Enhanced learning of rapid prototyping systems through multimedia

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Abstract Dedicated teachers around the world have continually sought to find better instructional strategies for their subjects. This paper presents the development of a multimedia application for teaching rapid prototyping to professionals and tertiary-level students. A CD-ROM was used as the instructional medium. This paper considers learning factors such as the organization and structure of the information, application of animations, visual aids and sound, the human–computer interface, and presentation styles, in relation to the CD-ROM's purpose of enhancing the education process for rapid prototyping technology.

Keywords multimedia; learning; education; rapid prototyping

Introduction

Multimedia refers to the integration of visual imagery, text, video, sound and animation to create an interactive and lively presentation. Although multimedia may not be suitable for every application, there is evidence that software developers and educators generally embrace it for its effectiveness in conveying ideas and bringing concepts to life in an interactive manner [1]. Educational theory also suggests that people learn most when they are actively engaged rather than passive recipients of information [2]. The learning curve to master a subject is greatly reduced with the use of multimedia. Educational studies have shown that when there are visual and auditory presentations as well as interactivity, the retention rate can reach as high as 75% [3]. Furthermore, multimedia courseware linked to the internet allows the user to efficiently obtain cross-references directly, for example through web links.

Another distinct advantage of multimedia learning is the ability of the learner to control his or her own pace of learning, whereas traditional teaching methods do not. Being able to do this leads to an optimization of the use of classroom time. Learners can navigate the contents of the multimedia presentation and select the sections that they want to learn, thereby planning their own learning experience. Studies of learner (user) control have identified a number of positive gains, including increased motivation, increased self-determination and increased achievement gained over more structured forms of the same materials [2, 3]. Animations and sounds in the multimedia package will reinforce the text, thereby making it clearer for the end-user to visualize the concepts than when conveyed in a book.

The subject, rapid prototyping (RP), that is presented is largely science and technology based. Also known as solid freeform manufacturing, it is a general name given to the family of modern fabrication processes developed to build three-dimensional engineering parts in a very short lead time [4]. RP is considered a relatively new

technology that was developed to overcome the limitations and long machining times of conventional fabrication processes, such as milling and shaping. Because of the layer-by-layer build strategy, a geometrically complex part that once took weeks to fabricate can now be made in a couple of days or even hours. Although this is an important modern manufacturing technology, it remains relatively unknown. There is therefore a need to present this technology to industry professionals and students in higher education.

A number of RP textbooks [5–9] have been written on the topic. However they do not convey the highly visual and technical nature of RP technologies, effectively due to the static nature of books in general. Thus, by adopting a multimedia approach, the concepts can be 'brought to life' to the learners.

The concepts of RP systems have been presented in an interactive multimedia form on CD-ROM. The RP multimedia CD-ROM can serve as a companion to an RP book written by Chua, Leong and Lim [5], or as an educational resource on its own. This new CD-ROM is an update on an article previously published in 1997 [10]. It is a significant improvement over the previous CD-ROM, which served specifically to compliment the rapid prototyping book [11].

In this paper, an overview on the multimedia approach in teaching RP technologies is presented. The various chapters in the CD-ROM will then be elaborated and the paper concludes with an evaluation and preliminary assessment of the multimedia package and future considerations for further enhancing the CD-ROM.

Rapid prototyping technology

Design and manufacturing companies today tend to have to compete not just locally but internationally in order to survive. Hence, it is more important now for these companies to reduce their time to market, so as to be able to compete effectively against the ever-increasing level of competition.

In the manufacturing industry, productivity is achieved by guiding a product from concept to market quickly and inexpensively [12]. Moreover, many companies find that the design of a product often takes up a high percentage of the manufacturing costs [13]. Therefore, with the use of RP, a part that once took weeks and months to prototype can now be produced in a matter of days or even hours. This allows the visualization, functional testing and verification of the end-product. Modifications to the part can now be quickly made before it is mass produced. This dramatically decreases the time and overall cost of bringing a prototype to production, resulting in a reduction in the overall time to market. This quick turn-around time would give companies a much-needed edge over their competitors.

