VIRTUAL REALITY AND RAPID PROTOTYPING: CONFLICTING OR COMPLIMENTARY?

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Abstract

It is likely that the uses for virtual reality (VR) will coincide with applications that rapid prototyping systems have already been used for. VR, with the ability to model real life environments, presents an ideal base for the design and development of new manufactured products. As a method of producing physical models directly from 3D CAD systems, rapid prototyping technology has also been used to visualise new product designs. This paper attempts to determine whether the two technologies are a means to the same end or whether they combine to form a more efficient route to product development.

Virtual Reality Systems

A virtual reality system provides a platform for computer generated images to interact with the user. As the user reacts to these images, requiring to change the scene in some way, so the computer complies. The images, along with other possible external stimuli show objects that combine together to form virtual worlds. Perhaps the best definition offered yet on the exact nature of VR comes from Zelter [1]. A virtual reality interface system must offer a degree of 3 key components:-

- **Autonomy:** objects must react to external stimuli, have collision boundaries and exhibit real world effects (e.g., coefficients of restitution, gravity, and friction).
- **Interaction:** one must be able to manipulate the parameters of each object in real time.
- **Presence:** a crude measure of the fidelity of the viewing system.

Whether the system used is desk top or immersive, VR is computer modelling of real life as experienced through sight, sound, and touch.

The above suggests that designers and engineers who wish to address the problem of development and improvement of interactive design tools should consider what benefits VR might offer. The Nottingham University VIrtual Reality Applications Research Team, VIRART, was formed specifically to investigate problems of this nature. By building up an expertise in VR systems, VIRART aim to liaise with industry and identify where VR can be used. Current systems are not as easy to use as they should be, and VIRART also set out to influence the development of the technology. With respect to industrial applications, VR appears to be useful in several areas:-

- Where the real world is too inaccessible, dangerous, or expensive to model in real life (e.g., nuclear installations).

- Where the worlds to be modelled are incomplete and require an iterative approach to determine their construction (e.g., control panel design).
- Where the ability to reorder the world requires the manipulation of parts in an unnatural manner (e.g., modelling large, heavy objects to be moved by hand).
- Where some of the required attributes within the world are unreal (e.g., abstract modelling of management systems).

It is considered that when referring to product design in general, the use of VR relates mainly to the 2nd and 3rd of these points.

Rapid Prototyping

Rapid prototyping technology focuses on reducing the lead times and costs associated with new product development [2]. As a new product is introduced, or as products are updated, various aesthetic and functional designs and tests take place. Somewhere during this process, a physical model is evaluated. Using conventional processes and highly skilled artisans, the construction of this single model can take many days.

Rapid prototyping systems are capable of making highly accurate models, or prototypes, in a very short time. The starting point for such systems is a good quality 3D CAD system. Solid models are constructed using the CAD system and then post-processed in a layer format to make them suitable for the prototyping machines. Models made in this way are therefore limited only by the scope of the CAD system and the resolution and dimensions of the prototyping system. Models can therefore exhibit very complex geometries indeed.

At Nottingham, extensive research is being carried out on various aspects of rapid prototyping. The Rapid Prototyping Research Group has had the opportunity to see the development of this emerging technology as it has made its way across the Atlantic to the UK. The group has been able to log the development from only a few machines in 1990 through to the varied and dynamic industrial and research usage of today.

Since Nottingham University has research groups working on both VR and Rapid Prototyping, it was considered appropriate to investigate where a combination of these technologies might lead. An experiment was devised to discover whether one technology falls within the sphere of the other. In this case, it was considered that VR may only provide the same facility that a rapid prototyping system gives when used with an appropriate CAD system. This would then make VR redundant for product development. The emphasis of the experiment therefore changes slightly to a study of whether VR can provide more than CAD, thus relieving the comparatively expensive rapid prototyping systems of some of the product development burden.

