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IMMERSIVE VIRTUAL REALITY AS AN INTERACTIVE TOOL FOR CABLE HARNESSES DESIGN

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Abstract: *This paper describes on-going research in the novel use of immersive virtual reality (VR) for the design of cable harnesses, which are used extensively in all kinds of electro-mechanical equipment. By immersing the designer in the process loop using technology of this kind, the initial research has shown that considerable productivity gains can be made over carrying out similar tasks using conventional desktop CAD systems. This work raises other issues associated with VR which now must be addressed so that its impact on product design lead times can be optimised to the full*

Key Words: *Product Design, Virtual Reality, CAD, Cable Harnesses, Design,Assembly Planning.*

1. Introduction

The trend for both design and manufacturing engineering in the past century has been to replace the human being in the information preparation and process loops by deconstruction and replacement of their tasks through some form of automation. "Intelligent" methods have been seen as ideal or desirable solutions to the 'problem' of having people directly involved in the process through using methods such a expert systems or genetic algorithms to name but two. Even with considerable research emphasis over the last 25 years in these areas the replacement of the human expert in the loop has still become well nigh impossible with a need to have them involved in all aspects of the product development process, unless considerable product standardisation has already taken place. However, as soon as variants are required then humans must once again become involved.

The work described in this paper draws on recently completed and planned research to highliught the fact that, using modern VR technology, instead of replacing the expert their skills and capabilities can be greatly enhanced by keeping them in the process 'loop' and allowing them to use their creative abilities more effectively to produce workable deign solutions. Rather than seeking to eliminate or reduce the role of the 'expert' by formalising (in some way) their tacit knowledge their task can be enhanced so that maximum benefit can be obtained from the use of their implicit, human expertise throughout the product design cycle.

This research has been carried out within the domain of cable harness design which is inherently a difficult and costly task. The wideranging requirements for this type of product in, say, the avionic, automotive and IT sectors provide diverse challenges for harness designers, manufacturers and installers alike. These end up being so complex and are usually designed at the tail-end of the mechanical design process such that errors in their specification and development may lead to the need for expensive redesign and unnecessarily higher costs. Other costs associated with this process include the physical manufacture of expensive prototypes to aid the laying out of harness assemblies in a 3D environment; even if 3D CAD systems are used to develop solutions. Problems encountered at this late stage in the product design cycle can lead to delays on the time required for new product introduction to the marketplace.

2. Prior Work

Previous work carried out at Heriot-Watt University has focused on the 'human in the loop-metaphor' due to the fact that it was recognised that there will probably always be a need to enhance rather than replace human input to design and manufacturing tasks (1). Initial novel immersive VR work proved that this technology could be used to successfully generate feasible assembly plans by logging an operator's actions in building a virtual assembly and post processing the appropriate assembly plans (2). This data source was also used to elicit simple knowledge rules from the tasks carried out during the assembly process.(3)

Later, feasibility work investigated another part of the product development cycle, that of engineering design. Supported by industry, this project successfully demonstrated that VR technology has the potential to play a valuable role in speeding up the design and planning of cable harness routes (4,5). This was the first published example of immersive VR being used as part of an interactive, engineering data generation task and which compared this technology to conventional CAD systems as a design tool.

Working in the early 1990s, investigators in the United States attempted to automate the choice of cable harness route (6) in a system used only as a post-design review tool with no interactability. Subsequent work used genetic algorithms for the automatic determination of cable routes (7). Another approach (8) involved techniques for routing 'strings' around 'solid' parts. Some routing work has also been carried out based on robot path planning applied to piping systems (9). A group at MIT, carrying out applications work on behalf of the US Navy, did look at applications relating to Human Factors issues and the use of VR for training. There is no evidence that any of this research has been applied industrially. It has been suggested that augmented reality could be used to allow operators to produce cable harnesses more efficiently (10). This idea has only been investigated by Krumenaker (11) who gives a review of similar augmented industrial systems but concludes that all are at a very early stage.