Although originally developed to help shorten product development and the manufacturing cycle, RP is also used by architects to produce scaled building models, by artists to create their sculptures and by forensic personnel for investigative analysis [14].

There are more than 50 different RP systems currently available today [7], each differing in the capability, processing techniques, materials and software support. They can be categorized into liquid-based, solid-based and powder-based RP

systems [5]. However, most RP systems generally follow standard processing steps to produce a part. The steps are as follows:

(1) Perform three-dimensional computer-aided design (CAD) solid modelling of the part to be produced.
(2) Convert the CAD files into a RP industrial standard data file format.
(3) Import the data file into the RP program of that system.
(4) Check for errors and missing data in the data file. Perform corrections where necessary.
(5) Digitally slice the three-dimensional CAD solid model into horizontal layers.
(6) Send the sliced data to the RP machine for production.
(7) Post-process the prototype. This includes removing the prototype of unwanted excess materials, cleaning and surface finishing (e.g. sanding and painting).

The time required for the entire process depends on many other variables, such as the type of materials used, part size, layer thickness, complexity and the selection of RP systems used to produce the part.

Development of the multimedia courseware

The organization of each chapter is standardized throughout the CD-ROM. The fundamentals of each chapter are presented first. This is then followed by more advanced and detailed information. However, the learner is not restricted to view the CD-ROM in a fixed order – there is the option to select the chapters or sub-topics that are of interest and advance directly to that particular material. This is particularly helpful if the user intends to make only selective references.

Tay [15] refers to multimedia as the woven combination of text, graphic art, sound, animation, and video. It is a class of interactive communication systems that create, store, transmit and retrieve textual, graphic, and auditory networks of information. Successful multimedia production can effectively combine various media, such as videoconferencing, interactive websites and multimedia learning, and further adaptations or functions can be made to cover regional and international variations.

The phases of a multimedia production can be categorized as follows:

- Identification of target audience.
- Logic flow chart/navigation map.
- Design/development of user interface graphics, animations and sounds.
- Testing and debugging.
- Packaging.

The initial stage of a multimedia production involves the identification of the target audience, the media requirements and project planning. It is at this stage that the designer decides on the theme and objectives of the production so as to tailor it to the needs of the target audience. The multimedia courseware presented here is designed for the following target audience:

- Undergraduate and graduate students who are studying or carrying out research in RP.
- Lecturers at university, polytechnics, junior colleges and secondary schools who teach RP or include it as a supplementary material for their students.
- Professionals from industry who want to update themselves on the latest RP systems.
- Individuals who have a general interest in the development and trends of new design and manufacturing technologies.

Next, a navigation map or a logic flow chart was developed. It was considered as the most important task to be done in the early stages of planning. The purpose of a navigation map was to enable the designers to have an overview of the entire structure of the courseware. In addition, it not only outlined the links among the various contents, but also provided a logical flow for the interactive interface. An example of a navigational map (hierarchical structure) of one of the chapters (Chapter 5) is schematically shown in Fig. 1. Its sub-sections, as well as its relationship to other chapters, are also presented.

With a clear understanding of the goals and scope of the development, the design phase follows. The design phase involved the specification of the content and the development of user interface graphics, animations and sounds. Normally, the

