INTEGRATING A VIRTUAL ENVIRONMENT AND A REAL MACHINING CELL TO REMOTELY ANALYZE THE MACHINING PROCESS

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Abstract. This paper presents a study which aims to integrate a virtual environment and a real machining cell based on video images status. The system allows the user to visualize real machining cell operations through a virtual machining cell environment in real time. Users can interact with the virtual model through an immersive multi-projection system. This system allows remote surveillance of the real machine and analysis of current machining operations as well as addition and integration of new 3D components.

Keywords: machining cell, virtual environment, CAVE

1. INTRODUCTION

Innovation is important for companies to be successful in the global market. According to Hernandez-Matias et al. (2008), high competitiveness leads to a continuous refinement of manufacturing processes. Additionally, it's well known that simulation is an effective way to refine a manufacturing process, identify production issues and avoid rework. Therefore, there is an increasing demand for tools which improve company's results and simulation tools are one of them.

Virtual Reality (VR) is considered one of the top technologies for simulation. The use of virtual reality simulation for analysis of manufacturing operations is increasing worldwide. In general, most simulation models use traditional computer interfaces with few options to make changes in real time (Dessouky et al. 2001). Furthermore, although many simulators offer the possibility of interaction, they can't put the user in an immersive 3-D representation of the simulated scenario (Pulugurtha et al. 2002). An immersive virtual reality system, like the CAVE-like systems, is one of the most advanced virtual reality tools and the most probable way for users to watch and interact with a virtual reality simulation.

The Multi-User Laboratory of Immersive Visualization (MLIV) of the University of São Paulo (USP) - located in São Carlos-SP - consists of a CAVE-like system which was used as an interface for the current research. Allied to the use of this immersive multi-projection system, an interactive system and a virtual environment of a real world machining cell were built, which permit several users to watch and interact with the model through simple and cheap devices. The system development has demonstrated that an interactive, three-dimensional display can, in some circumstances, add significant value to the remote surveillance process.

A CNC machine connection between a client and a remote server over the Internet is one of the possibilities of remote monitoring and analyzing a machining process. Nevertheless, some machines aren't prepared to send their data over a computer network, while others depend on proprietary software to perform data acquisition from their controllers. This paper presents a study which aims to integrate a virtual environment and a real machining cell based on video image status using only a low-cost camera (webcam). The images are processed locally and only the object position is sent over the network to update the virtual scene. This way it is possible to reconstruct the real scene in the 3D world with a low use of bandwidth.

Through a 3D virtual environment which reflects the real machining cell operations on-line, the user can evaluate the position of a cutting tool with more flexibility than through the use of regular surveillance cameras, since some visualization operations can be performed only in synthetic world, such as: look-around, walk-through and fly-through. This flexibility allows on-line inspection, monitoring, bottleneck identification, problem diagnosis, design and layout of the machining cell in real or almost real time, which help the shop-floor managers analyze the machining process.

The remainder of this paper is organized as follows. In Section 2, a background in immersive virtual environments is given, the immersive multi-projection system used in this study is described and the integration method proposed is explained. In Section 3 the results and discussion are carried out. Finally, Section 4 presents the conclusion and Section 5 addresses future development.

2. MATERIALS AND METHODS

The term Virtual Environment (VE) refers to a three-dimensional virtual space generated by computer graphics that provides multisensory and real-time interaction to users. Also called virtual worlds, these synthetic environments are characterized by three basic ideas: immersion, interaction and involvement (Morie, 1994). However, it is important to

note that it is not necessary that all of them coexist simultaneously, since not all VE are immersive (Leston, 1996). The visualization of a 3D scene in a conventional monitor, for example, is considered non-immersive.

In non-immersive VE, users are partially transported to a virtual world, through a projector or a monitor, but he predominantly continues feeling in the actual world. Although typical immersive systems are obtained with the use of head-mounted displays (video reproduction devices worn on the user's head) or CAVE systems (rooms in which the walls, ceiling and floor have real-time images projected upon them), the use of devices based on other human senses may introduce some degree of immersion in VE, including the monitors.

The idea of immersion is connected to the sensation of being inside the environment, that is, the user is involved with the application domain and has a sense of presence within the virtual world. The idea of interaction is connected to the computer's ability to detect the user's entry and instantly modify the virtual world and the actions on it. Moreover, the idea of involvement is driven by a person's level of motivation for involvement in a given activity.