A common theme running through all previous research in cabling system design is a desire to find ways to automate the generation of routings using computer based techniques. All recognise, however, how difficult this is due to the open-ended nature of the problem. There is almost total agreement that there will still be a need for human expert intervention to make fine adjustments and verify solutions.

3. The Design Metaphor

The research addressed in this paper focuses on the specific task of cable harness design. This approach is based on an 'Electrical System Diagram to 3D Volumetric Distribution' metaphor as illustrated in Fig. 1. The cable harness is considered as an integral and important component of the final product at the earliest stages of the design process. It is assumed that the conceptual ergonomic and mechanical design of the product proceeds in parallel with the electrical system design. The need to have an effective cable harness design is, however, recognised as an essential component of the final product. Cognitive engineering technology and methods are proposed to enable the designer to visualise, design and develop the final product in the following manner.

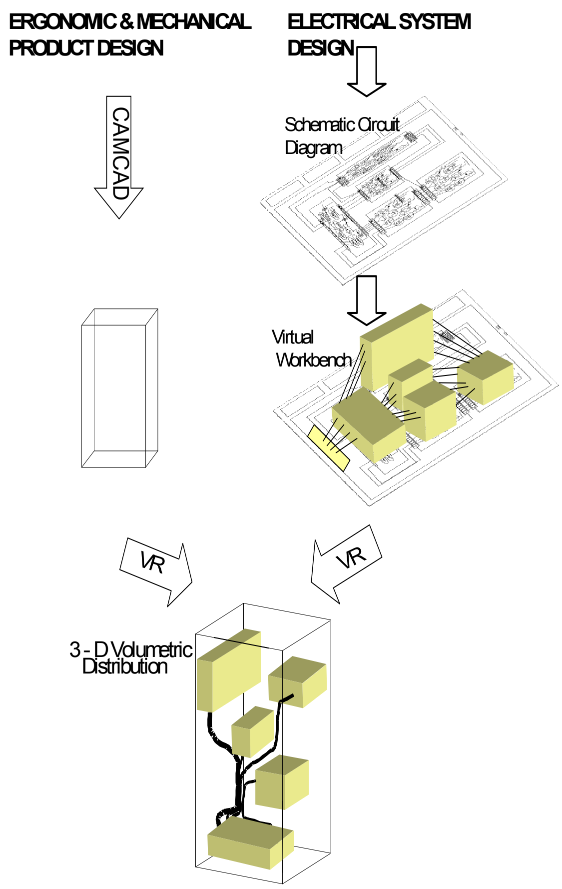

Fig. 1: The Design Metaphor

At the stage when the system design is approaching completion, both mixed and augmented VR will used to 'grow' and connect the volumetric representation of the electrical modules with their interconnecting cables as a solid model within a virtual '2D' workbench. When the workbench model is complete, the designer positions the modules, assuming 'elastic' cables, within the prototype mechanical structure. When the 3-D volumetric distribution of the modules is complete, the immersed designer can then 'grab and smooth' the cables into appropriate groups and channels to form cable harnesses. The cables will now fixed in space to define the geometrical structure within the volumetric distribution of the modules. From this data, downstream information can then be generated, such a bill-of-materials, cable manufacturing layouts, assembly instructions, maintenance checking etc.

4. Relevance to Industrial Design and Manufacturing

Ongoing research in this area at Heriot-Watt University has involved the close participation of a number of industrial partner OEMs who have a vested interest in improving the cabling aspects of their design-to-manufacture process. Analysis of the wide range of products and different cultures in these industrial sectors has highlighted important common areas of concern in cable harness manufacture. In addition, a typical generic structure to represent the design-to-manufacture process has evolved as illustrated in Fig. 2.