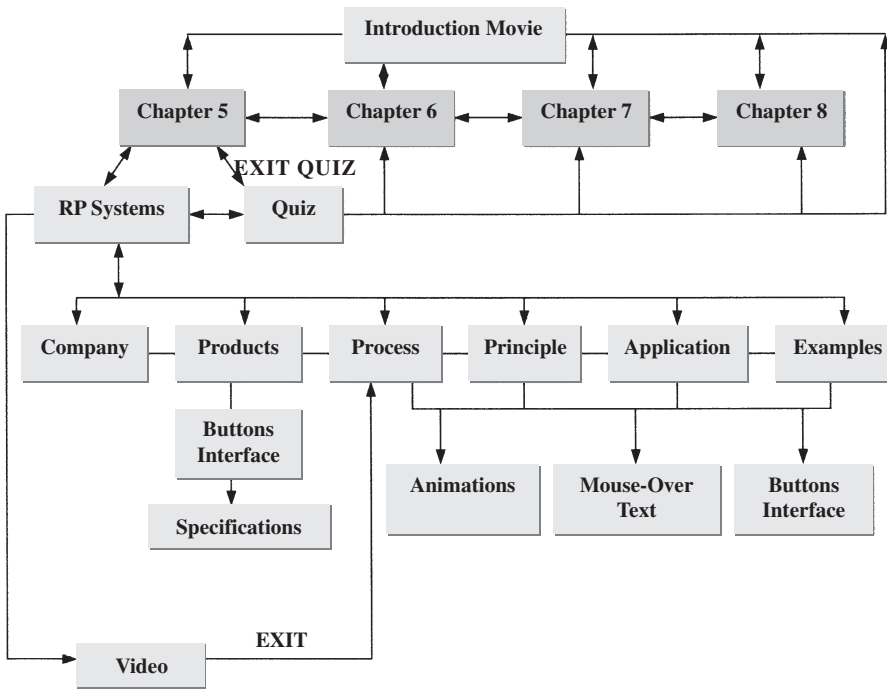

Fig. 1 *Hierarchical structure of Chapter 5.*

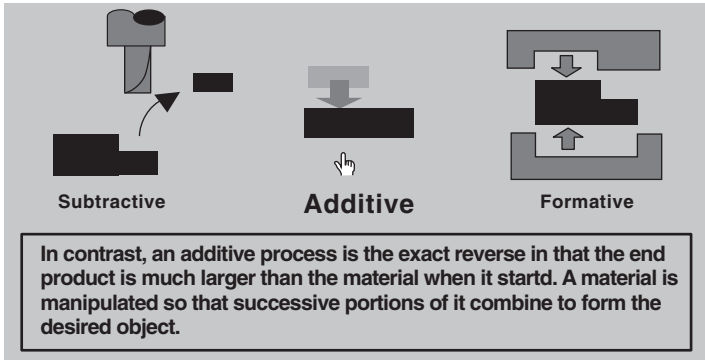

Fig. 2 *Mouse-over image icons with 'hidden' explanations attached.*

content focuses on the appearance of the material on screen as well as the entire layout design of the courseware. The user interface defines the ways in which the user interacts with the program. There are two kinds of element in the user interface design: structural and cosmetic [10]. The structural element defines how information is structured/linked and the types of functions that are being provided at each point of the application.

There are many ways of presenting text and images in an interactive multimedia project. Depending on the approach taken by the designer, it is possible to have interactive texts within images. This, however, requires the movement of the mouse by the user in order to obtain the required explanation or information. An example of this is shown in Fig. 2, where images have 'hidden' explanations attached to each animation.

The goals of a good design are to enhance the human–computer interface by effectively communicating ideas while balancing 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 [10]:

- Good information balance.
- Good visual balance.
- Simplicity and functionality of design.

The sole purpose of having good information balance is to enable users to draw their attention to more important information, while de-emphasizing that which is less important. This is usually achieved by ensuring that the screen is visually appealing and the colours chosen promote clarity in the delivery of the information. Most importantly, the layout of the user interface should be consistently clear and concise. The users should not at any point be left confused about the functions of the program.

The buttons and icons serve as an essential human–computer interface for courseware navigation. Users depend on the clarity, usability and consistency of these navigational tools to make the retrieval of information simple, easy and speedy [16,

17]. A poor interface will result in a lengthy search for the desired function or information [18]. In an interactive display, the user is frequently prompted to act on the information through the use of icon and button designs. Thus, the design, size and colour of the icons and buttons should be simple and self-explanatory.

