Section 1302

Understanding Machine Operations and Manufacturing using VRML

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Abstract

Over the past decade, there has been a growing need to use computers in the educational process. Software developers have started to take advantage of the most significant advances in computer technology most notably, internet-based networks. Undeniably, the Internet will be a vital part of education in the future. VRML or Virtual Reality Modeling Language is one of the many potential educational tools on the Internet. It is the acknowledged three dimensional web standard for visualization. It allows the viewer to examine the model at different angles and at different distances, all within a web browser. Animations, sounds and interactivity are also possible with VRML.

This paper describes the application of VRML and the imparting of manufacturing education to engineering students using the Internet. Good engineering programs are generally too complex to use, too costly and not widely available for engineering education. Engineering Design Graphics and Manufacturing Processes are generally compulsory courses in both the Aerospace and Mechanical engineering syllabus. The extensive use of the computer with the implementation of the laptop program in University of Oklahoma further encourages the need for virtual machines and a factory to supplement an engineering coursework. Also students can access the virtual models anytime and anywhere with a computer and a VRML player. The use of visualization tools also promotes interest and curiosity towards a manufacturing course.

Introduction

Frequently, mechanical and aerospace engineering students don't have enough exposure to the use of basic industrial and manufacturing equipment. It is not possible to bring real machinery into the classroom and on the other hand it is not easy to teach students outside the classroom particularly in the workshop. Therefore there is a need to have some medium of teaching that is easily available and allow students to learn interactively. VRML models supplemented with class notes on the web page can solve this problem by bringing virtual machine models into the classroom. The instructors would just need a laptop, a VRML capable browser and a projector to present the VRML models.

The Internet or the World Wide Web is a good source of vast amounts of information for research and education. Over the pass few years, the Internet has seen a tremendous growth in the amount of users and information. There has been research by many universities and government agencies around the world in developing VRML models on the web[1]. VRML developers have published their field of work ranging from virtual places, artificial intelligence, chemistry, engineering and many more. VRML models are emerging as fast as homepages appeared a few years ago. The purpose of this paper is to explain the potential use of VRML models for engineering education. This paper is going to introduce visualization of manufacturing processes, an area of engineering education which VRML can be used to supplement conventional teaching methods.

1. Internet and Computing Power

It is important to understand what Internet is due to the great impact Internet has on engineering education. The Internet is an international network of computers connecting together universities, companies, research laboratories, homes and government offices. The World Wide Web is the graphical user interface to the Internet. One can access the Internet using a wide variety of applications; the most common of which are the Web browsers.

The amount of data that can be transmitted increases as the bandwidth of the Internet grows. This allows for more 3D-model visualization over the Internet that can be CPU intensive in addition to accommodating large file sizes. For example, even in VRML, a common 3D file format for web use, the files are generally designed to be small but even these files can quickly become complex when trying to realistically model an actual object or system. Thus, it is expected that the increase in bandwidth will be offset by more complex models.

In addition to file size considerations, the ever increasing computer processing capability is also an advantage to the VRML world because more details can be added to a model without a large penalty in modeling time. It can be frustrating to wait for model details to load up and render as one moves about in a VRML world. Therefore the ever-increasing CPU power will enable more complicated VRML models to be created and used in engineering education.

2. VRML

One of the methods to present visualization models for engineering education on the Internet is VRML (Virtual Reality Modeling Language). VRML is a platform-independent file format for sharing 3D worlds on the Web[2]. VRML worlds are extremely versatile in that they support interactivity, animation, user modification, and embedded hyperlinks to other Web documents. Furthermore, VRML file formats are independent, therefore all computers (PC, Mac, Unix, etc.) that use a web browser can use and view VRML models with a VRML player. In addition to these advantages, VRML is inexpensive and flexible, hence this file format was chosen for this research project.

VRML format is less complex when compared to other 3-D CAD programs and can easily be published on any web site.

