Int. J. Engng Ed. Vol. 13, No. 2, p. 108–116, 1997
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A Multimedia Approach to Teaching Rapid Prototyping Systems*

C. K. CHUA, K. F. LEONG, H. K. CHENG and L. M. CHOW
School of Mechanical and Production Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798. E-mail: mckchua@ntu.edu.sg

Rapid prototyping (RP) is an emerging technology which is having a significant impact on product development cycle time and management. This technology enables the making of objects directly from computer models within the time and cost parameters needed by engineers to develop new products and prepare them for manufacture in quantities. RP is a multidisciplinary as well as fast evolving technology. The problem with presenting this technology for learning is the difficulty in covering the wide area of knowledge in a coherent manner. This paper presents a multimedia approach, which, with its visuals, animation and sound, is able to present the RP material in a more cohesive and interactive manner.

INTRODUCTION

RAPID prototyping (RP) systems, otherwise known as solid freeform manufacturing (SFM), represent the future in manufacturing [1]. The major advantage of this technology is the ability to build complex and difficult-to-machine models in a relatively short time. This means that the time to market for a new product can be drastically reduced. This is especially important in today's product development cycle, which is usually very short due to short life span of the product and pressure of first-to-market requirements.

RP systems can create free-form three-dimensional objects of virtually any shape directly from three-dimensional computer representations using raw materials and a modulated energy source. RP is best suited for non-repetitive fabrication of objects with great complexity in a short time without the cost and delay of expensive tools. This is because the objects are built as a stacked sequence of two-dimensional layers. Sequential layer building enables high geometric complexity including enclosed parts and completed assemblies such as meshed gears. The early application of RP was primarily in product design where parts were used for approval and in manufacturing where parts were used for small volume tooling. As technology continues to improve, RP can be used to produce finished production parts of multiple materials, colours and even designed composite materials.

Unfortunately, the technology of building physical models is not well understood by many. The technologies involved in RP are multidisciplinary and therefore difficult to present. Several books [1–3] have been written on the subject but such works in the printed form are often inadequate in explaining or describing such a highly technical and visual subject; the processing procedures of the RP systems are often difficult to visualize and comprehend. Through reading books on rapid prototyping, one may take a long time to fully understand how the laser beam is focused to the material and how the objects can be built in layers. A better solution is to see a RP system in action but this is often not possible because these systems are expensive to acquire and operate. One way to alleviate this problem is to present the material via multimedia form utilizing a compact disc (CD). This is developed to teach various levels of people who require information on the different aspects of this new technology in the shortest possible time.

Multimedia is more than just an effective combination of two or more media [4]. Multimedia is about using a personal computer (PC) as an effective tool for integrating a rich blend of media types and making it possible to bring these elements together in an interactive and cohesive manner. The development of multimedia communication has been made possible by the increasing power of computer systems and the continuing pervasiveness and diversity of the communications networks that are now part of everyday life for many people throughout the world. These two developments open up a much wider field of possibilities for business, commerce, industry and also education, healthcare and leisure.

The world of education has taken multimedia communication quite naturally and rapidly. It appears to be one of the major areas for the growth of multimedia products and services for many years to come. Multimedia packages for teaching engineering topics such as thermodynamics, robotics, fluid mechanics as well as RP, amongst many others, would make the learning process more lively and effective.

The multimedia compact disc read only memory

* Accepted 8 July 1997.

(CD-ROM) on RP is developed to enhance the users' understanding and appreciation of this technology. It utilizes animation and video clips to demonstrate the actual building processes of the various RP systems. It is easy to use on a PC with simple multimedia peripherals. The CD-ROM is developed as an integral part of the book by Chua and Leong [1] and is not meant to replace it. It is to encourage independent learning and allow greater diversity of learning for individuals. The CD-ROM includes the animations of the five most popular RP systems namely: stereolithography (SLA), laminated object manufacturing (LOM), solid ground curing (SGC), selective laser sintering (SLS) and fused deposition modelling (FDM). Through the CD-ROM, the users can see how the objects are built from each system and understand the capabilities and the limitations of each system.