The use of colours is a powerful visual impact tool for capturing and retaining the attention of the user. A good choice of colours will enhance the presentation of materials and the user's interaction with the user interface. Very often bright colours are used to highlight important information and to enliven the learning environment. For instance, a yellow background contrasted with a blue navigation bar would create a warm but attractive medium for learning. In addition, it is also used as a means of capturing the user's attention. Typical examples include colour-changing buttons and pop-up text to feedback to the user that some form of activation has taken place. Colours should be used sparingly but appropriately to match the contrast with the screen design and other features of the courseware–user interface. Apart from the need to provide clarity of information, the user's eyes should also feel soothed and comfortable when using the courseware. The colour schemes selected will depend a lot on the target audience as well as the theme and objectives set out by the multimedia team.

Animation adds visual impact to any multimedia project. For example, a flickering word on the screen can be more eye catching, and so could be used to stress important points. However, pure animation cannot stand by itself [10]. When the animation is effectively combined with sound or when it is supplemented by video, the entire program 'comes to life' and thus creates more excitement. The selection of an appropriate sound track can have a significant impact on the program. When sound is well synchronized with the animation, it not only enhances the application but it also brings about greater reality and liveliness to the presentation.

Design of the RP multimedia courseware

The primary objective of the multimedia CD is to aid the understanding and visualization of RP systems and to provide interactive learning for the different target groups specified earlier.

The hardware configuration needed to run the program includes a personal computer (PC) with at least 8 megabytes of random access memory (RAM), a quad speed (4×) CD-ROM drive, a display monitor with a minimum of 256 colours and a resolution of 640×480 pixels or higher, a video display card (capable of the above resolutions) and speakers. The program is executable in the Microsoft Windows environment (Windows 95 or higher). A media control interface (MCI) compatible sound card or Motion Picture Expert Group Layer 3 (MP3) audio is required to play the sound files (WAV).

The multimedia CD package was designed to be both user-friendly and interactive. Users can navigate through the program with ease in just a few clicks of the mouse button. The program begins with an animated main menu, which prompts the user to select the topics or chapters to be explored. There are eight chapters:

(1) Introduction.
(2) RP processes.
(3) Liquid-based RP systems.
(4) Solid-based RP systems.
(5) Powder-based RP systems.
(6) RP data formats.
(7) Applications.
(8) Benchmarking.

Each topic mentioned above details the various aspects of RP. For instance, in the introduction (Chapter 1), an insight on the fundamentals of RP and its advantages are given with the help of text and animated graphics.

In the chapter 'RP processes', the user is presented with the fundamental ideas on prototyping and the general method of producing the part using RP systems. The chapter provides the essential foundations of RP, especially for users who have little or no prior knowledge of RP systems, before they progress onto the later chapters.

The next three chapters cover specific RP systems. These are broadly categorized as 'liquid-based', 'solid-based' and 'powder-based' systems. The structure and organization of these chapters are similar; the user learns about the details of a company, its products, process, principle, applications, examples and the company's research and development on the system. Thus, users can choose to view the various sections through the use of the side navigation bar (see Fig. 3).

With a click of the mouse on the navigation side bar, an elaboration on the various sub-sections relating to that specific RP system can be accessed. The following information for that particular RP system is structured as follows:

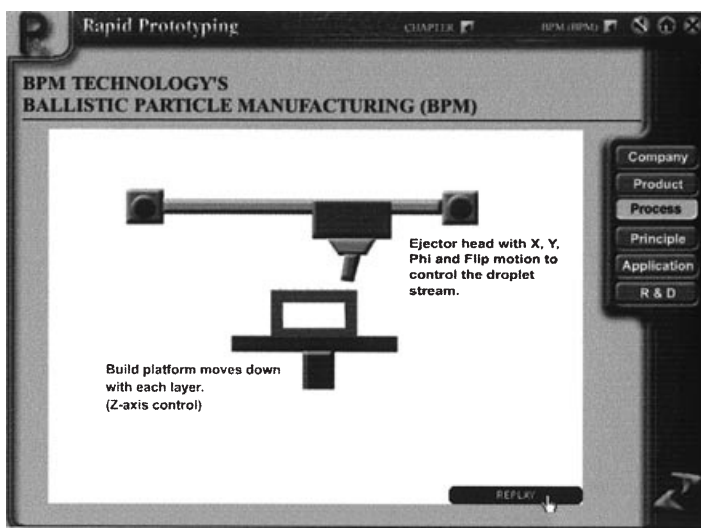

Fig. 3 *Animated process of BPM Technology.*

(1) In the 'Company' sub-section, the contact particulars (e.g. address) and brief history of the manufacturer are listed. This is to enable users to access more information, if necessary; it serves as a direct source of contact for the vendor concerned. In addition, it contains a brief background of the company and its accomplishments in the field of RP.
(2) In the 'Products' sub-section, the specifications and other technical information of the systems are displayed. Users would be able to check the machine size, work volumes, machine accuracy, types of materials used and other information pertaining to the technical details of the system. This informs users of the various and latest choices of systems available on the market.
(3) In the 'Process' sub-section, animation or interactive mouse-over images have been used to illustrate the building sequence of a prototype layer by layer (see Fig. 3). In addition, a detailed text explanation is given to aid users in understanding of the different RP processes prior to the animations. When the entire animation sequence of the building process has been completed, users can choose to replay the animation of the building process, to recapitulate or to go for other options available on the menu.
(4) In the 'Principle' sub-section, more in-depth explanation of the working concepts of the building process is given. This includes the type of laser and material used and the various parameters that influence the performance and functionality of the parts. In this manner, users gain a better overall understanding of the working principles behind individual RP systems.
(5) In the 'Applications' sub-section, users can view the different types of products manufactured by the RP systems. This is in conjunction to the process and principles that are discussed in the courseware, thereby bringing greater awareness of the capabilities of the RP systems.
(6) In the 'Examples', 'Case studies' and 'Research and development' subsections, information on the company's continuing efforts in its research and development on new materials and methods are highlighted. In addition, examples of costs and time saved by various companies are given to emphasize the advantages of RP systems.

Under the chapter 'RP data formats', the user can learn more about the software used to support these RP systems, such as the industrial standard STL file format. Here, users are given an insight into the various ways of tessellating a model, its problems and solutions, and the different translators that are available for use by RP systems. Other aspects of software-related information covered are possible problems while converting the CAD file to the STL file, how to check for such errors and how to correct them. Other newly proposed data formats, such as stereolithography contour (STC) and common layer interface (CLI), are also included in this chapter to provide a complete picture on the data formats available in RP.

In Chapter 7, entitled 'Applications', a more in-depth illustration of RP technology in different engineering fields, such as design and manufacturing, is presented. Apart from exposing the user to how RP is applied in the various manufacturing stages, such as product design, analysis, planning and tooling, specific case studies

of RP application are also given for the following industries: aerospace, biomedical, forensics, jewellery, coin and tableware. These examples are used to discuss the usefulness of RP in these fields. Although, they are not exhaustive, they give the user a fair idea of the repertoire of RP applications, and emphasize that their use is not restricted to the manufacturing industries.

Last but not least, the chapter on 'Benchmarking' gives users an understanding of the function of bureau services and the points to note when selecting one. In addition, the steps and costs of setting up a bureau service are also detailed. It should be noted that to illustrate how to up of a service bureau, the numbers quoted have to be fictitious in order to safeguard confidentiality of actual cases. However, these are sufficient to illustrate the considerations and calculation.

In exploring all eight chapters in the courseware, users have the option to return to the main menu, jump to any chapters or sub-sections, attempt a quiz (see Fig. 4), or exit the program at any point. The quiz is programmed so that the order of questions, as well as the order of multiple-choice answers, is randomly different each time a user attempts it. An example of the power of the random quiz system is as follows: If 10 multiple-choice questions are chosen randomly from a pool of 15 quiz questions, each question having 4 possible answers, the total number of permutation available becomes 1,441,440! This makes it more challenging for users attempting the quiz and gives them a more accurate assessment of their understanding of the subject.