Product Development

Some products are purely functional, whilst others require consideration of aesthetic features to achieve an acceptable design. Designers may possess many technical skills, but they may not appreciate, and be conversant, with computer systems. Even if they can use CAD tools, the technical elements related to what is ostensibly an engineering environment may compromise their artistic ability. Similarly, functional products (e.g., engine components) may require other aspects of design to be considered. These may not relate to the primary function of the product and the designer may therefore be unaware of their effect. For instance, the product may perform perfectly, but is it accessible to easy assembly and maintenance? Only when a part is put in context can it be seen whether it qualifies on all points. To this end, many products go through a physical modelling phase to prove the design fully.

To overcome the above points of conflict between flexibility in design against functionality in the most efficient manner, several solutions can be put forward:-

- **Use conventional modelling techniques (such as clay and card constructions), then digitise them into a CAD system.** This is a compromise between free design and engineering design but it is expensive and may not be time efficient.
- **Train aesthetic designers in CAD.** Some designers are very proficient in the use of CAD software. Many consider that such systems restrict their ability to freely design products. Products with aesthetic properties (e.g., virtually <u>all</u> consumer products) require much consideration to the design media used.
- **Form teams with both aesthetic and engineering designers in close consultation.** This is perhaps the easiest and most common solution. However, inability to communicate between group members is also common, making this a potentially unstable situation subject to the characteristics of individuals.
- **Improve CAD systems to reduce the skill requirement to operate them.** This is the approach adopted by CAD companies. The solution in part is by providing software tools to perform the same function several ways. However, the CAD environment is always likely to exhibit an engineering bias even if VR based devices are used for the interface.
- **Produce a form of 'digital clay' to allow modelling within a computer based system.** This is the VR company approach. The interactive environment and tools for manipulation are there already. What is lacking is the ability to dimension the product effectively to allow for functional design.

It is obvious that the last two points are linked. CAD systems are being developed with VR based interaction. They are however significantly different from existing VR systems (the compromise being generally attributed to the perennial 'lack of processing power' problem). The panacea would be if VR systems could retain their excellent autonomotive and interactive properties, whilst adding advanced graphic definition and sculpture tools. The question therefore evolves into one of whether VR systems should be developed to look more like CAD systems? If they should then careful consideration must be given; not to what tools should be provided, but what features of CAD should be left out to allow free expression in design. Since much is already known about CAD tools this experiment concentrated on whether it was possible to create a 'digital clay' approach using a VR system.

<u>Example Worlds</u>

The experiment required the creation of design environments using the desk top VR system, Superscape. Any preference between desk top and immersive systems was not made at this stage. This system was available to the research team and was seen to provide sufficient features not to restrict the creation of these environments.

The first product chosen was a water thermostat housing for a small automobile. This product was based on a real design and is one that is very familiar to the Rapid Prototyping Group being the subject of many experiments in the past [4]. This is primarily a functional product being a single mechanical structure, constructed from a few primitive component elements. As can be seen, the product looks representative but is far from accurate. The nozzle and base components can be distorted to provide a range of designs for assessment. If put in context with the rest of the engine, say, the product could be assessed for position and ease of maintenance (figure 1). It is unlikely that anyone will be concerned about the aesthetic appearance of products like this one. It could be assessed in terms of suitability, however, a shorter nozzle could be functionally correct, using less material in its construction. It may however produce unacceptable difficulty when connecting the associated hose pipe. A larger nozzle, in contrast, may make it more difficult to access the mounting bolts.