While visual perception is our primary sense, other senses should also be encouraged to provide a full immersion such as hearing and touching. This can be achieved with automatic positioning of the person and the movements of the head, allied to the use of stereo sounds, and force feedback or tactile-feedback devices.

2.1. The immersive multi-projection system

Advances in scientific simulation rapidly led to the generation of multi-terabyte sized datasets of unprecedented spatial and temporal resolution. The interactive visualization resources these datasets demand overwhelm the display capabilities of the typical desktop system, both in terms of raw graphics processing power and display resolution. In order to address this issue, researchers have explored the possibility of combining multiple standard resolution projectors into a single system to increase total display resolution. Such multi-projector display systems are currently under development at a number of research labs. An example of these systems is the CAVE (CAVE Automatic Virtual Environment) virtual reality/scientific visualization system (Cruz-Neira, 1995).

The CAVE is a virtual reality interface whose abstract design consists of a room whose walls, ceiling and floor surround a viewer with projected images. The first CAVE system was developed at Electronic Visualization Laboratory at the University of Illinois in Chicago and presented at SIGGRAPH in 1992. Since then, both academic and non-academic institutions have combined multiple projectors to form a single unified display device based on CAVE.

The Multi-User Laboratory of Immersive Visualization (MLIV) of the University of São Paulo (USP) - located in São Carlos-SP - consists of a CAVE-like system which was used as an interface for the remote interactive surveillance. As this system is an essential part of this research, this section will describe the MLIV by means of its hardware and software constitution.

2.1.1 Hardware

The multi-projection system of the MLIV consists of three projection screens with dimensions: 3.2 x 2.4 meters (front wall), 2.4 x 2.4 meters (right wall) and 3.2 x 2.4 meters (floor) as shown in Figure 1.
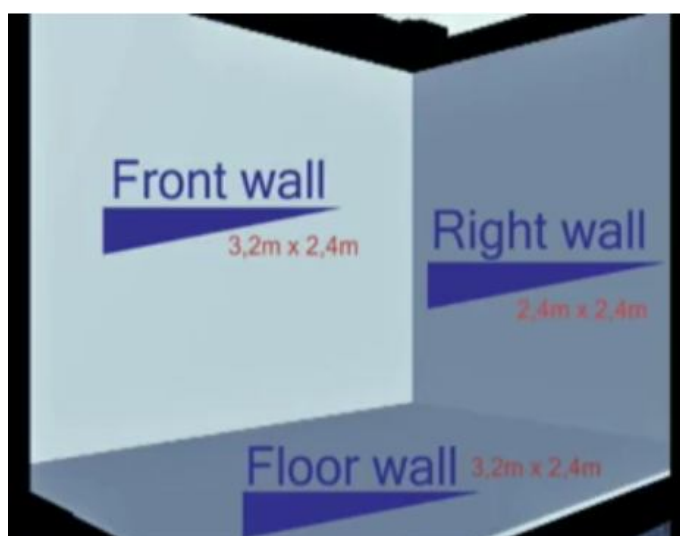

Figure 1 - Multi-projection walls dimension

For each projection screen there are two Christie DS +60/DW30/Matrix 3000 projectors, a computer with an Nvidia Quadro FX4500 video card and 4GB of RAM. Each computer is connected to the projectors through DVI cables. There

is a main computer where one can access or control the three other computers responsible for the screens. The mounted system allows the passive stereo visualization mode, where each projector is responsible for the image visualization of one of the user's eye.

The images for the right and left eyes are projected superimposed on the screen so that the use of stereoscopic glasses is necessary to obtain the feeling of immersion in any virtual environments. The stereoscopic glasses used in MLIV are INFITEC filters. This type of system allows the immersion of multiple users within a virtual environment, as long as each user wears a pair of stereoscopic glasses.

In multi-user virtual reality systems such as CAVE-like systems, it is recommended to use a surround sound system, so that all users can be immersed in the virtual environment both visually and with respect to the three-dimensional sound.

In the MLIV CAVE-like system, a 5.1 surround sound system with five speakers and a subwoofer was used, as shown in Figure 2. This kind of sound system enables the use of standard audio (stereo or mono) or 3D audio. Furthermore, some algorithms also allow the use of 5.1 surround sounds along with head tracking, creating a complete sound simulation (Soares, 2010).

Excess reverberation can confuse users as to the correct positioning of the sounds triggered, thus the CAVE room has carpet on the floor and/or lining the walls to eliminate inadequate reverberation.