The actual VRML file is a textual description of the model that can be created using any text editor or word processor. VRML file names end with the extension .wrl and contains seven main types of components including a VRML header, prototypes, shapes, interpolators, sensors and scripts and routes

VRML building instructions must include precise sizes and distances to control the size and placement of shapes built within VRML's three-dimensional space. Currently, VRML only uses polygons to build the 3-D objects, however future releases are expected to include spline and NURB based objects. Geometric transformation such as scaling, rotation and translation is also possible in VRML. To create interactivity in the VRML world, a wiring route or path between two nodes is required. Once a route is built between two nodes, the first node can send messages to the second node. These messages are known as events and contain a value, similar to field values within nodes.

2.1 VRML Browser/Player
Similar to other software that needs a container program to play it, VRML has its own player to view the VRML models. This is similar to other media types, such as sounds and movies, where the Web browsers passes that file information to helper applications called plugins. These plugins are programs that enable you to view non-HTML information within the Web window. To view VRML documents, the user needs to get a VRML helper application or plug-in called a VRML player that works inside the browser. When the player reads a VRML file, it builds the world described in the file and places the model inside an interface within the browser window.

There are a number of VRML players that are available for both main browsers (Internet Explorer and Netscape Navigator). Some of the most common VRML browsers available are Silicon Graphics' CosmoPlayer (www.cosmosoftware.com), Intervista's World View (www.intervista.com), and Dimension X's Liquid Reality (www.blaxxun.com).

2.2 VRML Authoring Software
Due to the expected need for creating 3-D models quickly and efficiently, software developers have come out with authoring tools for VRML. Even though VRML files can be constructed and edited with any text editor, the files quickly become large and unmanageable using just a text editor. To assist in the designing of VRML worlds, there are a number of VRML authoring software available that enables the creation of VRML worlds to be much faster and simpler than using just a text editor. Among these are Cosmo Worlds, Homespace Builder, VR Creator and Site Pad. Most of these software programs provide advanced graphical tools for creating, editing, optimizing and packaging VRML content.

In addition to VRML editors, most CAD software programs support VRML as an export option because of the growing importance of having a user's 3D work published on the web[3]. However, one drawback of using the export option in CAD programs is the lack of

VRML code optimization. Thus CAD generated VRML files generally have too much detail and takes more polygons to describe the geometry then what is needed. The end result is a large file that causes long download times. It should also be noted that most CAD programs do not read or import VRML files.

In the future, Interactive 3D graphics will be embedded in word processors, spreadsheets, and presentation software. Currently Microsoft is working towards improving data visualization for PowerPoint, Word and Excel. Users have realized that there is a need for a 3D format that can serve the ever expanding Internet community. VRML format appears to be able to serve this purpose well.

2.3 VRML Limitations and Optimization
VRML is designed to work well when used with both very powerful computers and very inexpensive machines, allowing the VRML to trade off image or simulation quality for improved performance and increased hardware performance[4]. VRML worlds should also scale with network performances, from 14.4K modems that are common today to multigigabit connections that might become common in the future.

Similar to other file formats, VRML has it own share of limitations. One of the limitations is that the amount of polygons in the VRML dictates the rendering time. The more polygons present, the more CPU (Computer Processing Unit) time are needed to render the 3-D object. Simplicity is a design constraint, compromising details for faster rendering time. On the other hand, if the file size gets too large, a faster Internet connection speed will be needed.

As mentioned previously, there are some tradeoffs in performance versus contents of a VRML file. Therefore, optimization is an essential part of creating VRML worlds. Given existing limitation on bandwidths and rendering speed, any world, which isn't carefully optimized, may be too slow to capture the audience's interest [5]. Content must be balanced with the performance requirements to keep everything running at interactive speeds. Level of Detail (LOD) node can enclose different versions of a shape in varying levels of details. The LOD node is used to reduce the number of polygons visible at one time. For instance, if a level of detail node is used on a box object, when the user is far away from the object, the VRML browser would load up the model with less detail so that it does not need to render the extra details. This directly decreases the rendering time of the CPU, which then translates to faster movement in the VRML world. Other methods of optimization include, replacing complex surfaces with textures, inline code, collision nodes, and reducing the precision of floating point numbers to reduce file size and use of compression (gzip).