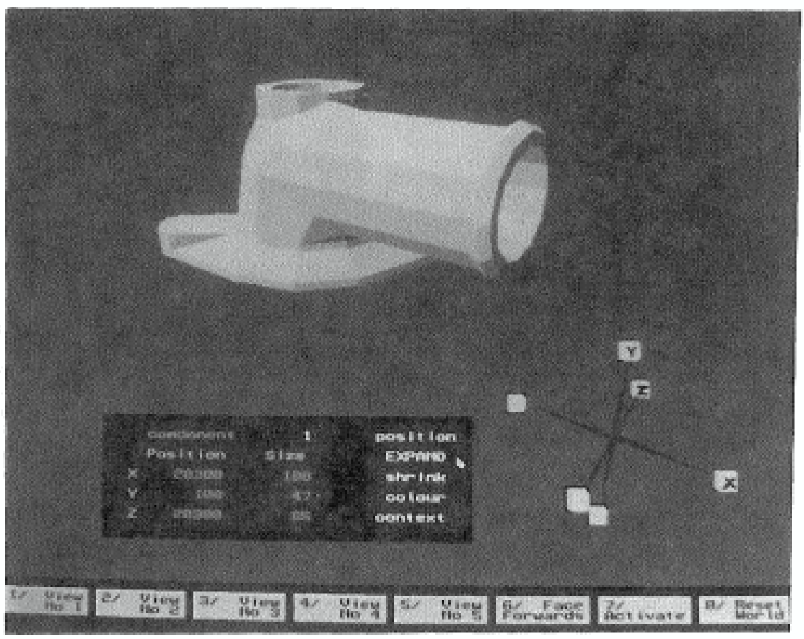

Figure 1 - Complete View of Thermostat Housing

The second example world created was more detailed. This dealt with a product that combines aesthetic attributes with functional elements. The product chosen was the front panel of the 486 computer used to run the VR software. This panel is made up from sub panels that form specialised elements like buttons, disk drives, and LEDs (figure 2). These elements were combined with more general blank features that effectively fill in the gaps. These elements are initially laid out in front of a blank panel that represents the mounting conditions. The designer has the ability to place these components on the mounting panel. It is possible to change the size, shape, position, and colour of each of these elements to assess the effects of different layouts.

This computer panel is a consumer product and therefore must exhibit aesthetic as well as functional features. It is also part of a system that includes the screen, keyboard, and mouse. It must therefore look pleasing within the context of the entire computer. Views must be acceptable from appropriate angles and each component can be positioned to achieve the best result in many scenarios (figure 3). Assessment of ergonomic features like the clarity of layout and the position and size of control buttons can also made for different configurations.