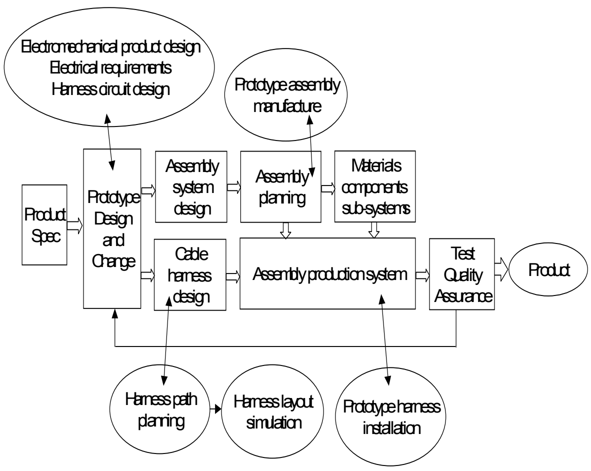

Fig 2: The Design-to-Manufacture process.

The typical design process follows the sequential steps of initially designing the harness and its assembly system. Very often a physical prototype harness is assembled within the structure of the product to form the basis for the final design, assembly planning and harness production. This is tested to verify the production methods used. It has been demonstrated that the introduction of harness design within a VR environment can give several benefits. When the geometric layout of the product is defined in a virtual space, the cables can be routed by the designer walking through that space. The prototype harness can be simulated and manufacturing details extracted from the simulation without relying on the physical manufacture of the prototype harness.

5. Contrasting Approaches to Cable Harness Design

The typical CAD system approach to produce design and manufacturing information for a harness is to interact with the CAD 3D visualisation to produce the basic cable layout and associated routes and then produce a physical layout of the prototype in cable form. Design evolution creates the design model that interacts with the prototype design and change section of the process system as shown in Fig. 3.

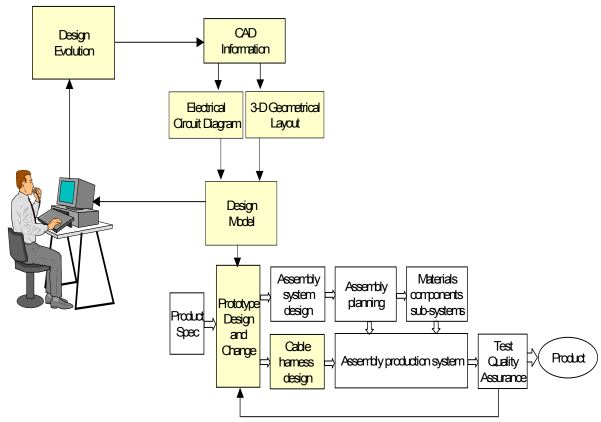

Fig. 3: Traditional CAD interaction within the Design-to-Manufacture Process.

The current research phase is directed toward interacting with the design process as shown in Fig. 4. Here, the designer is immersed in the virtual environment with the capability of arranging the sub-systems under design and development. The cable harness is formed by moving the sub-system modules into place, with the "elastic" cables taking a route defined by the designer. The VR system not only produces manufacturing information but also gives further detail of the assembly method, planning and production system.

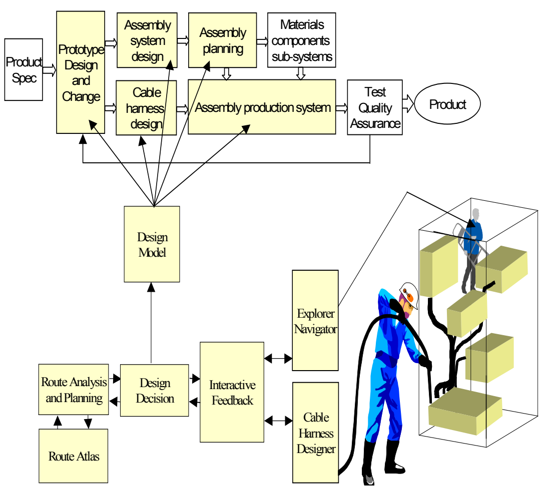

Fig. 4: Immersive Virtual Reality interaction with the Design-to-Manufacture Process.