The software used to create 6 channel audio sound files was Adobe Cool Edit 2.1. The file format used was the Windows WAVE PCM 16-bit 6-channel interleaved, a WAV file with capacity to record six channels of audio in a single file. OpenAL audio library, a VRJuggler compatible C++ library was used for multi-file playback during the implementation of virtual environments.
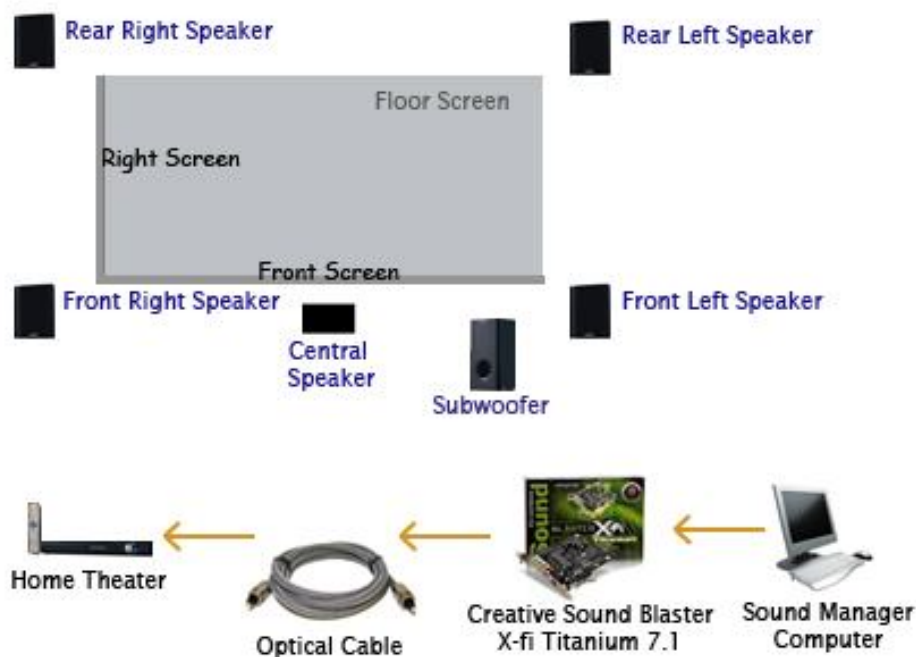

Figure 2 - 5.1 Top view of the CAVE-like surround sound system

2.1.2 Software

The operating system used on all computers of MLIV is Microsoft Windows XP Professional. For the modeling of virtual objects and scenes, Blender Software version 2.48a and OpenGL libraries for C++ were used, among others. The programming platform used is Visual C++ 2005 Express Edition along with VR Juggler 2.2.1 to enable the provision of virtual environments in the multi-projection system. The VR Juggler software allows the use of tools that facilitate and enhance the development of virtual worlds for multi-projection. To import the 3D models and create the scene graph, OpenSG 1.6.0 has been used. The relation between VR Juggler and OpensSG is shown in Figure 3.
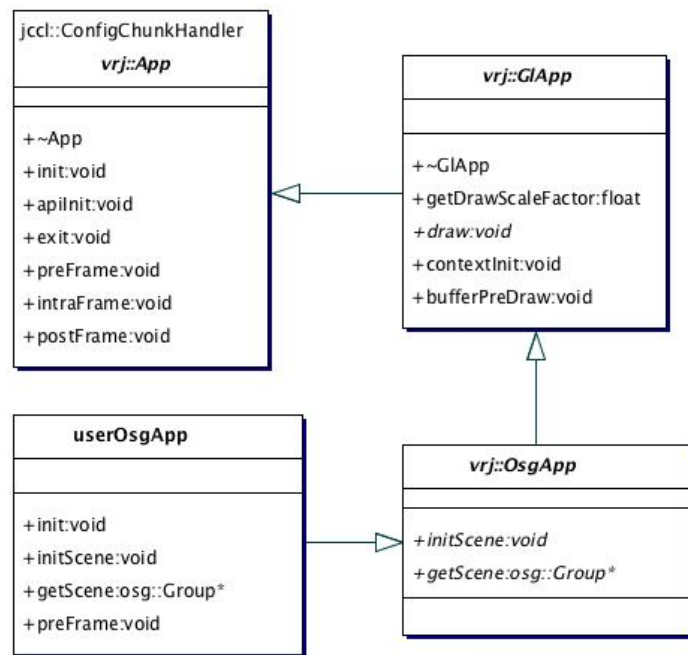
Figure 3 - VR Juggler and OpenSG classes' relation

Interaction is done through a simple webcam, a laser pen and the open C++ library called OpenCV. The webcam is positioned at the intersection of all the three walls, over the floor wall.