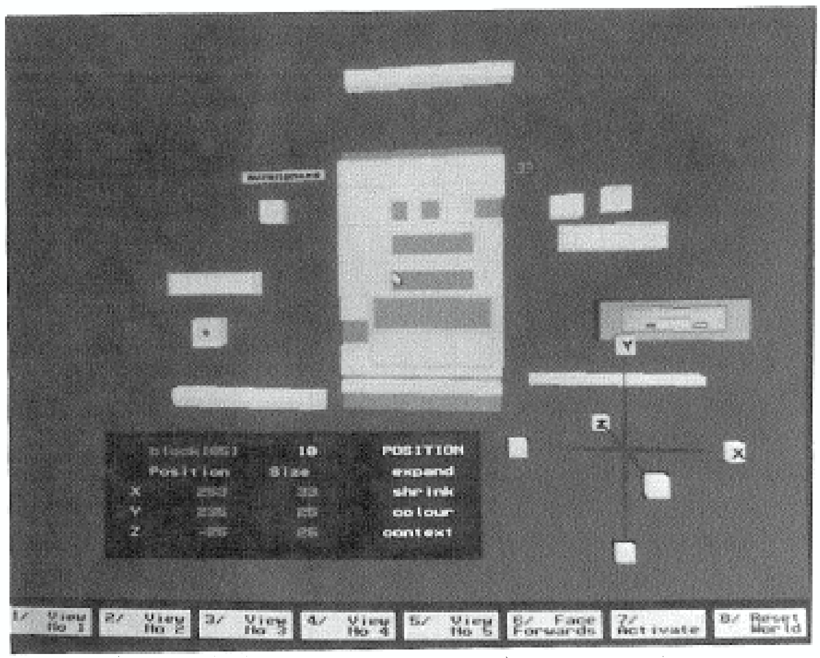

Figure 2 - Base Design System for Computer Panel

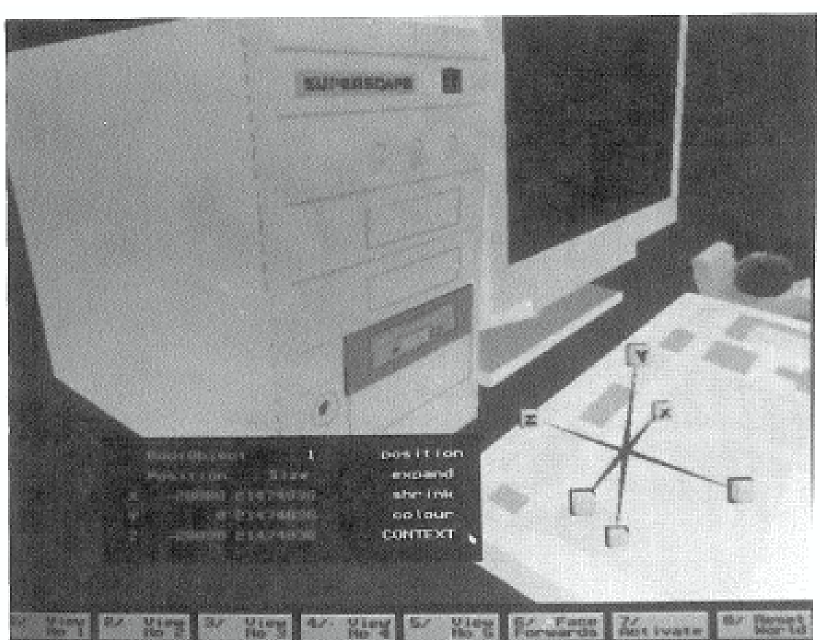

Figure 3 - Completed Computer Panel Placed in Context

The concept of 'digital clay' is more refined in this second case. The elements within the world can be distorted and positioned with ease by merely selecting an item using a mouse driven pointer. The world manipulation controls can then be used to control the attributes of each selected element. The disk drive has greater functionality than the other items and therefore its features are more constrained. Different elements can therefore be changed with different degrees of freedom, dependent on whether the context of their movement is appropriate.

Experimental Analysis

It was found that the design environments were indeed straightforward to understand, use and manipulate. Rudimentary user trials showed that products could be rearranged with relative ease. Users also adapted to the environment with very little instruction, understanding both the reason for the experiment and the tools provided to change the world. Nobody, however, used the tools to produce products other than the ones designated; a point worth mentioning. These were however initial tests and further more detailed trials are essential to analyze fully its use as well as the necessary requirements for improvement.

In real life, the user performs a more qualitative assessment of the environment by way of comparison between objects within the working context. Quantitative tools were available in the example worlds in the form of readouts of position and size of the components. It was found that people using the worlds did not make use of these tools. The example worlds did appear to form the basis of a useful artistically biased tool for product development. It does not appear that quantitative elements are an essential requirement. What is essential is the ability to interface quickly and efficiently to appropriate CAD systems. These transported object descriptions can then be used by the design engineers and form the basis of an iterative process. Currently, Superscape supports the DXF file format but it is hoped that higher formats will soon be made available.

Further Requirements

There are many features that currently do not exist that a designer would probably prefer in a VR based design tool. Some of these features relate to current limitations in the VR system used whilst others relate more to the example worlds created. The latter are obviously more easy to change under the control of VIRART. Some of these points are more for discussion than specified desired changes.

It is uncertain at this stage whether the example worlds should be context specific. It has already been stated that users did not attempt to design out of context. This may have been because all those who have used the system to date have had an engineering background. An aesthetic designer may have used the system differently but may also consider the example worlds too restrictive. The possible solution could be to present the system at two levels. At the low level is the purely creative environment with no predefined elements. Simple blobs of 'digital clay' can be combined to form more complex structures. At higher levels, objects appropriate to the design context will be provided alongside these simpler elements. The next test will be to provide designers with non context driven tools to see whether they can be used to generate something completely original.

The speed of response and resolution of the system are both inferior to what would ultimately be required. This does not mean however that true, life-like representations are essential to the working of the system in this context. As the number of facets increases on the screen the speed of response does appear sluggish on what is a comparatively slow machine (PC 486 running at 33MHz). As such for simple objects the speed is probably adequate making it useable in its present form.