6. An Exemplar Generic Cable Design Task and Preliminary Results

Three constituent groups are identified in defining an exemplar generic task. These are the CABLE technologies, the GEOMETRY of the product and the production PROCESS. The detailed elements of the groups are currently beyond the scope of this paper but will be addressed in later publications.

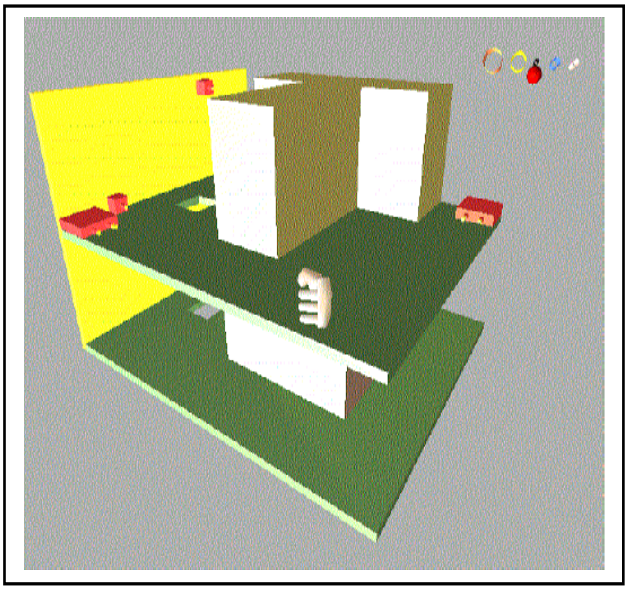

Fig 5 : The CHIVE virtual environment representation of the main sub-system generic assembly module.

The initial phase of this research programme produced a system called CHIVE (CHIVE (**C**able **H**arnessing **I**n **V**irtual **E**nvironments) (12) which focused on routing cables through a generic assembly representing the main sub-system of a product as shown in Fig. 5. This assembly contained features from all of the industrial partners' products and addressed routing through confined spaces and bulkhead holes into multiple level compartments. It then compared how this system performed in relation to a number of conventional CAD packages. The follow-up research phase is focussing on flexible harnesses with fixed point fastening and connectors within the new design modelling metaphor throughout the whole cable design process.

The initial phase of this research programme demonstrated that immersive VR does have an important role to play in the generation of cable harness designs (12). Considering only the routing of harnesses within electro-mechanical equipment, a set of immersive VR cabling tools were developed for creating cable harness layouts as illustrated in Fig. 6. The user interacted with the data by means of a head mounted display (HMD), a 3D mouse and pop-up menus.

Using a number of tools on the pop-up menus (4), the most appropriate routing strategies and harness configurations could be identified to determine cable routes through the product and then select the relevant cable types. The operator used the interactive routing tools to produce different types of wire harness such as single wire layouts, branched multiple wire layouts to bundle wires layouts. Once the harness layout was completed a wiring list was generated.

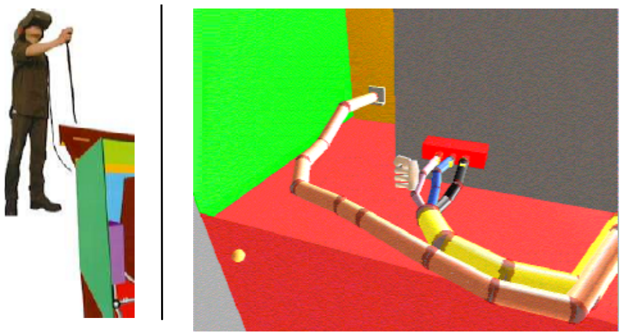

Fig. 6: A user utilising CHIVE for routing a cable harness in the virtual world.

Industrial trials compared the cable routing capabilities of CHIVE with established commercial CAD cabling systems.