2.2 Integrating a Virtual Environment and a Real Machining Cell

The main purpose of this research is to provide a method of monitoring and analyzing the machining processes through the use of image status captured from a low-cost camera. The use of images instead of other data acquisition method is justified since some machines either do not offer network communication or demand the use of a proprietary software to remotely acquire its status. In order to overcome these limitations, this study intends to create a virtual environment which is updated with real data extracted from the machine status captured by one or more webcams.

Once the traffic of large images through the Internet would just increase the use of bandwidth, all image processing and data extraction is performed locally. Only the position of each real object is sent over the Internet so that the virtual scene can be remotely updated in real or almost real time.

The method used to extract the real object positions through the camera images is based on the use of colorful markers attached to movable parts that compound the real scene. These markers must have uniform colors and different colors from the real objects in the scene. Regular RGB colors (Red, Green and Blue) are better recognized by a simple webcam, so the colorful markers must be as similar as possible to these three colors. For example, it is better to attach a blue marker to an orange robot than to attach a red marker to an orange robot, because the marker color and its background color will be better recognized and separated by the system. The idea is to identify, through image processing, only the colored markers and ignore the rest. The position of the virtual objects will follow the markers size and position.

2.2.1 Tracking of Markers

The algorithm used to recognize the colorful markers attached to the objects is based on the method proposed by Okuma et al (2000):

1. The first step is to prepare a set of marker information that contains the color information and the known 3D positions in the world coordinate system;
2. The screen coordinates of the markers in the input images are acquired: all of the pixels in the frame buffer are scanned to extract marker pixels of a predefined color. Markers of known positions are extracted and tracked based on their color information;
3. Based on known 3D positions of the markers a mapping between the screen coordinates and the world coordinates is performed. The camera pose is expressed by a 4x4 transformation matrix that converts the

world coordinate system to the camera coordinate system. This matrix is called a model-view matrix. Among a model-view matrix (M), a position of a point in world coordinate (w) and its position in the camera coordinate (c), the Eq. (1) stands.

$$c = Mw \qquad\qquad\qquad\qquad (1)$$

2.3 Case Study

A virtual machining cell was modeled similar to a real one. For this study, only one movable part was tracked by a single camera which is capable to track the X and Y axes (left-right and bottom-up). Figure 4 shows a real and the virtual machining cell.
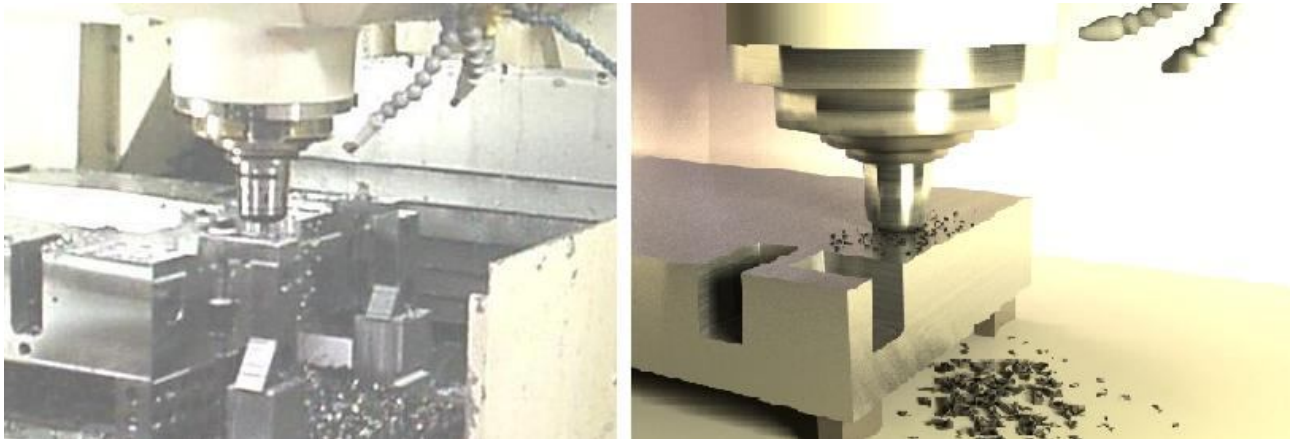

Figure 4 - A real and the virtual machining cell

It is possible to extend the system using two cams, one in front and the other above or aside the machining cell and two colorful markers tracking three axes (X,Y and Z).

