Design metaphors and cognitive ergonomics in immersive virtual reality: an engineering case study.

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ABSTRACT

This paper is concerned with the application of immersive virtual reality (VR) in the product engineering environment. VR has the potential to revolutionise product engineering by enabling access to tools, visualisation and visual and tactile-based interface technologies which will greatly enhance the creative, conceptual and perceptual capabilities of designers and manufacturing experts. Utilising the domain of cable harness design, this industry-based work demonstrates that – through well designed cognitive and human factors system design, analysis and experimentation – immersive VR can be used as an effective tool for the generation of design and manufacturing information. However, considerably more work is required in to determine what form these system interfaces should take and how they can be made to impact on creative engineering tasks.

1 INTRODUCTION

This paper discusses the application of immersive virtual reality (VR) in the product engineering environment. In such systems, the user is surrounded by a virtual world generated by computer graphics and, using various types of peripheral input and tracking devices, they can interact with these data in real time and move around, modify and create data as required.

VR technology in all of its forms could revolutionise the engineering environment of the future [1] and will greatly enhance the creative, conceptual and perceptual capabilities of designers and manufacturing experts. New ways of interacting and presenting data to the engineer will lead to a greater emphasis on virtual prototyping thus enabling a more detailed study of the design, functional, aesthetic, ergonomic and manufacturing issues associated with products and processes along with their associated lead times and costs. Recent studies have demonstrated how immersive VR in particular can provide functional benefits to engineering processes in diverse areas such as assembly and machining [2, 3, 4] and design [5, 6, 7].

However, this type of environment contradicts the 'traditional' approach to developing knowledge-based engineering solutions (for example, expert systems) that assume human knowledge and expertise can be represented in software, thus removing the human from the process. However, particularly in the domain of design and manufacture, this has been found to be notoriously difficult. An alternative approach is proposed which acknowledges that the involvement of the human expert is inevitable in the foreseeable future and that environments can be provided such that explicit and implicit human expertise can be applied effectively in the engineering design cycle. The human expert becomes part of the design "system" which supports their expertise through the effective application of modern computer hardware and software, in particular, by means of carefully designed, highly useable interfaces that have been formally evaluated [8]. The context of this work is the costly task of designing and planning of cable harnesses, which are often so complex that their design tends to be carried out as a tail-end activity in the product development process.

1.1 Research context

Early cable harness design work was carried out in the USA in the 1990s in an attempt to automate the choice of a cable harness route [9]. Subsequent work used genetic algorithms to tackle the same problem [10]. Wolter and Krol routed 'strings' around 'solid' parts [11] and in some projects robot path planning has been used and applied to piping systems as a routing solution [12]. Early work at Heriot-Watt University [7] showed that immersive VR has a role to play in this design process. Recent work at Iowa State University [13] uses a VR system for routing flexible hoses which validated VR as a practical tool but did not analyse it's effectiveness as an interactive design tool. However, there is no evidence that any of this research has been used in an industrial environment.

A common theme running through this research is the attempt to automate the generation of routings and a realisation of its difficulty. There is some agreement that there is and still will be a need for human expert intervention to make fine adjustments and verify solutions; therefore it is timely to investigate the nature of new human-based tools to support the interacting of data within this domain.

2 CURRENT RESEARCH

The virtual reality metaphor described builds on prior research which explored the automatic generation of assembly plans [3], where VR was used as a tool to observe and log assembly planners assembling digital models. This showed that immersive VR could be both a manufacturing tool and a design/knowledge elicitation tool. Feasibility work later demonstrated that VR also could play a valuable role in speeding up design tasks [7]. This led to the hypothesis that further identifiable metaphors were possible, and necessary, to support the engineer generating design solutions with the use of VR.

In this research a visual metaphor is used, termed a "Designer's Workbench", which is abstracted from "natural" work practices normally used by engineers (Figure 1). Cognitive engineering technology and methods enable the designer to visualise, design and develop the final product from a 2D schematic on a virtual tabletop to the 3D cable harness distribution.

