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DEVELOPMENT OF A 1:1 SCALE TRUE PERCEPTION VIRTUAL REALITY SYSTEM FOR DESIGN REVIEW IN AUTOMOTIVE INDUSTRY

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ABSTRACT

The recent improvements of Virtual Reality (VR) technologies makes it feasible for automotive design reviews to be carried out in a virtual world. Design review with virtual prototypes could reduce costs by eliminating the need to build physical prototypes, help speed up the design process, and enable the simultaneous examination of different design options. However, the most important challenge to address is whether a true 1:1 scale representation of the vehicle can be achieved in VR; whilst such claims are frequently made, how this is achieved is not reported in the research literature. In this study, a VR system with 1:1 scale true perspective display was created and calibrated using a large stereoscopic screen and optical tracking system. Various vehicle models of differing fidelity were used to test the capability of the system and ideal sizes of model identified. This paper also reports the use of several virtual tools for the design review process, which augment the immersive experience of the observer.

Keywords: Design review, Automotive, Virtual Reality

1 INTRODUCTION

The automotive vehicle design process involves taking sketches of the designer's initial ideas through several different modelling processes, whilst increasing the fidelity of the representation, as the design solution matures to the final, production ready, vehicle definition. Typically a mixture of sketches, virtual models based upon computer-aided design (CAD) data, and physical mock-ups will be used throughout the design development process. For the assessment and evaluation of appearance, style aesthetics, and user experience, it is common practice to rely upon physical mock-ups (Zorriassatine *et al.* 2003). However, in the earlier design phases, many adjustments and modifications will be required to the design before it becomes a mature solution; these changes must be re-evaluated using either a modified or new physical mock-ups. This trial-and-error approach is clearly one of the biggest bottlenecks in the product development process (Fiorentino *et al.* 2002). The drawbacks are represented by the amount of time to build physical mock-ups, the cost incurred, and the inability of rapid manufacturing techniques to provide the final look necessary for appearance and aesthetic evaluation (Oh *et al.* 2004). As an alternative, assessments with virtual prototypes would be highly beneficial (Kim *et al.* 2011).

With rapid development of both hardware and software in the last decade, VR systems are widely used in the design phase for styling reviews (Ni *et al.* 2006; Buxton *et al.* 2000).The distinct feature of VR systems is an ability to create a sense of depth perception by the observer through its use of stereoscopic imagery . In 1998, Purshke and his co-workers (1998) developed an intuitive VR system for vehicle design; the designer could change the colour, surface structures of the car's interior, or any arbitrary components. Fruend *et al.* (2002) proposed a vehicle design review system using augmented reality; the designers built different virtual models using different components and could change the appearance of exterior design. This system was established for the purpose of evaluating ergonomic considerations on the interior design of a vehicle from a series of defined seating positions. To achieve a true perspective display, many VR systems track the positions of the operator, so that the displayed image is a projection of the model referenced to the location of the operator in the VR world co-ordinate system (Cruz-Neira *et al.* 1992). More recent developments focus on how to achieve 1:1 scale by using a head-mounted display (Chen *et al.* 2008; Combe *et al.* 2008) and a large stereoscopic screen (Watanuki *et al.* 2010).

Creating a 1:1 scale, true perspective, stereo image is an important criteria for the acceptance of VR technology by automotive designers who wish to evaluate a virtual vehicle mock-up. Gogel and Tietz (1973) showed that perceived motion concomitant with lateral head motion provides information permitting a recalibration of perceived distance. They suggested that motion parallax enables this recalibration and consequently a better understanding of egocentric distance. Paille et al., (2005) also showed that in a dynamic condition (i.e. with head-tracking) distance perception was improved. Leroy and his co-worker compared the influence of the head tracking, interpupillar distance, the position of the virtual object in relation to the screen, and the orientation of the modified shape on the quality of the perceived stereo image; the results showed that all of these parameters seem to have an influence, but head tracking appears to be the most important for good perception (Leroy *et al.* 2008). Furthermore, a study conducted by Rock and Harris (1967) showed that body perception (i.e. visualisation of the user's own body) could influence the user's size judgments if his body is visible during the size evaluation of an object. This finding is consistent with the recent study carried out by van der Hoort (2011).

