle (β) of the cameras varies according to the following formula that was derived from a simple geometrical consideration.

$$\beta = \arccos \frac{\sqrt{l^2 - \frac{d^2}{4}}}{l} \quad (1)$$

In this formula l is the distance between the object and the camera while d is the user's IPD. This function, however, doesn't consider the object dimension because the distance l is calculated from the centre of the virtual object thus, when the user tries to see a large model, the real distance l is lower. In order to solve this issue we have corrected the formula according to the size of the virtual object that was approximated with a sphere (bounding sphere).

$$\beta = \arccos \frac{\sqrt{l^2 - \frac{d^2}{4}} - r}{\sqrt{\left(l^2 - \frac{d^2}{4} - r\right)^2 + \frac{d^2}{4}}} \quad (2)$$

where r is the sphere radius.

3.2 Preliminary Test

In order to reduce the distortion due to the different convergent angle between cameras and displays we introduced in our cameras control software a constant value that was determined empirically through a preliminary test. During this test we also evaluated the differences perceive by the user when β is calculated using the formula (1) (normal method) or with the second one (2) (bounding sphere method). In order to perform this test we have developed a setup where the user can see through the fixed parallel display while the cameras are mounted on the servos and they are positioned on the desk (Fig.1).



Fig. 1. Setup of preliminary test

We performed the test with 10 users (7 male and 3 female) that have previous experience with stereoscopic viewing in order to set more significant conclusions. At the beginning of the test we measured the user's IPD and we set the distance between cameras and between displays to the same value of the user's IPD (this is the same registration that the user can set on our VST-HMD). The IPD value is also set on the cameras control software. During the test the user sees alternately three different virtual objects (elongated, squared and rounded) at different distances (2m, 80cm, 40cm, 15cm). For every object we proposed three different values of constant angle (0° , 3° , 6°) and the two different modalities to calculate the distance of the virtual object discussed in the previous section. The average duration of the test was 15-20 minutes.

The results of this preliminary test reveal that with the proposed configuration (parallel displays and converging cameras) there aren't problems when the user sees distant objects; while, when the objects are nearby, we observed that if the constant angle is between 0° and 3° the user improves the ability to reconstruct 3D images of near objects. The constant angle instead does not influence significantly the viewing of distant object. We also estimated that this value is proportional to the user's IPD that can be determined by this equation:

$$\beta' = \beta - IPD/35 \quad (3)$$

For what concerns the two different methods to calculate the distance of the objects, we observed that the normal method improves the viewing of the part of the object that is near to the marker while the bounding-sphere method improves the visualization of the part of the object that is near to the user's point of view. Obviously the use of the two methods does not influence the viewing of small objects but has a significant role for big ones. The effects of the bounding sphere method are also related to the geometry of the object. In fact the users have some viewing problems when they see the object where one or two dimensions are predominant respect to the other (elongated object).

3.3 Design of the VST-HMD

The layout of the components of the VST-HMD was designed in order to satisfy different morphological characteristics of the users. The optimization of the layout was

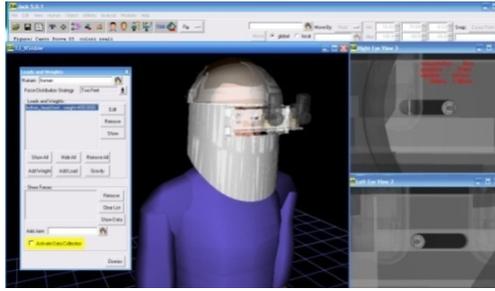


Fig. 2. Components layout configuration by using Tecnomatix Jack

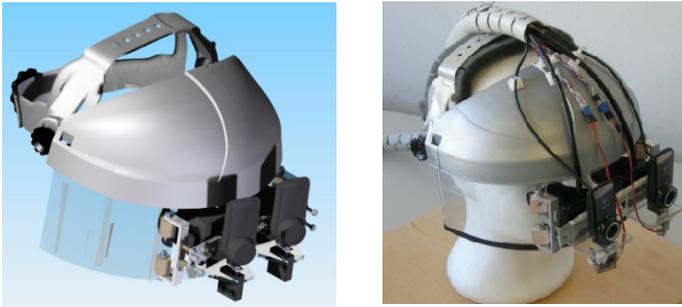


Fig. 3. Digital and real models of the assembled VST-HMD

achieved by using the ergonomics and human factors software Tecnomatix Jack [12], which is generally used to improve the ergonomics of product designs and workplace tasks.

This software enables users to position biomechanically accurate digital humans of various sizes in virtual environments, assign them tasks and analyze their performance. Thanks to this software we implemented a simple routine that allowed to check the correct positions of the monocular displays for different virtual users with different IPD and head size (Fig. 2). The obtained results are used to defining the registration range of the three translational degrees of freedom (dof) of the monocular displays. These data were used to support the design of the frame where cameras, monocular displays and servos are mounted. The modeling and the virtual assembly into the digital model of the safety helmet of the frame were realized by using a CAD system.

After this developing phase of digital model of the frame, we made manually the frame with light material, like aluminium alloy and plexiglass; then we assembled the other components and we fix the frame onto the safety helmet. The weight of the device is about 850g. Fig. 3 shows the digital model and real model of the VST-HMD.