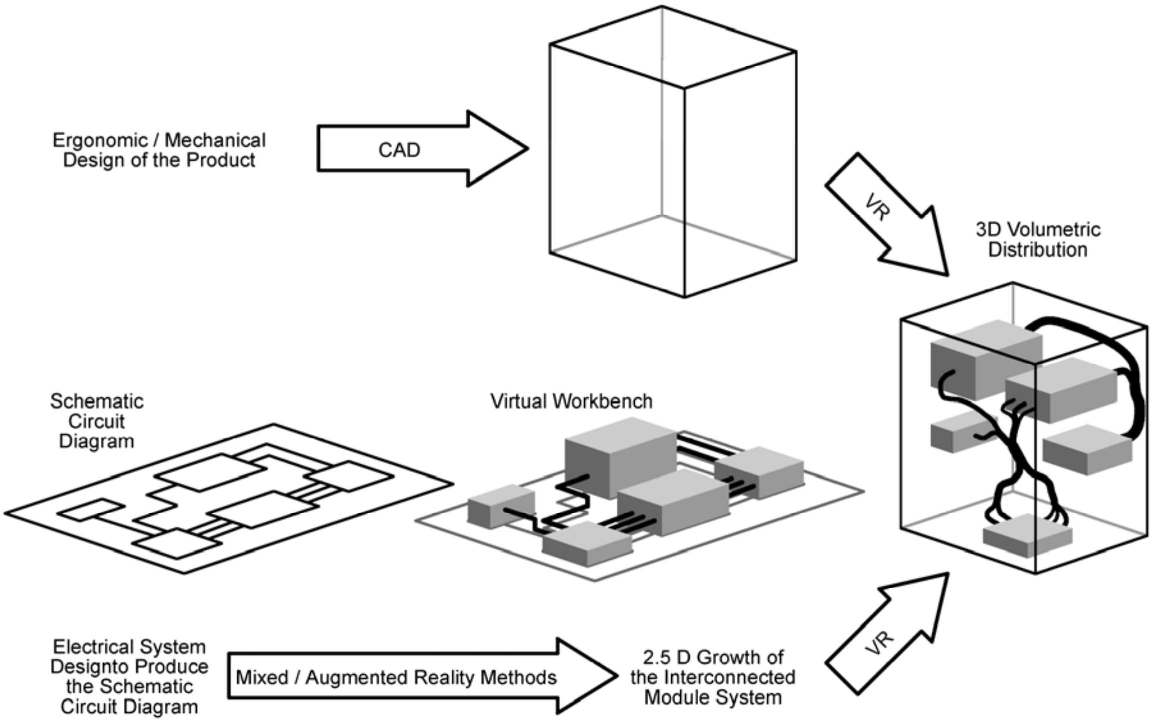

Figure 1. The 'Designer's Workbench' metaphor

2.1 Phase 1 Research – Immersive VR Cable Routing

In phase 1, a VR-based toolset was produced for routing cables through a generic assembly (Figure 2 and Figure 3). In designing this, the aim was to provide engineers with a software environment that represented actual design tasks in a virtual world. Called CHIVE, or "Cable Harnessing In Virtual Environments", it was implemented on an HP725/75 workstation using DVISE software with CAD imported models. User interaction took place via a head mounted display (HMD), 3D mouse and pop-up menus.