3. Applications

Due to the need for 3-D visualization, Web-based VRML can be used in almost all fields of study including art, business, engineering and sciences. The main benefit for the student or learner is the ability to view and explore a virtual environment that they can visit or enter. Examples range from working in a factory to exploring the inside of

bacteria. In short, if a picture is worth a thousand words then a VRML model is worth a thousand pictures. Not only is VRML a picture, but it is also dynamic 3–D environment that interacts with the user. However, VRML is not the only way to publish 3-D but it is one of the cheapest and easiest method. Three-dimensional models can also be published on the web using Java 3-D.

Most Computer-Aided-Design (CAD) developers realized the importance for engineers to publish their work on the web. For instance, the newly released Pro/ENGINEER 2000i from Parametric Technology Corp provides capabilities to publish designs on the Web, attach hyperlinks to components in an assembly, and view and access 3D assemblies from any Web browser. Though Java programs in commercial software are highly capable of publishing the actual model, it is not widely available to most engineers. The high cost of getting a commercial CAD program that can publish models to the web prevent most engineers from sharing their ideas on the web. The importance of publishing one's engineering work on the web, in addition to journals is to gain recognition and also share ideas with other engineers.

3.1 Applications in Manufacturing
A good example of VRML usage in engineering is the 3-D visualization of processes, machinery and robotics in the manufacturing field. Engineers can use VRML to display three-dimensional manufacturing data or models to managers so they could make better decision together. For instance, a group of students taking the capstone class could present to their sponsor the 3-D VRML model using any Internet capable computer in a conference room instead of having to meet in the CAD lab to demonstrate their model. The model can then be examined and determined as to whether the design expectations have been met. It is easier for mechanical and aerospace students to explain their design with a 3-D model rather than presenting 2-D drawings. Note that 2-D drawings are still important when the design is to be submitted to the machine shop.
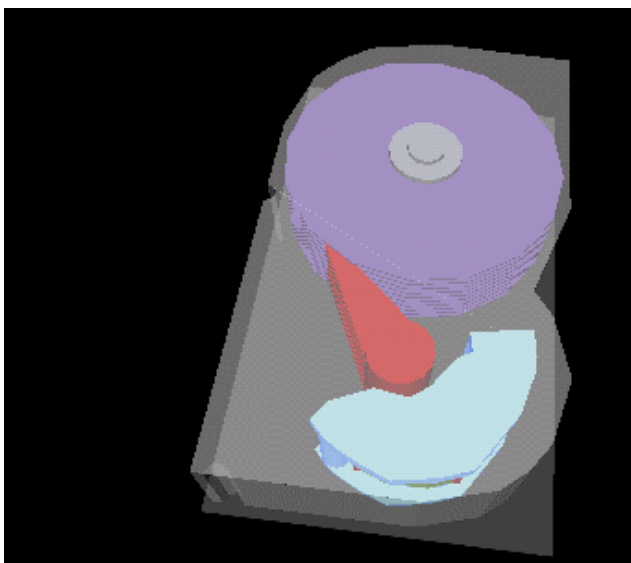
3.1.1 Engineering Education

Fig. 1 Hard Drive Design and Visualization

VRML worlds that are broadcast over the Internet have many potential uses in instructional and educational settings. VRML can be helpful in an engineering course because it can provide better flexibility in viewing data. Views can be customized for each application and animated. This makes learning easier and fun. For example, a 3-D VRML model could show the 3–D stresses of a beam under a loading. The student could examine, rotate and view it at different angles which makes learning the concept of beam theory

