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Future directions for the development of virtual reality within an automotive manufacturer

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ABSTRACT

Virtual Reality (VR) can reduce time and costs, and lead to increases in quality, in the development of a product. Given the pressure on car companies to reduce time-to-market and to continually improve quality, the automotive industry has championed the use of VR across a number of applications, including design, manufacturing, and training. This paper describes interviews with 11 engineers and employees of allied disciplines from an automotive manufacturer about their current physical and virtual properties and processes. The results guided a review of research findings and scientific advances from the academic literature, which formed the basis of recommendations for future developments of VR technologies and applications. These include: develop a greater range of virtual contexts; use multi-sensory simulation; address perceived differences between virtual and real cars; improve motion capture capabilities; implement networked 3D technology; and use VR for market research.

1. Introduction

In the automotive industry the development and application of new technologies is a key factor for success in an increasingly competitive market that requires faster time-to-market and ever higher quality of products (Choi and Cheung, 2008; Lawson, Salanitri and Waterfield, 2015). Virtual Reality (VR) has been seen as one of the technologies that can help achieve these aims (Mujber et al., 2004). VR is a system which permits users to interact, move, look at, and be immersed in a 3D environment (Rheingold, 1991). In the automotive domain, VR has resulted in benefits in several applications. These are described in the following paragraphs.

- *Design*. Car design is a process requiring continuous modification and reviews, with the necessity to revert to previous decisions several times before the car finally reaches production (Fiorentino et al., 2002). This characteristic has been seen as one of the most expensive and time consuming aspects of the process. Indeed, as Gomes de Sá and Zachmann (1999) stated, the early design phases can impact on up to 70% of the total cost of a product. In this scenario, VR can reduce cost and time by replacing physical mock-ups with virtual ones (Shao et al., 2012). This can support simplification of the review process by avoiding the rebuild of physical mock-ups in case of design errors or changes (Kim et al., 2011). Moreover, VR can be used for design and evaluation during an early stage of the development process, before expensive and time-consuming physical mock-ups are produced (Lawson and Burnett, 2015; Lawson et al., 2015). Another utility of VR in design is the possibility of having multidisciplinary teams and teams spread across the world, to work together on the same prototype at the same time (Mujber et al., 2004). Regarding this, Lehner and De Fanti (1997) tested distributed VR for large vehicle (i.e. loader) development, demonstrating a cost-time reduction and quality increase.
- *Virtual Prototyping (VP)*. As a sub-section of *Design*, Virtual Prototypes are in some instances used to replace physical mock-ups. With recent progress in the capabilities and development of software and hardware, VR can replicate physical models allowing for a drastic cost and time reduction derived from the avoidance of building physical mock-ups (Kulkarni et al., 2011). Moreover, in the decision making process, VP can simply procedures and avoid the so called "bottleneck effect" (Fiorentino et al., 2002) which manifests from errors in the early stages of a component's development and constant reviews, leading to the necessity of rebuilding physical mock-ups. With VR this effect could be avoided with the possibility to modify a VP in real time.
- *Manufacturing*. The application of VR to manufacturing is called Virtual Manufacturing (VM). VM has been defined as the use of VR or computers for the development of a product (Shukla et al., 1996). The advantages of VM range from the improvement of the decision making process to cost reduction (Mujber et al.,

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2004), to the enhancement of risk measures and control of manufacturing processes (Lee et al., 2001).

- *Virtual Assembly (VA)*. Related to VM, VA permits the assembly and disassembly of virtual objects (Qiu et al., 2013). VA allows the evaluation of worker's well-being and health and safety measures due to the possibility of creating virtual representations of workplaces. Jayaram et al. (1997) observed that VA gives an enormous advantage in the process of design and new tool implementations in improving product quality and reducing time-to-market.
- *Training*. Borsci et al. (2015) demonstrated that mixed reality training of automotive service operations is preferred by trainees over traditional observation-based approaches. Moreover, studies have shown that with simulated training, task completion is improved over training on real equipment from the 50th percentile to the 66th (Stone, 2001). Furthermore, as Borsci et al. (*under review*) demonstrated for assembly and disassembly tasks, the retention of information after two and four weeks is higher for participants trained with VR than with other systems.