A preliminary assessment of the CD-ROM was carried out during its alpha-testing phase of development with a group of 12 people. Functional aspects of the multimedia CD-ROM, such as colour combination, user interface, animation and video, among others, were tested. It was generally found that the user interface was easy

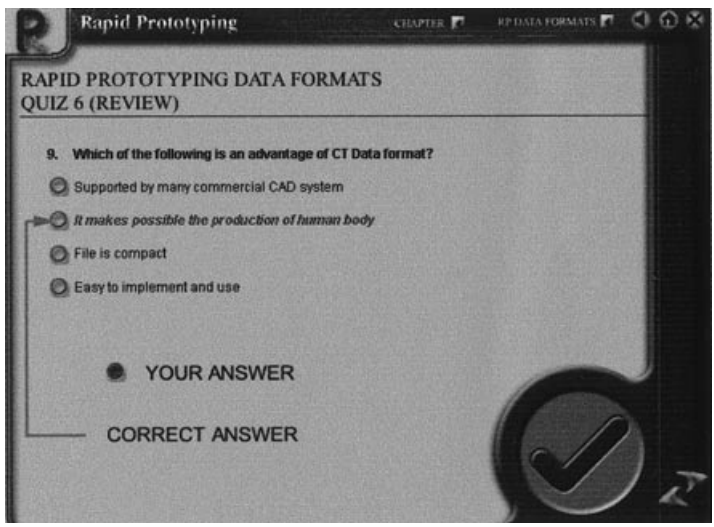

Fig. 4 *Answer review to quiz questions.*

to learn and use, although a minor bug in the page forward/backward navigation controls was identified. However, this problem was easily rectified. The testers also commented favourably on the animation and video included, as they were able to see the RP processes in motion. Further work will be carried out to improve the functionality of the program and put the CD through a beta-testing phase with target users before it is eventually released to the general public.

Summary

In summary, from this multimedia courseware, the user can learn, compare and contrast the advantages and disadvantages of each system without having to come into contact with the physical hardware.

Although this RP multimedia courseware is a significant improvement over the initial program, further improvements can still be made. Future work could involve improving the animation graphics to elevate the realism and overall quality. This is, however, a function of the present state of technology. Another added feature to enhance learning would be to include a voice-over narration to the courseware. A narration feature will help the user absorb the materials covered in the courseware better, as the user will be able to hear and read at the same time.

Further to this, it is often useful to have a search function and help files to assist users locate particular keywords of interest. One way of doing so is to develop a search engine for the software. With this added feature, the program will improve on its user friendliness for all levels of the users.

In must be noted, however, that the multimedia CD-ROM is not meant as a replacement for textbooks or traditional lectures, but rather to act as a personal 'tutor' to convey the RP concepts presented in the book. Perhaps the most useful contribution of the courseware is that it will allow the students to learn at their own pace and in their own time. Through the use of animations, video and user controls, the readers are able to visualize and thereby grasp the concepts presented in a shorter period of time compared with reading the book alone.

Conclusions

Multimedia is capable of creating an enhanced learning environment, which makes learning easier and faster. As such, many educational institutions and software developers are increasingly creating multimedia courseware and educational software to assist students and lecturers, among others, to learn more effectively. Rapid prototyping, being a highly visual and technical subject, makes learning it through textbooks a rather laborious task for students. However, through the use of such multimedia courseware, learning about RP technologies is significantly simplified.

The RP multimedia courseware can also serve as a quick reference for busy engineers and marketing personnel who need to check information. The courseware also benefits those who are keen to learn more or who want to keep abreast with developments in RP. On-going work on the multimedia package will involve continuous updates of existing information and the addition of new information in this field.

Lastly, a voice-over narration added to the courseware would give it, literally, a 'voice' of its own.

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