The camera was positioned in front of the machining cell and connected to a notebook. One red marker was attached to the movable part. The webcam tracks the part's movements locally and sends the position information to the CAVE main computer through an Ethernet connection. The CAVE main computer receives the information through a C++ Server/Client socket communication. The information is sent through a buffer, where the position values are stored. There is a thread function in the notebook holding the webcam which allows the system to constantly send information. The buffer size increases proportionally to the amount of marked movable parts.

There is another thread function in the CAVE main computer that constantly monitors the defined computer network port to get position data. The main computer updates the model position information right after it receives position data. Hence, the synchronization speed is limited only by the network speed, since threads allows parallel processing in the CPU.

Users can interact with the scene, by changing the point of view, or by stopping the model update to analyze the operation in off line mode. They can move around or zoom the virtual scene by holding a laser pen which has its light tracked by another webcam inside the CAVE, as described above.

3. RESULTS AND DISCUSSION

The developed system displays the actual position of a particular cutting tool or robotic arm of a machining cell through a virtual 3D model previously created with the same characteristics as the real model. The display can be performed from any angle or position of the three-dimensional space, approaching or moving away without degrading the resolution of the scene, performing with low bandwidth.

The developed system shows that it is possible to make remote surveillance of machining cells even for machines which are not ready to communicate with computers. It is done through visual recognition, with a simple and cheap webcam.

The created system can be used to robotic or non-robotic machining cells, but in its initial stage, when used to robotic machining cells, the remote surveillance doesn't compute joint angles of the robots' arms. The developed virtual model has its arms' positions individually updated. It just recognizes the real robot arm position's changes through the position and size of the colored marker and updates the virtual robot arms position. Working with a scene graph system, all virtual objects, including the robot arms, work in a hierarchy system. In other words, if the base of the robot is moved, all its arms move too.

There's no synchronization flag in communication, because it could decrease the system synchronization speed between the real and the virtual worlds. The system always updates the virtual robot position with the last data acquired. Lost data due to network problems may cause the virtual model to move roughly. The system performance and synchronization works well for an Ethernet connection but it can be considerably decreased through the use of an Internet connection.

There must be no obstruction between the machining cell and the webcam and the lights of the area of the machining cell must always be turned on to improve webcam data.

The aim of this system is to permit not only surveillance, but also simulation of the machining cell properties and characteristics. With a common surveillance camera it is impossible to change anything, because there is no virtual world, just successive images. The system also allows users to stop the on line acquisition of data and change some parameters of the virtual world to analyze an off line simulation. It can be considered a decision-making system.

This system was not created originally for machining cells. It is a variation from other virtual reality tracking devices which were based in colorful markers attachment and webcam capturing. There are some challenges to be overcome for its use in machining cells, like the tool path updating the parts and the closed machining devices where it is difficult to install a camera.

4. CONCLUSION

In this paper, a method to integrate a virtual environment and a real machining cell was created with cheap devices and by using open-source libraries, which reduce the project costs. It was also verified that a system like this can improve the means of surveillance, simulation and control of machining processes more efficiently than common simulation systems or normal surveillance cameras systems. The routes traveled by workers within companies can also be reduced.

The system development has demonstrated that an interactive and immersive system can add significant value to the control, simulation and surveillance process, such as adding new constraints to simulate an off line operation and watch it closely as well as to keep all simulation acquired data for decision-making. A CAVE system also provides a multi-user access to virtual worlds.

5. FUTURE DEVELOPMENT

The main goal of this work is to achieve a complete integration of the virtual environment and the real machining cell, allowing users to control the real machine through interactions made in the virtual world. For now users can analyze the 3D model in real time or manipulate the virtual robots and environment parameters in off-line mode to create a simulation, but the system still isn't able to send data to the real machining cell or to update the tool path over the part. Thus, the next step of this work is to send data from the virtual environment to the real machining cell, by using machines equipped with network cards and to add 3D parts which could be updated by the 3D tool.

6. ACKNOWLEDGEMENTS

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