Given these benefits of VR to the automotive industry, several automotive OEMs are currently investing in the development and implementation of VR products. One example of this is Jaguar Land Rover (JLR), whose design and engineering headquarters in Warwickshire, UK hosts the Virtual Innovation Centre (VIC), a world-leading centre for VR technologies for automotive applications. Examples of some of the VR technologies already implemented at JLR are: A Cave Automatic Virtual Environment (CAVE) with high performance hardware and photorealistic software, a Powerwall, and a marker-based body motion tracking suit for ergonomics investigations. However, due to a continuous increase in the quality of VR systems, and the progression of knowledge around the human factors of their use, a review was conducted to identify new opportunities in the field of VR for automotive applications. The review, reported in this paper, encompasses interviews with JLR employees to identify issues with existing properties and processes, an analysis of the issues and new opportunities for the firm, a literature review on the human factors of VR in automotive and relevant related applications, and finally the creation of a set of recommendations for developing existing systems at JLR and implementing new technologies. A summary of early results was published in Lawson, Salanitri and Waterfield (2015); this paper reports on the full review upon completion of the work.

Thus, the review was constructed of the following three phases which form the structure of this paper:

1. Interview with company staff
2. Analysis of issues and opportunities
3. Literature review on relevant studies in VR applications

Thereafter a set of strategic recommendations are made for developing VR technologies for automotive applications. While this review was commissioned by JLR, the recommendations are likely to be applicable across other automotive companies. The findings are also likely to be applicable to other industries (e.g. defence, aerospace, rail) in which ergonomics assessments are conducted as part of an engineering development process, with pressure to minimise the costs and time associated with physical prototype evaluations or the late identification of issues.

2. Interviews with company staff

2.1. Participants

A total of 11 JLR employees were recruited for the interviews. The participants were recruited from a variety of engineering functions and allied disciplines with an average of 6.8 years in their current role (SD = 6.6) and of 16.1 years at JLR (SD = 13.7). All participants were approached by the researcher based on recommendations from the VIC of people who are currently using VR or who have expressed interest in using VR as part of their processes.

2.2. Materials

A questionnaire was developed to understand interviewees' current usage of vehicle properties (both physical and virtual) within JLR. To research this topic, questions were included regarding current use of properties, users of the properties, the number of users at any time, and when the properties are used within the vehicle development processes. Participants were also asked which aspects of human interaction with the vehicle are necessary for their design and engineering activities. The questionnaire was refined with input from a representative of the JLR Virtual Innovation Centre, and from colleagues from the Human Factors Research Group at The University of Nottingham. The scope was limited to VR and physical properties and processes with a high degree of human involvement and interactivity; simulation processes such as Computational Fluid Dynamics (CFD), which do not concern direct human interaction with vehicle, were excluded. The final questionnaire was divided into 12 topics gathered in 2 categories (Table 1).

2.3. Procedure

Participants were invited to a private meeting room. They were asked to read a participant information sheet and sign a consent form. The researcher explained the purpose of the study before asking questions about VR use in a semi-structured format. The study received approval from The University of Nottingham Faculty of

Table 1
Division of topics and categories derived from the questionnaire.

	Categories	
Topics	Physical Properties	Virtual Properties
	Current use of physical properties Including which properties are currently used, their purpose (e.g. design, evaluation, communication), and use within the vehicle development process.	Currently used virtual processes/properties (examples as for *Physical Properties*).
	Important attributes to be demonstrated on physical properties, e.g. appearance of the vehicle, exterior road scene, noise, reach/clearance, movement, vibration, touch or other.	Important attributes for virtual properties (examples as for *Physical Properties*)
	Limitations of physical properties/processes	Limitations of virtual properties/processes
	Users of physical properties (e.g. external customers, internal customers, seniors), from what perceptive are they used (e.g. assembly operator, customer, engineer) and how many users are typically involved in any activity.	Users of virtual properties (examples as for *Physical Properties*)
	Whether comparisons of alternative design proposals are an important part of existing processes and if so, what properties are used for these?	
	Whether reviews of competitor cars are part of the development process, and if so, when and how does this take place?	