In this article, the application of multimedia on a CD-ROM for teaching of RP systems is presented. It first gives an overview of the advantages of using a multimedia approach for teaching RP systems. The development of the multimedia package is then described. The paper concludes with the evaluation of the design of the RP multimedia package and presents some recommendations for future improvement.

RAPID PROTOTYPING TECHNOLOGIES

The primary motivation for using RP is in the term 'rapid'. In today's market where the competition is stiff and requirements stringent, it is absolutely essential to cut down the time to market. Any tools or technologies that can accelerate this will be imperative. RP helps to significantly reduce the prototyping process, resulting in substantial savings in both time and costs.

The fundamental idea underlying RP is that its builds the physical model layer by layer usually in a horizontal manner as opposed to the conventional machining processes which remove excess materials from a block of workpiece [1–3]. This means that more complex and difficult-to-machine models can now be built as they can be modelled easily on many of the surface and solid modellers available today.

Common to much conventional manufacturing, RP starts from a computer-aided design (CAD) model. But unlike conventional manufacturing the model must represent the physical part to be built as closed surfaces that unambiguously define an enclosed volume. This enclosed volume ensures that all horizontal cross-sections are closed curves when the model is sliced. The CAD model is next converted to the STL file format. The STL format approximates the surfaces of the models by polygons. The STL file can be very large if the model has many curved surfaces. In some cases, IGES (initial graphic exchange specifications) data may also be acceptable. A computer program is used to analyze the STL for errors and missing data and then slice the model into cross-sections if there are no errors. Otherwise repairing of invalid models is required [5, 6]. These cross-sections are then systematically recreated through the solidification of liquids or amalgamation of powders and are then combined to form the 3D model. One other possibility is to create the cross-sections as thin and solid laminations that are glued together to form the 3D model.

Although there are more than twenty different RP Systems, they can be classified into three main categories [1], namely:

(1) liquid-based RP systems,
(2) solid-based RP systems
(3) powder-based RP systems.

Included in this CD-ROM, five systems are covered, namely stereolithography (SLA), laminated object manufacturing (LOM), solid ground curing (SGC), selective laser sintering (SLS) and fused deposition modelling (FDM). These represent a major portion of the principal systems available today.

SLA and SGC come under a liquid-based RP system because parts are produced from a liquid photopolymer resin. In the SLA, the resin undergoes a photopolyermerization process when exposed to a laser beam, which scan across the surface of the resin. The liquid polymer changes into a solid state at the point when the laser beam comes into contact with the surface. The building of the part is done layer by layer. Support structures are needed to support some of the critical areas of the parts. An elevation mechanism will lower the part by a depth equal to the layer thickness after a new layer is formed. This process continues until the part is completed. Post-processing is necessary to harden the model and remove the supports, if any.

The process involved in SGC is slightly more complicated than in SLA. SGC involves creating a temporary photomask of each layer, applying a thin coating of photopolymers and exposing the layer to a burst of ultraviolet light to cure it. The unsolidified residual photopolymer will be removed and replaced by liquid wax. The wax is then cooled to produce a solid layer. Thus the part is supported by solid wax which obviates the need for special supports needed by SLA. The part is then milled to give a constant increase in height. The process is repeated with the next layer until the entire model is built. At the end of the process, there is a solid block of wax encasing the finished model. The model is then retrieved by melting away the wax.

LOM and FDM are classified under solid-based rapid-prototyping systems as the parts are made from solid material. LOM makes use of sheet materials with adhesive backing. Plastics, metal and even ceramics sheets can be used but Kraft paper with polyethylene-based heat seal adhesive backing is most widely used. This is because it is both cost-effective and environmentally benign. Like most RP system, the building of the part is done layer by layer. This is done without the need to create additional support structures. A laser beam traces the outline of the part on one new layer of material. A new layer of the part is created when a new layer of material is spread over it and rolled over by a hot roller, which laminates them together. This process is repeated until the part is complete. Post-processing is necessary to remove the excess material from the part.