The purpose behind the work described here was to develop a virtual vehicle mock-up capability for design reviews in automotive applications. From our understanding of the previous work in this area, the important features of the system would be:

- a stereoscopic virtual reality projection system
- head tracking of the observer
- image projection referenced to the observer
- observer size referencing with own body

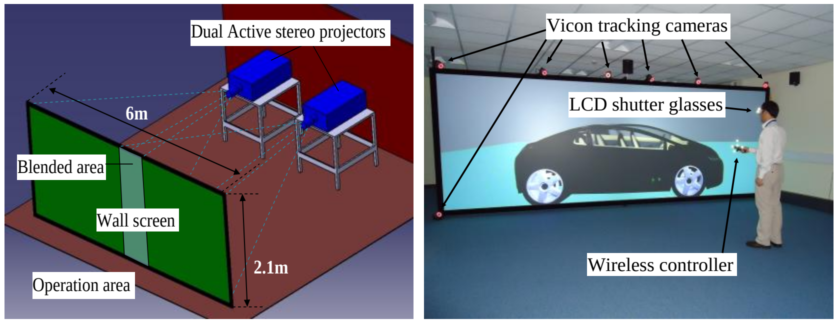
2 VR SYSTEM

2.1 Hardware development

The installation of a VR system in the laboratories of the Virtual Engineering Centre (VEC) was constrained by the physical dimensions of the space available; consequently, a flat projection screen of length 6.0m and height 2.1m has been constructed as shown in Figure 1(a).

Two CHRISTIE WU7K-M WUXGA DLP active stereo projectors are placed behind the screen. Each projector can generate a 1920 x 1200 image at a refresh rate of 120Hz, but the displayed image only has a resolution of 3390 x 1200 (3.6 million pixels in total) because of a 450 pixel blend in the middle of the screen. The workstation for the VR system is a DELL Precision T7500 with a dual hex-core CPU, 48GB RAM, and two NVIDIA Quadro 6000 graphic cards each capable of rendering 1.3 billion triangles per second.

As shown in Figure 1(b), operators must wear NuVision 60GX wireless LCD shutter glasses that are synchronised with the projectors to perceive a stereoscopic image. Objects in the active area (5m width x 4m depth x 2m height) immediately in front of the display screen can be tracked by 12 Vicon Bonita infrared cameras with a positional accuracy of at least ±0.5mm. Position and orientation data for tracked objects are broadcast across the VEC network using a VRPN protocol. A wireless Splitfish Dual SFX Evolution joystick controller can be used for interacting with the virtual environment.



(a) (b)

Figure 1 (a) The powerwall display for VR system (b) The operational area

2.2 System architecture

Firstly, CAD surface geometry data with associated material and texture information are transformed to a 3DXML format and imported into Virtools as tessellated surfaces. Virtools is an authoring tool for creating VR environments where CAD models are arranged in the 3D VR world alongside representations of the surrounding environment, virtual light sources, and virtual cameras. The display output of Virtools is configured to create images on a projection reference that matches the resolution of the VR display screen. Secondly, optical reflection markers are attached to the shutter glasses worn by the operator. The tracked position and orientation of the operator's head are used to control the position and orientation in the 3D VR world of a virtual camera that is used to represent the observer's point of view (POV). Virtools uses the position and orientation of the POV camera, CAD models and projection reference to create a projected image of the CAD model on the display that appears to the observer to be a true perspective of the observed object. The continuous tracking of the observer's head position enables the projected image to be appropriately modified as the observer moves around the active space. Thirdly, Virtools alternatively creates left and right eye images to enable a stereoscopic perception of depth; interpupillar eye distance controls the strength of the depth perception and is pre-defined in the configuration of the display, and can be changed if necessary. Finally, the virtual environment can be controlled by the operator with a wireless joystick controller to move, turn and interact dynamically with the model.

2.3 Software development and calibration

To display a true perspective image, a projection reference is created in the 3D VR environment, which is the same size and position as the display screen in the real world. The POV camera is programmed to face the projection reference at all times and its viewport frustum coincides with the four corners of the projection plane, Figure 2(a). To calibrate the display to a 1:1 scale, five 400mm x 400mm benchmark blocks were created with faces co-planar with the projection reference, Figure 2(b). The display settings were adjusted to ensure that all the blocks were displayed in 1:1 scale on the display screen.