easier especially when it comes to showing the location of maximum or minimum stresses. Another good example that can illustrate the use of VRML in engineering education is the VRML mechanical catalog. An example of this can be found at the site http://www.evl.uic.edu/fred/cat_dev/vscript2/cat1_main.wrl. The catalog allows the viewer to see a mechanical part, explode the assembly, and link to the respective URLs that contains the parts specification. Another capability of VRML is its ability to view 3-D objects by altering the transparency. This can be effectively used to show different level of parts or how they fit together. For example, the user could set the transparency of the outside parts to 100 percent so that the inner components are viewable and how it works. Figure 1 shows a VRML model of a hard drive where the user can specify the height and width of case, number of disk, radius of disk and most importantly adjust the transparency with the slider.
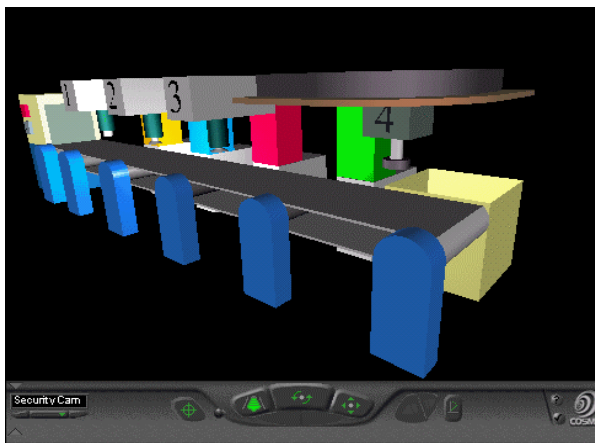

Fig. 2 VRML model of the potato packing line

One of the focuses of this paper is to introduce animated manufacturing processes. For example, a manufacturing process of packing potato chips allows the viewer to understand how each process works and how the end product is packaged. Generally students learn better when they are able to visualize it. Students can learn even better and have fun with the interactive machining process. Figure 2 depicts the fully operational VRML model when viewed in a browser. When the process button is on, a tin would appear and it would go through the first process of chip dispensing into the tin subsequently to the sealing of the tin, lid placement and moving the cans to the packing box.

A virtual machine is a software emulation of a real machine. A virtual machine has an instruction set, just like a physical machine. Frequently mechanical and aerospace students don't have enough exposure to the use of manufacturing equipment in their manufacturing class. By creating three dimensional machine and components; not only can the students rotate and examine the part from different angles but also operate or run the virtual model. By imparting the concept of each part of the machine, the students can easily pick up skills needed to enable them to design something that can be practically machined.

Within the VRML code, scripts and sensors can be used to detect the actions of the user. Also, interpolator nodes can be used to animate any object within the world, such as mechanical components or parts. The interactivity that can be added to a VRML world also includes the ability to change parameters while the user works with the object.

Another focus of this paper is to introduce the virtual lathe made in VRML, which illustrates the ability for a user to operate virtual equipment over the Internet. This lathe has interactivity built in it by using JavaScript and routing nodes and sensors and is shown in Fig. 3. Like a real physical machine, the virtual lathe can be instructed to perform certain tasks by pushing or touching buttons on the control panel.

Fig. 3 Interactive Virtual Lathe Modeled in VRML

The virtual lathe is useful to illustrate to students how products are machined and what are the processes involved. For instance, it is easier to illustrate in the class, material removal sequence efficiently. This lathe is really a simplified version of the actual lathe but it is sufficient enough to show how the lathe works. The large red and green buttons on the side of the lathe are used to start and stop the lathe chuck from spinning. The lathe has a control panel that pops up when the green button is clicked which has additional capabilities as seen in Fig. 3. The control panel consists of the indicator, two sliders and one reset button. The indicator on the monitor panel and the sliders are used to translate the movement of the table and tool. The numbers below the control panel shows the tool location.