In the FDM process, the modelling material, usually wax or plastic, is in spool form. The filament on the spool is fed into an extrusion head and heated to a semi-liquid state. The semi-liquid material is then extruded through the extrusion head and then deposited in ultra-thin layers, one layer at a time at the desired location. This process continues until the part is complete. The FDM Software, *SupportWorks,* can automatically determine if supports are needed and generate them if required. Supports created can then be easily broken away when the part is complete.

SLS is one of the systems classified as a powder-based RP system. The SLS process is the only technology with the capability to directly process a variety of materials including engineering thermoplastics, investment casting wax, metals and thermoplastic composites. To start the process, a thin layer of the heat-fusible powder is deposited onto the part-building cylinder within a process chamber. A laser beam scans out the shape of the part. The interaction of the laser beam with the powder elevates the temperatures to the point of melting, fusing the powder particles and forming a solid mass. The intensity of the laser beam is modulated to melt the powder only in the areas defined by the part's geometry. The rest would remain in powder form serving as natural support for the part. When the cross-section is completely drawn, an additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer. This prepares the next layer for scanning. This process continues until the part is complete. The final part is solid enough and does not need post-curing. The finished part is reasonably fine and requires only minimal post-processing such as sanding.

The technologies involved in RP are multi-disciplinary, involving computer science, chemistry, physics, software engineering, mechanical engineering, electronics, etc. and is therefore difficult to present in a simple straightforward manner. Words are often inadequate in explaining or describing such a highly technical and visual subject. Even diagrams have their limitations as they are invariably static. Most RP technologies and machines have different working principles and materials, thus some form of visuals or animation are important and essential. The processing procedures of the RP systems are the most visually intensive part. One can understand the working principles of RP systems better by seeing them in action than reading directly from printed books. As the information comes from different sources, especially from different vendors, there is a need to consolidate and present the information in a coherent manner. Multimedia is chosen to teach RP because it offers the most effective and expressive tool to enhance communication. Multimedia teaching is more effective and efficient as more topics are covered in a short time without subduing any information. Moreover, multimedia provides a high degree of accuracy in presenting information, especially the principles and functions of type of RP technologies are ensured. Adapting multimedia teaching for RP is a useful and rewarding experience for the users. They can peruse the principles of RP systems and navigate through the program at their own pace without going through pages and pages of texts. For users who do not have much engineering background, multimedia teaching offers the easiest way to learn and understand the principles of RP systems.

DESIGNING A MULTIMEDIA PACKAGE

Multimedia is a combination of texts, graphics, sound and animation. The success of a multimedia production requires an effective combination of the various media. A well designed multimedia package should enhance the communication of ideas and balance the functionality of the program with its usability. The main goal of communication is to draw the user's attention and priority to more important information on the screen. This involves giving attention and priority to critical information while not emphasizing the less important information.

The phases of a multimedia production could be seen as a cross between the traditional software development cycle and that of a movie production [7]. They can be broadly categorized into the following:

- analysis and planning
- design
- storyboarding and scripting
- media preparation
- testing and revision
- packaging and distribution.

The analysis and planning stage involves content analysis, target audience, delivery requirements, media requirements, staffing requirements and project planning. It is at this stage that the designer decides what should be included in the multimedia software in order to cater to the needs of the target audience, the strengths and weakness of different media with respect to the content, the type of skills involved and the time available.

Multimedia production requires many skills covering several disciplines. Both creative and technical people are needed to bring out high