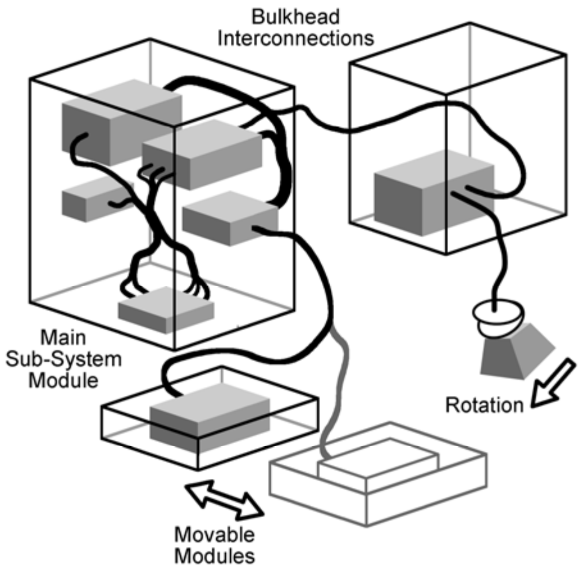

Figure 2. Schematic Representation of an Exemplar Generic System

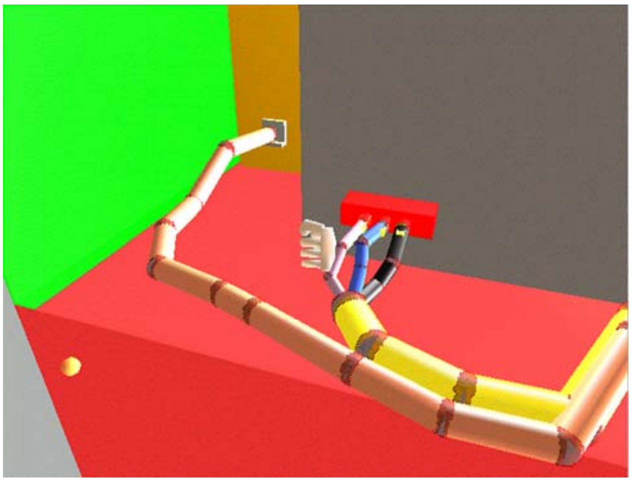

Figure 3. A user utilising CHIVE for routing a cable harness in the generic assembly

To evaluate CHIVE against CAD tools, five cable harness designers from four companies routed cables in VR and one of ProENGINEER™, SolidDesigner™ and CATIA™. By comparing Task Completion Times (TCTs) it was found, for a simple single-level layout, that the participants took between two and four times longer using CAD. Direct observations and video analysis showed that only half of the participants made errors in VR compared to CAD. In multilevel assembly routing VR gave productivity gains of between 3:1 and 5:1.

The number of mouse clicks, the number of mouse clicks per minute and keyboard entries were also measured for both VR and CAD single-level and multilevel tasks. From these it was found that that the VR system required significantly fewer mouse clicks than the CAD systems.

A questionnaire was also completed and was used to compare the ease of use of VR with CAD as well as their suitability for carrying out harness design. These results indicated that the VR system is comparable to CAD systems in this domain and could potentially be a more effective tool for spatial tasks such as routing cable harness assemblies.

2.2 Phase 2 Research - Development of the Designer's Workbench Metaphor

However, in this early work it was difficult to separate the influence of the graphical user interface of the VR system from the influence of the cable harness toolset. What aspects of the system give the improved performance? In addition, further investigations under controlled laboratory conditions are required to ascertain the exact nature and magnitude of these performance benefits. This has led to evolving the 'Designer's Workbench' metaphor as a vehicle to study this process in more detail. VR is used as a powerful tool for collecting data that should also facilitate more effective human-computer interaction and allow analysis of the causes of the VR system productivity gains in more depth. To do this, a better understanding of the design process and underlying cognitive processes is required by involving the observation of designers at work, using verbal protocols and extracting data from designs and design documents. In addition to these formative methods, tightly focused experiments are used to evaluate the usability of portions of the interface, with alternative interface ideas being evaluated. The aim is to produce a "natural" environment and an ability to easily modify digital product models that reflects the way engineers make changes to prototypes. The new system is implemented on an SGI® Octane2™ with a stereo HMD and Pinch® Gloves using WorldToolKit (WTK); the design environment and equipment are shown in Figure 4.

Figure 4. Cable creation and editing

The initial results and feedback from the industrial users are encouraging and support the theme of the current research paradigm; namely that of involving the human in the design loop.

3. DISCUSSION OF RESULTS

This research has begun to show that, when compared with conventional experimental work, experimental controls and procedures are greatly enhanced by the effective use of immersive virtual reality. VR data is less prone to errors of measurement and the technology is a flexible tool for altering experimental conditions in a controlled manner. This allows variants of experiments to be produced enabling replication of results. Experiments can be quickly extended and data capture automated yielding data with low errors of measurement thus enabling better identification and control of experimental variables [16].

The close collaboration with industry in this research characterises the research team's user centred approach and the results demonstrated the potential advantages of VR. This shows that the application of VR need not be a deskilling process. On the contrary, it can be supportive and can serve as a useful tool to enhance design knowledge thus reducing design errors, lead times and the need for physical prototypes. The evolution of the concurrent product engineering environment of the future will require a much deeper understanding of the human factors issues to enable the effective creation of user-friendly, intuitive tools for the engineer of the future [1].

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