3.1.2 Construction of the Virtual Lathe in VRML
The virtual lathe in Fig. 3, was modeled in Cosmo Worlds and includes JavaScript to facilitate user interaction. The final VRML model contained 1072 polygons and had a file size of 29 Kb. To further reduce the file size, the file was compressed into a 'gzip' file type that reduced the file to only 5 Kb. It should be noted that VRML players recognize 'gzip' files and automatically uncompresses the file when loaded into the player. Gzip can be done using any compression software that supports this file format. For this example, gzip is done automatically when the VRML world is published in Cosmo Worlds. This is certainly acceptable for downloading through the Internet, even with a home modem. The majority of polygons were due to the cylinders used to model the gear settings, drill and the chuck. It is for cosmetic purposes and can be taken off to reduce the file size even further. There are two types of objects in VRML. One consists of a customized shape node such as cone, box and cylinder. Basic parameters can be changed on this shape object such as the radius of the cone. The second object consists of points, lines and polygons. In other words, the object is created with the use of line, surfaces and points. Since it is created by points, lines and surfaces, it is allowable to change each single parameter of the entity, thereby giving much more flexibility to draw complex geometry

rather than using only the basic shapes. Cosmo Worlds refers to this type of object as PEP (Points, Lines and Polygons). The lathe motor is broken into a PEP object and some faces of the box are extruded out. All other parts of the lathe uses the basic shapes available in VRML.

To allow the user to interact with the lathe, touch sensors were placed on the sliders, indicators and lathe buttons. When the start button is touched, the sensor will activate the script and the time sensor. The script will take in the SFTime field value and activate the control panel that pops up. SFTime is a floating point value that gives the absolute time measured in seconds since 12:00 midnight, GMT, January 1,1970. In other words, it takes in the time when you activate the sensors and perform a job that the script defines. This time field value is typically used to start or stop animation. In addition, the input to the time sensor would activate the Orientation Interpolator, which in turn makes the chuck rotate. The Orientation Interpolator in VRML computes a rotation based on a list of key rotations specified in radians. Both touch and plane sensors are used to control the slider and the indicator for controlling the tool and table position in the X and Z-axis. The touch sensor's value is true when an object is touched it when the pointer is activated. The translation of the sliders and the indicator is routed to the script. The script takes in the field SFVec3F values and output it to the table and tool. The SFVec3F field is a 3-D floating- point vector that specifies the 3D position. The output values however are multiplied with a factor so that a small translation on the indicator results in a bigger translation change in the tool and table. Subsequently, the translation values of the tool will be sent back to the script, which takes in the value and output it to a string in a Text node. Since the model is drawn in meters, the script converts the units to meter. The Text node then displays the position change as the tool position is moved. Constraints have been set on the plane sensor and the position of the tool so that it would not overlap with the other objects. Using the if and then statements in the script allows a more realistic model for instance restrict the maximum movement of the machine table so that it does not go into the machine casing. This is done by setting the maximum distance to a specified maximum realistic distance. Sliders' translation and indicator's position is routed together through the script in order for the other to move accordingly when one of them is repositioned. The touch sensor on the reset button sends the value of the touchTime to the script. The script in turn set the X and Z position back to zero. Thereby setting all the parameters back to 0.

Once the control panel of the virtual lathe is activated, it stays in that position regardless of whether the user rotates the lathe or zooms out. The control panel transform is actually placed inside a collision node together with the proximity sensor. The field values of position_changed and orientation_changed from the proximity sensor are routed to the translation and rotation of the control panel's transform. The purpose of doing that is to allow the position_changed and orientation_changed fields to recalculate the vector each time the user moves around so that the control panel always stays on the upper left hand corner. The objective is to recalculate the fixed position of the control panel from the viewer whenever the viewer moves. The collision node is set so that the control panel transform does not collide with the lathe's transform. There is a switch node in the overall collision node. This is for turning the control panel on and off. When the touchTime on

the start button is sensed, the script would send a 0 value into the field whichChoice and it would display the control panel. The touchTime field is to obtain the time when the touch is detected and the whichChoice field activates the script. On the default however, the field value would be –1 so that it wouldn't display the control panel. Vice versa, the stop button when touched will send in a –1 value into the whichChoice field.