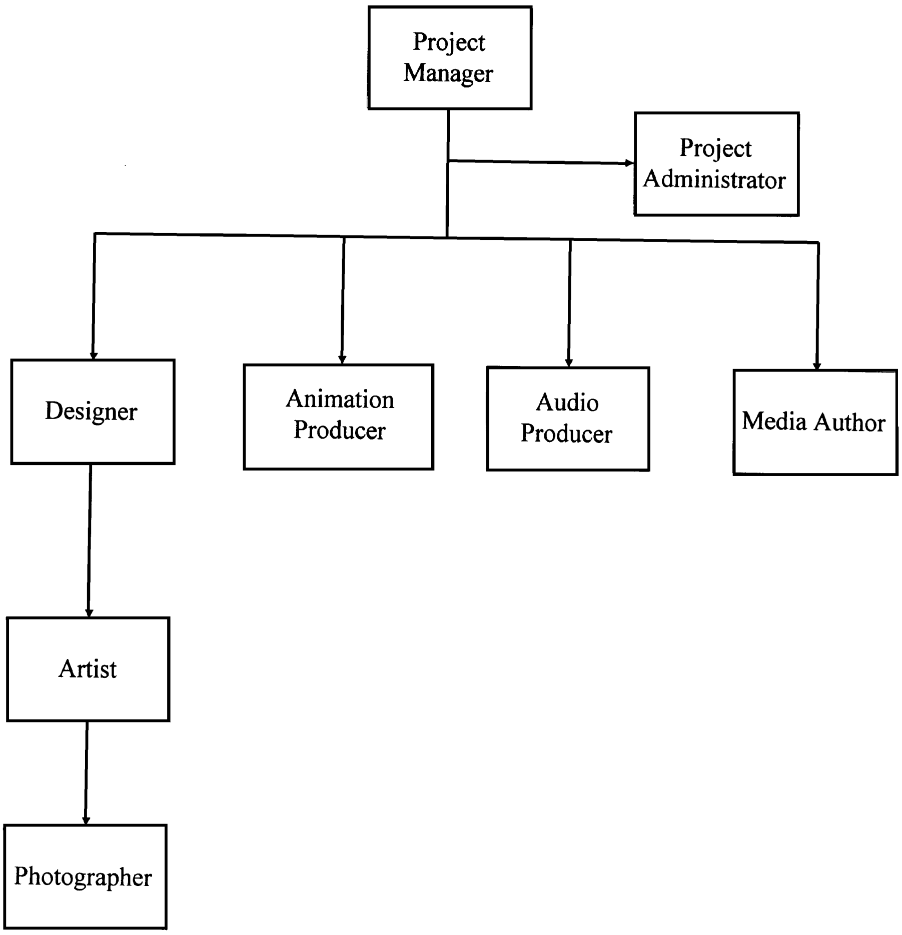

Fig. 1. Ideal staffing for a small multimedia production.

quality in a production. Figure 1 shows the level of staffing for a typical multimedia production.

For this multimedia package development, the configuration is scaled down to that shown in Fig. 2 because of personnel constraints. With this configuration, the design-cum-media developer will have to cover the duties of the designer, animation producer, sound track producer and media author.

With an understanding of the goals and the scope of the development, the flow of the program is established with a task list and the time

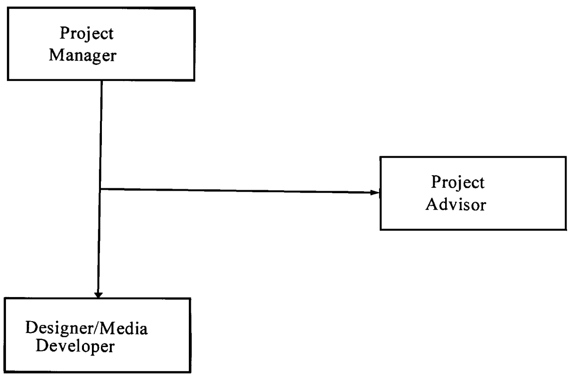

Fig. 2. Actual staffing level.

allocated for each task. This is extremely crucial especially when there is severe time and personnel constraints.

The design stage involves the specification of the content and the user interface. Content focuses on the look or appearance of the material on the screen and the user interface defines the ways a user interacts with the program. There are two kinds of elements in user interface design: structural and cosmetic. The structural element defines how information is structured and linked and what functions to provide at each point in the application. The cosmetic element defines the design of the appearance of buttons and icons and how they are placed on the screen.