Six experienced expert cable harness designers from four industrial collaborators participated. Their CAD experience ranged from three to fifteen years and none of them had used an immersive VR system before. The CHIVE expert involved in the study was a researcher with three years experience in using and developing the system. The cable routing modules used by the partners and compared with CHIVE in the trials were from the following packages:

Pro/ENGINEER™, SolidDesigner™ and CATIA™ (the piping module). The generic assembly used during these tests is shown in Fig. 5 with examples of routing at various stages of the process given in Fig. 7.

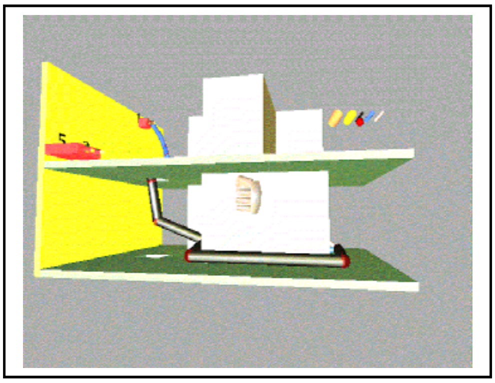

Fig. 7: Examples of virtual cable routing in CHIVE; an overall view of wire bundle through a bulkhead.

By comparing the Task Completion Times (TCTs) it was found, for a simple single-level layout, that that the participants took between two and four times longer to complete the routing task using the proprietary CAD systems. On average the experts took 6.2 minutes using CHIVE and 15.2 minutes using conventional CAD for a single-level assembly. Direct observations and video analysis showed that only half of the participants made errors in CHIVE compared to using CAD.

For multilevel assembly routing CHIVE gave productivity gains of 3:1 to 5:1. Other measures used were the numbers of mouse clicks, the number of mouse clicks per minute and keyboard entries. With the single-level assembly the experts made on average 309 mouse clicks using CAD as compared to 30 clicks by an expert using VR. With the multi-level assembly the experts using CAD took on average 16 minutes as compared to an average of 4 minutes using VR. The average number of mouse clicks using CAD was 369 as compared to 89 using VR. The average number of clicks per minute using CAD was 24 as compared to 20 clicks per minute using VR. A questionnaire was also given to participants after every VR and CAD trial, which was used to compare the ease of using CHIVE with the established CAD cabling tools as well as its suitability for carrying out harness design in the immersive VR system. Feedback from this showed that the CHIVE system is comparable to conventional CAD systems in the domain of harnessing and that immersive VR can be used as a more effective tool for routing cable harness assemblies.

8. Discussion and Conclusions

This preliminary work - the first published example of a 'ring-fenced' design task using immersive VR - has shown that the TCTs were between two and five times faster using VR; even though the experiments were heavily biased towards CAD. The VR interface appears to have a significant impact on TCTs and the results from the questionnaire indicate that participants found the CHIVE system comparable to current commercial CAD systems for the routing of cable harness assemblies.

Park (13) stated that harness design requires an in-depth three-dimensional spatial reasoning, which, as stated by Kloske (14), CAD systems tend to lack due to their conventional flat screen display. These results present evidence that the two or three degrees of freedom of movement on a flat screen provided by current CAD cable harness routing systems inhibits the user’s ability to route cable layouts especially in complex 3D assemblies. Immersive VR, on the other hand gives users the ability to change their viewpoint quickly and provides six degrees of freedom of movement thus showing great promise as a suitable environment for routing cable harness assemblies.

It is also shown that, in general, immersive VR can be used as an interactive design tool as well as being useful in the actual routing of cable harnesses. It must be noted that the industrial trials only compare CAD systems with the overall CHIVE environment. They did not analyse which elements within CHIVE actually contribute to the improved performance, such as the sense of presence, effect of immersion, the user-interface, etc. This will be a crucial aspect of virtual and other computer aided engineering technologies used for product engineering in the future. Which technologies are best suited for a task? What makes them so? And why? This is what the follow-on research will be attempting to tackle.

The preliminary evidence, from the Heriot-Watt research, indicates that, rather than seeking to reduce or even eliminate them, experts provided with interactive tools such as those described can use their implicit, human expertise in the design process more effectively.

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