At present, when the lathe is turned on, an audio file is played to simulate the sound of an actual lathe. In VRML, sound is accessed through the use of the 'AudioClip' node that links to a sound source. Both WAV files and MIDI files can be used with VRML. WAV files are easy to use but can cause file size problems since they are not compressed. On the other hand MIDI files are not true digitized sound waves like WAVs, but equations used to reconstruct the sound. This allows MIDI files to be small, but does not accurately reproduced the actual sounds. In this virtual lathe a small WAV file size of 3K was used. To minimize the file size, a short sound was looped indefinitely until the virtual lathe is turn off. One advantage of using sound files in VRML is that it supports sound spatialization. Sound spatialization is a digital sound that appears to emit from a specific point in 3-D space. For instance when the user gets nearer to the sound source the sound appears to be louder or when the sound source is towards the right, the right speaker would sound louder than the left speaker.

As the user monitors the lathe, information about the system is written to the VRML world. This was done with a simple JavaScript that truncates the floating-point numbers and then writes them to a text field in the VRML world. The truncation is done with a JavaScript that takes in the floating-point numbers and converts it to text string. From the text string, only those digits that are needed are processed and output back to the text node.

Attempts have been made to create a Proto node in which the inner radius and other radius of a hollow cylinder can be changed. Proto node is a customize node that can be reusable. However the Proto node has not been integrated into the virtual lathe. It is possible to write a script that gives a warning whenever the tool cuts too much of the workpiece material. Further work can be done to change the speed of the chuck and display some animated sparks when the tool touches the workpiece.

3.1.3 Industrial Applications
The rise of Intranets – private network based on Internet, is promoting concurrent engineering, communication, and cross platform sharing of information especially between manufacturers, suppliers and customers. As a result, customers or clients can view the VRML product while it is in the designing stage and give feedback before it is manufactured.

Customers or clients too don't need to have the same CAD software to be able to view the VRML model. What they need is just a VRML browser. Furthermore, VRML parts are cheap and easy to develop compared to standardizing a CAD software for all the suppliers and manufacturers so that they can all view it. VRML is also a good

presentation tool for meetings or when proposing a prototype. It would make the proposal much more attractive.

Combined with Javascript or Java, operators could be trained using a virtual machine before using the real machine. Therefore saving training cost, machine cost, freeing up the real machine for the real work and ensuring the operators' fitness to operate the real machine.

Furthermore better visualization tools such as VRML can enable engineers to develop better manufacturing processes. Usually in a factory, the CAD model is not easily accessible to the manufacturing engineers; therefore they need some visualization tools to view how the end product should look like to help them in their job. Furthermore, license of the CAD software is usually limited in one company. Therefore preference would go to the R&D engineers first instead of the manufacturing engineers.

Instead of hiding all the information in many levels of queries, it is easier to publish the part and the VRML model in the Intranet so that all levels of workers could access it or password the site to allow only certain group of people to view it. Sometimes when the engineer can't remember the part number and could only remember how it looks like, he/she has to go through a lot of hassle to pull up the Bill of Material (BOM). On the other hand if he knows the part number but can't remember how it looks like, he/she can download the design drawings and determine which part it actually is. Therefore if the manufactured parts are link by some organized web pages, it would provide easier retrieval of information and accessibility through any computer in the factory.

4. Summary and Conclusions

In an effort to bring more visualization into design education, VRML has been shown to be a useful 3-D file format that can used on the Internet. The use of VRML as a tool in manufacturing and engineering education is beneficial to the engineering community since virtual environment makes learning fun for engineers and education. Most importantly, there is no constraint on the time and place for the users to view and interact with the virtual models. For instance, students can view and try out the VRML models outside their class-time. Further work can be done by engineers to enable a sharing of exported VRML design in the web where it would allow other engineers to study and comment about the designs. This in turn promotes concurrent engineering. Manufacturers of mechanical parts can maintain a VRML web site that shows 3-D VRML models and save cost from printing the part catalogs. On the other hand, engineers can examine the 3-D model of the parts before buying. The engineer's judgement is generally better with a 3-D model compared to a 2-D drawing in the catalog. In conclusion, VRML is not at it's full potential and could well develop to make engineering education a much more interesting experience.

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