The goals of a good design are to enhance the communication of ideas and to balance the functionality of the program with its usability. To achieve these goals, there is a need to organize the content to meet the following requirements:

- good information balance
- good visual balance
- simplicity and functionality in design.

By having good information balance, it means drawing the user's attention to the more important information while de-emphasizing the less important information. As the user is getting information directly from the screen, a good visual balance between static and dynamic screen elements are very important. The designer has to manage the use of the screen space in order to make sure that the screen is visually appealing and the colours chosen promote clarity in the delivery of the information. In an interactive display, the user is frequently prompted to act on the information. Thus, the screen design must not only be clear, it must also be consistent. This aids user navigation through the program. If this rule is not observed, then it might leave the user frustrated and disinterested to use the software, thus defeating the original purpose of the software.

Colour is a useful tool for capturing attention. Effective use of it will enable the user to focus on the important things on a particular screen. On the other hand, indiscriminate usage of colours will leave the user disorientated, confused and frustrated. The colours chosen for the text should promote clarity of the information and the background colour should be light in order to give a smoothing and comfortable feeling.

The storyboarding processes for the production of the multimedia software serves to present a logical sequence of events to the user whereas the script describes the mood of the various events. This part is important as it serves to control the user attention and thus improve on the information retention rates of the users. This can be done by suitably selecting the fonts used, introducing voice-over or background music, creating special effects like blinking buttons and synchronizing text with animation sequences [8].

Pure animation cannot stand alone by itself. When animation is effectively combined with sound, the program becomes more exciting. The selection of an appropriate sound-track can make a significant impact on the program. When sound is well synchronized with the animation, the presentation becomes more lively and well organized. Correct combinations of colours and light are added to various objects to make them more photo realistic.

DESIGN OF THE RP MULTIMEDIA PACKAGE

The primary objective of this multimedia package is to aid the understanding and visualization of five RP systems described earlier in this article. The target audiences for this multimedia package are generally university students or lecturers who are using this as a teaching aid or for technologists and engineers who are keen to learn about RP technology.

The hardware configuration to run the program includes an IBM compatible PC (with at least 4 MB random access memory), a 1×2 quartz (minimum) CD-ROM drive, a display monitor with a minimum of 256 colours and a resolution of 640×480 or higher and two speakers. This program is executable in the Microsoft Windows environment (version 3.11, Windows 95 and Windows NT compatible). A media control interface (MCI) compatibles sound card is required to play the wave or musical instrument digital interface (MIDI) audio.

The program is designed to be both user-friendly and interactive. Users can navigate through the program simply by using the mouse. The program starts with a main menu (see Fig. 3) which prompts the user to select the system to be explored. The names of the RP systems are spelt out in full to ensure clarity. A soft 'Quit' button at the bottom end of the menu allows users to quit the program easily. Upon clicking on a selected system, the program will bring the user to a system menu. From there, the user can choose to view the details of the description product, its process, its applications, its key benefits and company manufacturing the selected system.

Fig. 3. Main menu showing the contents.

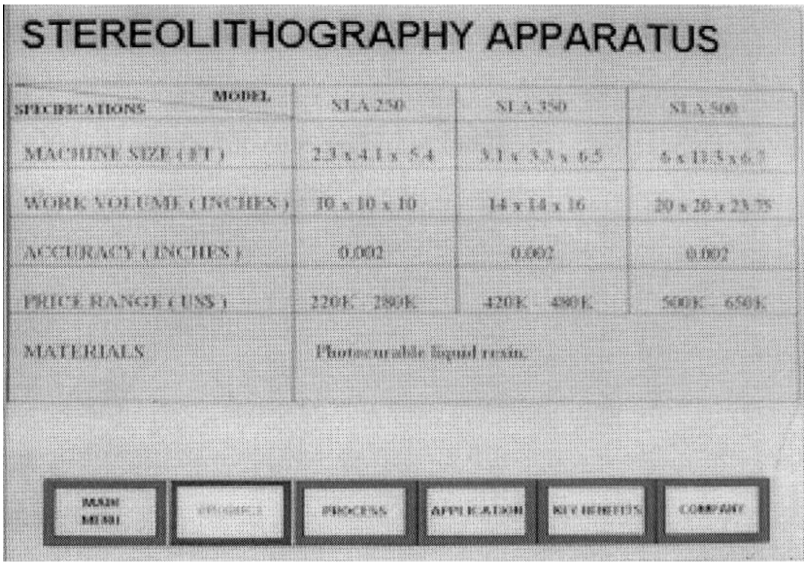

Fig. 4. Specifications of a sterolithography system.