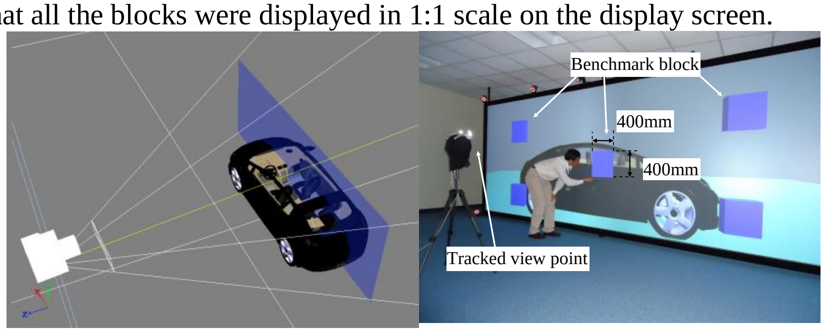


Figure 2 (a) The projection referential plane gives operator a true perspective view. (b) Measurement and adjustment of the display of the benchmark block

In addition, several virtual tools were developed to facilitate the design review process: the virtual hand; a virtual turn table; dynamic interaction; collision detection card; a 3D pointer; and material and texture alternatives. These are illustrated in Figure 3.

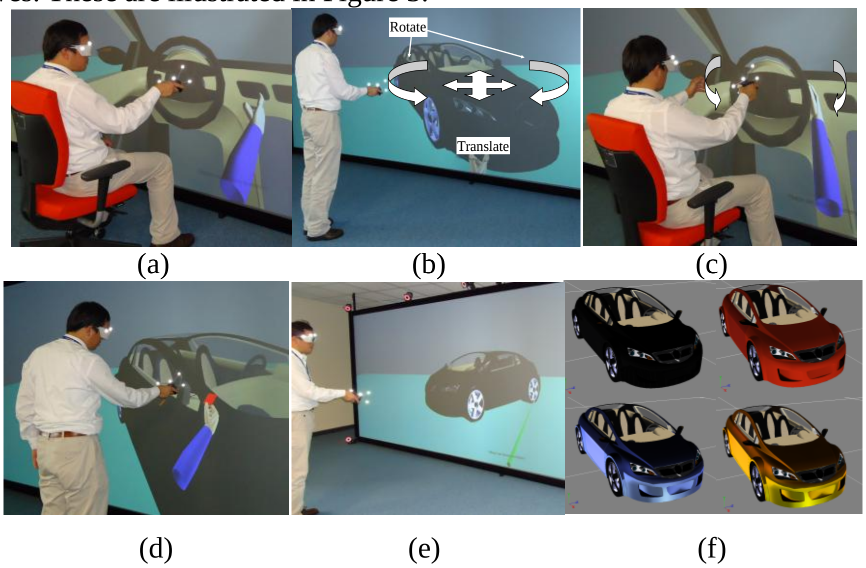


Figure 3 Virtual tools for design review: (a)virtual hand, (b)virtual turn table (c)Dynamic interaction, (d)inspection card, (e)3D pointer, (f)material and texture alternative.

3 PRACTICAL EXPERIENCE

Throughout its development, the VR facility has been evaluated by industrial engineers and designers for design reviews of automotive interiors and exteriors. In all cases the vehicle CAD models were limited to the visible "A-surfaces" with materials and textures applied appropriately. For interior design reviews, the observer needs to be immersed inside the vehicle so the CAD models are placed on the observer's side of the projection reference in the 3D VR world. We found that by sitting approximately 1.5m away from the display screen a fully immersive experience could be achieved with the 110° horizontal FOV and 60° vertical FOV that this position creates. For exterior design reviews, we generally place the CAD model behind the projection reference in the 3D VR world to ensure the whole vehicle was always in view.

For both interior and exterior design reviews, the continuous tracking of the observer's head position and orientation provides an image on the display screen that is a 1:1 true perspective of the vehicle from the observer's POV. The large active space in front of the display screen allows the observer to freely interact with the 3D VR world by "walking around" the virtual vehicle or by merely moving the head to a different POV. The virtual hand is a useful device, which creates a connection between real and virtual worlds that re-enforces the true scale of the virtual vehicle in the mind of the observer. However, the VR system is only able to display images from a single POV, therefore the tracked operator is the only person to see a true perspective image; passive observers cannot see true perspective images of the target object.