4 Application for Product Design Assessment

In order to evaluate the effectiveness of our VST-HMD we have developed an AR application by using the OSGART [13] library. The aim of this application is to perform some tests in order to collect, from a pool of testers, data and comments about usability and ergonomic aspects of the system. For what concerns the visualization, the AR application acquires the real scene from the cameras mounted on the VST-HMD and generates two images which are visualized on the VST-HMD displays by giving to the user the possibility to perceive the scene depth. In order to ensure a perfect overlapping of the right and left images, the convergence angle between the cameras is regulated according to the distance between the virtual object and the user's point of view as discussed in section 0. The AR application calculates this distance and sends the angle value to the servos that moves the cameras so that the user can see the virtual object properly both near and far. Correct position and orientation of the virtual object are guaranteed by a bi-dimensional marker: in addition it is also possible to move, rotate and scale the virtual object by using a remote control system. In this case we have used the WiiMote [14] control system. The integration, between WiiMote and our AR application, was realized by using the Wiiyourself [15] library that allows us to acquire all information about the WiiMote integrated appliances. Furthermore, the AR application makes use of some combinations of pressed buttons and values coming from accelerometers that allow the user to interact with the virtual model.

4.1 Testing Scenario

The testing scenario, which we have developed for testing the use of our VST-HMD, concerns the validation of the re-design of the windscreen of an existing motorcycle. Initially we have digitalized the real motorcycle windscreen by using reverse engineering techniques; then a designer has made some aesthetic modifications on the digital model of the original windscreen and he created some new virtual prototypes of the new windscreen. In order to evaluate and appreciate the modified shapes of the windscreen, we proposed the use of our VST-HMD and our AR application that allows us to superimpose the virtual windscreen onto the existing motorcycle. In this AR environment the users could see and interact with the virtual prototypes in order to appreciate the differences among them.

The testing session performed in our AR environment involved 5 users. The users included 4 engineers and 1 designer; all of them had previous experiences in using AR environments. The session was video recorded for subsequently analysis. When the users worn the VST-HMD, for the first time, they actually needed to accustom themselves to the stereoscopic visualization of the device but, after few seconds, they could see correctly. Before evaluating the mixed model the users tool in their hand the WiiMote control that was located on the table. In this first task the users hadn't great difficulty to localize and to reach the WiiMote.

The testers looked at the motorcycle and could see the mixed image: the real motorcycle and the virtual windscreen. In addition, by using the WiiMote control the testers were able to change the virtual model to display. When a tester went closer to the virtual windscreen, because he wanted to see better some details, the convergent



Fig. 4. User during the interaction and user’s point of view

angle of the cameras changed according to the distance between the user's point of view and the virtual object. The testers were allowed to move, rotate and translate the virtual models by using the WiiMote.

After the testing session the users compiled a questionnaire about the efficiency of the system. They were asked to rate each answer from 1 (bad) to 6 (good). The questions and the average value of the answers are reported in the table below.

Table 1. Testing session questions and rates

<i>Evaluation of the VST-HMD</i>	
A1. Video quality	4.8
A2. Is the representation of the windscreen realistic?	4.7
A3. Is the virtual windscreen integrated in the real scene?	4.4
A4. Do you perceive distortion or other visualization defect?	4.0
A5. Have you problems viewing or discomfort at the beginning of the test?	3.9
A6. Have you problems viewing or discomfort during the test?	2.7
A7. Do you perceive correctly the scene depth?	5.4
A8. Are you able to see the windscreen closely?	4.0
A9. Have you problems viewing or discomfort after the test?	2.0
<i>Evaluation of the interactive AR design review</i>	
B1. Can you appreciate the difference among the models?	5.0
B2. Can you easily interact with the models?	4.7
B3. Do you consider that this methodology is effective ?	4.5

4.2 Evaluation Results

The testing sessions have allowed us to validate the use of VST-HMD visualization system and the interactive AR design review application. The first impression and comments on the visualization system from the testers was about the little field of view of the displays and about the little delay of the video streaming that, after all, is acceptable. All of the users saw the scene in the correct way by perceiving the depth sensation both of the real objects than the virtual ones.

The analysis of the answers to the questionnaire highlights that the VST-HMD gives the possibility to see the virtual and the real objects at the same time with good quality (question A1). The representation of the windscreen appears realistic enough and well integrated with the real motorcycle (questions A2, A3). Despite the fact that the users perceive correctly the scene depth (question A7) they found some defects

and some distortions during the visualization. This phenomenon is most likely related to the quality of the commercial devices that we have used to assemble the VST-HMD and surely to the different fov between the cameras and the display. The control system, which controls the convergent angle of cameras, provides a correct regulation when the user tries to see the windscreen closely (question A8) and the speed of control seemed appropriate to the purpose. For what concerns issues about users' discomfort, the users did not report of any particular problem during and after the test (question A6, A9) while they felt some discomfort at the beginning of the test during a period of time required for eyes adaptation.

For what concerns the AR design review application, the users appreciate the possibility to switch among the different models in order to compare accurately the proposed solutions (question B1). The interaction, with the virtual model of the windscreen performed through the WiiMote control, is quite natural (question B2) and allows to extrapolate the virtual object from the real position in order to validate some aspects more easily. Globally the users consider the developed AR interactive environment very effective (question B3) and they supposed that the integration of the two proposed environments might reduce significantly the time for the industrial product development.

5 Conclusions

In this paper we have described the development of our VST-HMD prototype that allows us to solve the issues related to the viewing virtual objects closely. Our proposed solution is to control the cameras convergent angle by using two micro servos. This solution was validated by performing some preliminary tests. In addition we also validate the use of the VST-HMD through a testing session performed with our AR application for design review. In this testing session the users could see and interact with the virtual prototypes in order to appreciate the differences among them. The results of this testing session reveal the effectiveness of the device and outlook the possibly use during the design review phase of the industrial product.

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