In each of these topics, the users can access the following information.

(a) In the products module, the specifications and other technical information of the system are displayed (see Fig. 4). Users can check out the machine size, work volumes, machine accuracy and the price range of the system. The different types of material that can be used by the system are also listed here.

(b) In the process module, the program has the ability to animate the building sequence of a prototype layer by layer. The procedure at each stage of the animation is highlighted in blue. After the completion of the animation of that stage, the blue wordings will change to grey. When the entire animation sequence of the building process has completed, a 'Replay' button appears automatically at the bottom left of the text (see Fig. 5). Users can either choose to replay the animation of the building process, to recapitulate or go for other options available on the menu.

(c) In the applications module (see Fig. 6), the user can browse through still visuals of the products manufactured by the selected system using the 'forward' and 'backward' keys displayed on screen. They can also check out the comments made by some users of the system to have an understanding of its capability.

(d) In the key benefits module (see Fig. 7), the advantages of using the selected system are listed.

(e) In the company module (see Fig. 8), the address, phone number and e-mail address of the manufacturer of the systems are listed. The

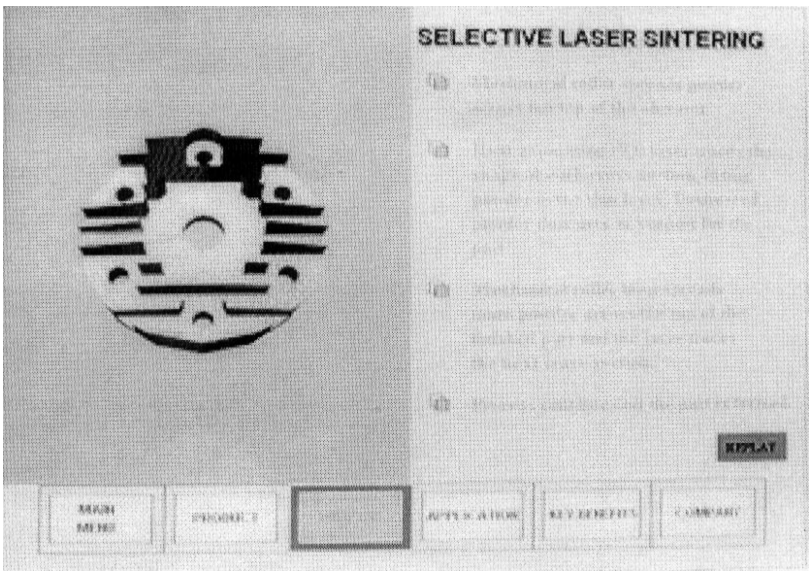

Fig. 5. Process module of a selective laser sintering system.