So far the examples have not allowed the user to define custom elements. A facility to create new shapes with different shapes, surface features, textures, texts, etc. is desirable. This could constitute a form of digital pen and paper to be used along with the digital clay modelling system. In effect, this becomes CAD meets DTP in 3D.

Continuing on from this point, it is also not possible to manipulate parts as much as would be desired. For example, at present the disk drive cannot be turned on its side. This stands to highlight one of the main differences between desk top and immersive systems. The manipulative ability within an immersive system appears to be more intuitive than a desk top system through its ability to provide more direct contact with the virtual world. With the desk top system, parts are manipulated via the world control tools rather than directly. With an immersive system, the tendency would be to literally grab hold of the object.

Integration with Rapid Prototyping

When the stage is reached where quantitative test data is required then physical prototyping becomes necessary. Rapid prototyping systems shorten this process dramatically making it possible to recoup a significant capital investment in a short period. The operation time of these machines is still significantly long. Generally parts are in a finished, useable state in around 2 days. If all that the part is required for is to assess factors like dimensional fit, accessibility, optimal position, aesthetics, then a system that operates in real time is much more appropriate.

The primary use for rapid prototyping systems is not therefore in qualitative assessment phase of product development. Manufacturers are realising this, and much more use is being made of soft tooling processes (like investment casting) to produce test parts and for short production runs. This is a much more important role for this technology to fill. Competitive marketing policies still dictate that physical models be created for purposes like tendering and user evaluation. VR, with its capacity to model real life provides a practical replacement for rapid prototyping in this sense. VR has the potential to fulfil at least some part of the first 4 uses for rapid prototyping described by Jacobs [2], those of visualization, verification, iteration and optimization. There is no possibility of VR fulfilling the 5th use, that of fabrication. With VR supporting, the more expensive rapid prototyping technology can therefore be considered free to perform the more production related tasks.

The ideal product development environment is therefore a rapid prototyping base supported by CAD systems to supply the engineering detail. VR systems will be linked to the CAD systems that are designated for product development with aesthetic content. A possible layout can be seen in figure 4. This figure also shows the post-processing unit for conversion of CAD solid models into a layer format suitable for the rapid prototyping machine. The ratio of machines is indeterminate but 1 rapid prototyping machine could quite easily support 4 or 5 CAD workstations with perhaps 2 of these working along with

VR software (preferably on the same platform). This ratio of CAD to rapid prototyping machine is likely to be larger where VR is employed.

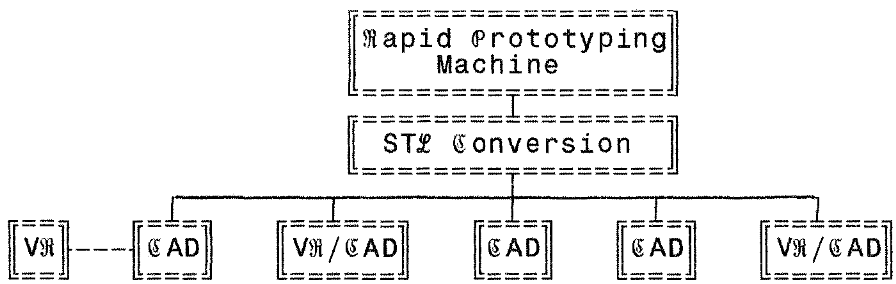

Figure 4 - Proposed Configuration for Optimum use of Rapid Prototyping System

In conclusion, VR is cheaper and less technical to use than rapid prototyping. The turnaround of ideas is much faster with VR and therefore this technology is likely to benefit the aesthetic designer more than the design engineer. VR provides a complimentary technology to rapid prototyping, but the interface is most suitably accommodated through CAD. At some time in the future CAD and VR will merge but not until processing speed has significantly increased to the general user. The potential use of VR does make some of the intended uses of rapid prototyping redundant, but it is impossible to use VR beyond the point where testing or production is required. After all, it is only software.

References

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