The effectiveness of the immersive experience relies heavily upon the fidelity of the vehicle models and the responsiveness of the VR system to the dynamic changes in observer POV. As the vehicle design matures, the number of features detailed in the CAD model increases and the number of surfaces to be rendered rapidly rises; this reduces the refresh rate of the displayed image. If the refresh rate becomes too low, the observer will see a lag between actual head position and the displayed POV image that reduces the quality of the immersive experience; this reduction in performance quality often elicited the most negative reactions from the evaluators. To test the capability of the VR system, the behaviour of several different vehicle models was evaluated in the virtual environment using the Virtools diagnostic tool. The fidelity of models ranged from 90,000 to 25,000,000 surface faces displayed. The refresh rate of the display, i.e. frame rate per second (FPS), was measured for each model and is shown in Figure 4.

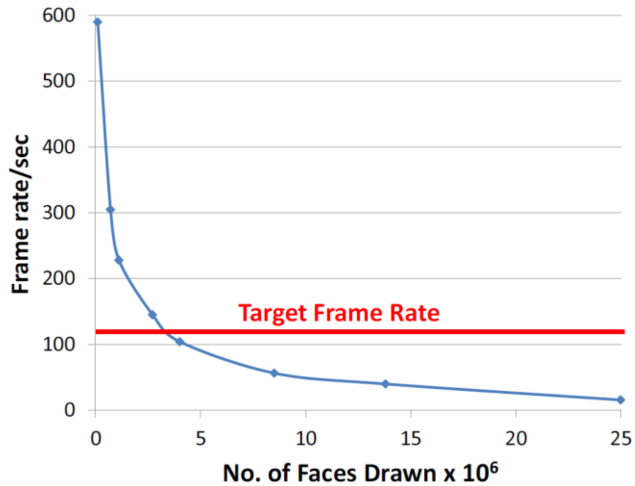


Figure 4 FPS declines as the model size increases

Ideally, the FPS should be greater than 120Hz, i.e. the refresh rate of the projectors, though 60Hz , i.e. 30Hz per eye, is an acceptable minimum (Lien *et al.* 2010). Consequently, from the observations made, the ideal size of CAD model should be no greater than 3 million faces, but models with up to 8 million faces are acceptable. In dynamic tracking mode, the VR system is rendering approximately 500 million faces every second and the time to render is about 98% of the total compute time between frames. Furthermore, managing the tracking system using a separate computer and minimising the number of active objects being tracked helps ensure that the refresh rate on measured observer position and orientation achieves the 120Hz ideal; typically the observed latency of the tracker was between 5-10 milliseconds.

4 DISCUSSION

Creation of a true perspective display has been achieved with the VR system described here. The position and orientation of the operator must be dynamically tracked to ensure that the projected image provides a true perspective with respect to the instantaneous position of the operator. The stereoscopic display creates discrete images for each eye so that the observer can get a good sense of depth in the virtual world being observed. The large size of the stereoscopic display allows for full sized cars to be displayed to a good resolution and calibration ensures a 1:1 scale projection is achieved. To achieve a good display refresh rate, ideally, the vehicle model should be restricted to 3 million surface faces, though models with up to 8 million surface faces are acceptable. By maximising the display performance of the VR system, observers have reported a high degree of satisfaction with the sense of immersion they perceive, which is further augmented by use of the virtual tools, and in particular the virtual hand.

Although this VR system has demonstrated its capability for supporting design reviews in the automotive industry, it still has some limitations. Firstly, true perspective can only be perceived by one operator during the design review; passive observers see a distorted and elongated projection of the car. Secondly, during the review process, the operator must face the display screen at all times; this limits the ability to inspect the vehicle freely, which would be especially useful for interior review.

5 CONCLUSIONS AND FUTURE WORK

In this study, a 1:1 scale and true perspective VR system was developed and calibrated for design review in automotive industry. Several inspection tools were created and capacity of the 3D display was evaluated. Our future work will concentrate upon greater integration between the real and virtual worlds to enhance the confidence levels in the truth of the displayed images, and the use of tracked head mounted displays to provide the 6 degrees of freedom necessary to inspect cars in a completely natural and comprehensive manner.

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