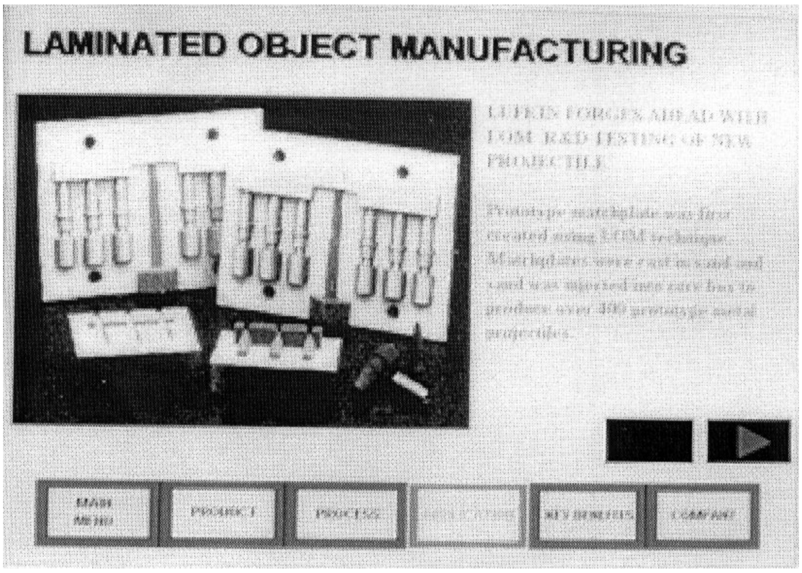

Fig. 6. Application of a laminated object manufacturing system.

person to contact for further information on the system is also listed here to enable the user to follow up on more information, if necessary. It also serves as a direct source of contact for the vendor concerned.

After exploring some or all of the five modules, the user can then return to the main menu and view another system. When the user has finished navigating all the five different systems, he or she will have a good understanding of RP and the type of system that is most suitable for a particular application.

For this CD-ROM, it is estimated the average user can attain a reasonable understanding of the RP technology within an hour or so without having to go through the many pages of texts. Realistic animation of the different RP systems allows the user to observe how prototypes are being made on these systems. The user can appreciate the advantages of these systems and understand the limitations of these systems without having to come in contact with the physical hardware. The information included in this CD-ROM is presented in an interactive manner so that the user can access it easily. The user can browse through the program at will, without losing track of the information.

Like any other software, the present program has the need for improvement. Future work will involve designing a tutorial that can test and enhance user's level of understanding of RP systems. When the user happens to answer a question wrongly, the program can re-route to the appropriate section in the program that provides the right answer. In this manner, the user can clear up

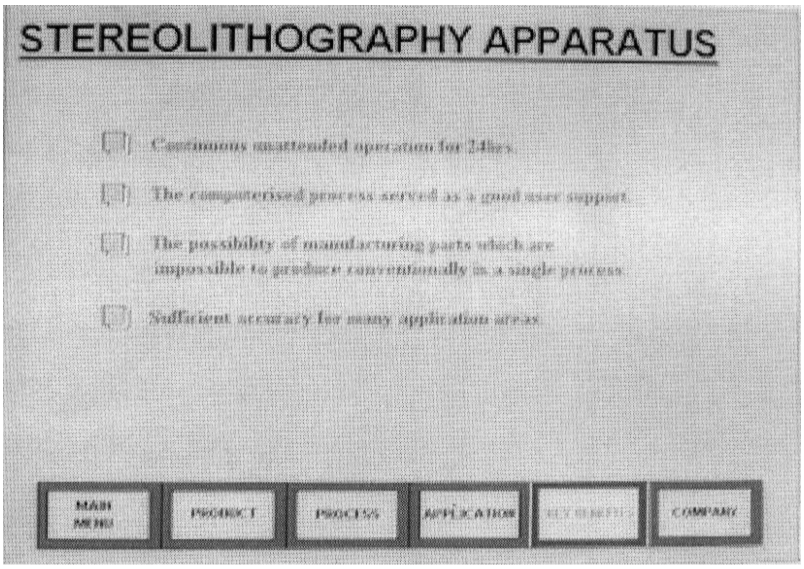

Fig. 7. Key benefits of using a sterolithography system.

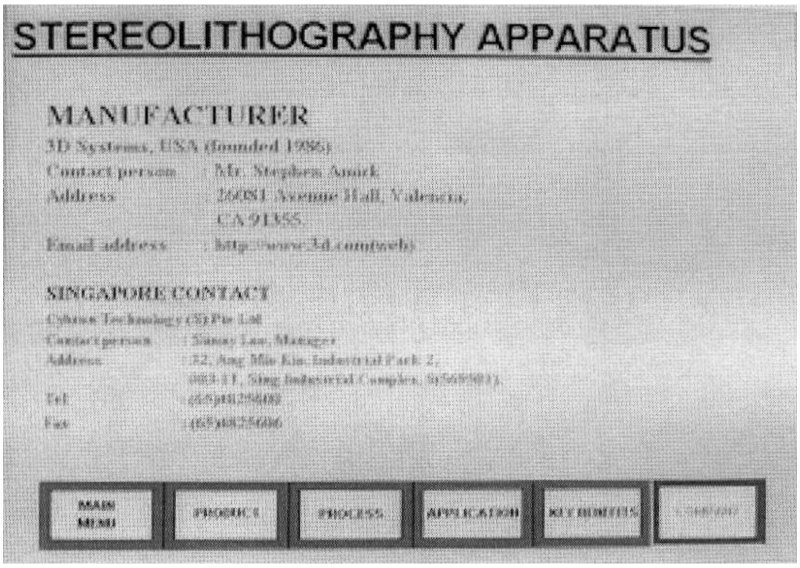

Fig. 8. Manufacturer of stereolthography system.

any misconceptions or doubts more effectively. Another improvement will be synchronizing the sound with the animation. The program can run in a narrative manner. In this way, the user can gain better understanding of the RP systems when he or she can see the animation of the RP system and listen to the narrator explaining the process at the same time.

CONCLUSION

Multimedia is widely acknowledged as an environment with great potential for learning and education. Rapid prototyping is a highly visual and technical subject. The technologies involved are multidisciplinary and fast evolving. The ability of multimedia to explain the principles of RP systems far surpasses that of books. This RP multimedia package is a useful tool for teaching RP to engineering students or technical personnel. It can serve as a quick reference for engineers who are keen to know more about rapid prototyping but can not afford the time to go through the books. Future work in developing the software will involve refining the program to run in a narrative manner and to add in tutorial, which may serve as a gauge of the level of the user's understanding of RP systems.

REFERENCES

1. C. K. Chua and L. F. Leong, *Rapid Prototyping: Principles and Applications in Manufacturing*, John Wiley & Sons, Inc (1997).
2. M. Burns, *Automated Fabrication: Improving Productivity in Manufacturing*, New Jersey: Prentice-Hall (1993).
3. D. Kochan, *Solid Freeform Manufacturing*, Amsterdam: Elsevier Science Publishers (1993).
4. A. Sloane, *Multimedia Communication*, McGraw-Hill (1996).
5. K. F. Leong, C. K. Chua and Y. M. Ng, A study of stereolithography file errors and repair, Part 1: Generic solution, *Int. J. of Advanced Manufacturing*, **12** (1996) pp. 407–414.
6. K. F. Leong, C. K. Chua and Y. M. Ng, A study of stereolithography file errors and repair, Part 2: Special cases, *Int. J. of Advanced Manufacturing*, **12** (1996) pp. 415–422.
7. F. Botto, *Multimedia, CD-ROM and Compact Disc: A Guide for Users and Developers*, Winslow, England: Sigma Press (1993).
8. T. Yager, *The Multimedia Production Handbook for PC, Macintosh and Amiga*, London: Academic Press (1993).

Chee-Kai Chua is a senior lecturer in the School of Mechanical Production Engineering. He has published over 70 technical papers in the area of CAD/CAM and rapid prototyping and co-authored a book on *Rapid Prototyping Principles and Applications in Manufacturing*. He sits on several international conferences international program committees dedicated to rapid prototyping.

Kah-Fai Leong is also a senior lecturer the School of Mechanical Production Engineering. He is also the co-author of the book on *Rapid Prototyping Principles and Applications in Manufacturing.* Other than in RP he has also published in areas in product design and design education.

Huang-Kheng Cheng is a researcher in the Gintic of Manufacturing Technology, Nanyang Technological University. He graduated from the School of Mechanical and Production Engineering in 1996.

Lai May Chow is an undergraduate in the School of Mechanical and Production Engineering, Nanyang Technological University. She received her Diploma in Mechatronics Engineering from Ngee Ann Polytechnic in 1994.