Measuring the Student's Success Rate Using a Constraint Based Multi-modal Virtual Assembly Environment

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Abstract. Personnel Training is considered as the most important prerequisite in the assembly operations of any kind of equipment/apparatus ranging from simple nut-bolt assembly to complex equipment (e.g., aircraft engine) assembly. This paper presents a novel Virtual Reality Training System (VRTS) for the constraint based assembly of a 3phase step down transformer. The ARToolKit [1] markers are used for interaction with the VRTS. The system improves the technical skills of students in the real assembly environment. The analysis shows that the average success rate of untrained students is 35.7% while that of trained students increased to 81.5%.

Keyword: Virtual assembly environment

1 Introduction

Virtual Reality (VR) technology appears to be the most dominant learning tool due to its distinctive scientific nature which can be used to model real or non-real situations by using artificial, extremely interactive 3 dimensional (3D) worlds [2]. Virtual reality learning environment are more useful than traditional blackboard teaching methodology where knowledge acquisition takes place due to the exchange of technical interactions with other people or systems. The use of VR in education is a great branch in teaching techniques with different forms such as virtual teaching and training, virtual labs, and virtual schools after multimedia, computer, and cyberspace [3]. One of the most critical cause of the limited use of VR in school education is the unaffordable cost [4] [5]. The cost of availability, establishment, and maintenance of highly immersive systems and related devices prevent the large scale use of this technology [6]. Low level instruction design of virtual teaching environments is another concern [5] [7] [8].

In developing countries engineering universities and polytechnic institutes are following traditional teaching methodology. In traditional techniques, teachers follow textbooks, chalk and board, and 2D drawings for teaching. These techniques fail to represent the real world phenomena's and facts. Furthermore there is a lack of student's interest in these teaching techniques.

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This paper addresses the development of a desktop based 3D Virtual Reality Training System (VRTS) for students of polytechnic institutes/colleges. This system guides students in the assembly of a 3Phase step-down power transformer. VRTS is a multi-modal user friendly 3D virtual environment that allows users to improve their learning process in an interactive manner with reasonably low cost. The interaction includes free navigation, object selection and manipulation in the virtual environment. This interaction is achieved through ARToolKit markers based on its visibility and movement. During interaction with the system the user is given multi-modal (Audio-Textual) information about a particular object such as its name, properties and functions. The objectives of the development of VRTS are the following:

- To study the effect of VRTS on students' learning of the theoretical aspects of technical education.
- The effect of VRTS in technical skills acquisition.
- The applicability of skills acquired through VRTS in real situation.

The rest of the paper is organized as: section 2 describes related work, section 3 presents VRTS, section 4 presents experiments and evaluation and section 5 describes result analysis. Finally in section 6 conclusion and future work is described.

2 Related Work

Immersive virtual reality technology is widely in use since 1960. "Sinsorama" was the first single user console system used in entertainment to capture spectators' attention. It also had the ability to use different human senses to provide the illusion of reality [9]. The use of VR in teaching and training began in 1980 [10]. In 1990's the scope of VR extended to educational projects such as Science Space, Safety World, Global Change, Virtual Gorilla Exhibit, Atom World, and Cell Biology [11]. Currently the use of VR in education is an active research area.

Ng et al. [12] have developed a virtual environment which helps users in cable routing and designing in electro-mechanical products. Head Mounted Display (HMD) was used for display and 3D mouse for interaction. The system is immersive in nature, but the high cost of HMD and 3D mouse limits its applicability in education. Angelov et al. [13] have presented a computer generated 3D virtual training system. The system was used for training and learning about power system operation to its workers. A 2D Mouse is used for interaction with no 3D navigation in the environment.

Wang et al. [14] have made a math learning virtual environment system which helps students to understand mathematical concepts. Menus and 2D buttons are used for interaction with environment. Here 2D mouse and keyboard are used for interaction. Pasqualotti et al. [15] developed mathematical representations for modeling buildings and virtual city. The system uses 2D mouse for interaction and there is a lack of free navigation in the environment.

Real Time Relativity (RTR) presented by Savage et al. [16] is a 3D simulation software for physics that provides interactive game-based experience. There is no direct interaction with objects. Kaufmann et al. [17] designed the PhysicsPlayground, an Augmented Reality application. It was a real time 3D virtual environment for physics experiments in the area of mechanics. The system used costly HMD for display, a wireless pen and a Personal Interaction Panel (PIP) for interaction. Dede et al. [18] have developed an immersive 3D virtual environment for physics education. The environment contains virtual objects and students can perform experiments on these objects. This system used (HMD) for display, 3Ball or stylus for interaction which makes the environment highly expensive. Loftin et al. [19] developed a physics based virtual laboratory where students could observe the virtual environment as well as the virtual object's properties. The system also used a head mounted color stereoscopic Silicon Graphics 4DD20VGX display, a 3D auditory system, a hand gestures obtaining system (hand glove) and a Polhemus (magnetic position and orientation system) for observing user eye's direction, head and hand position. The use of specialized devices makes the system complex, costly and unaffordable in real situations.

Virtual Radioactivity Laboratory (VRT) developed by Crosier et al. [20] for teaching the radioactivity in secondary school level. A comparison is also made between VR with traditional teaching methodology. The system used 2D mouse to perform different tasks. Zhang et al. [21] designed a multisensory feedback Virtual Assembly Environment (VAE), in order to assess the user efficiency, satisfaction and consistency. The system used Trimension's V-Desk 6, highly immersive L-shaped workbench, shutter glasses and infrared emitter, and Wand for interaction. The system can't be adopted in education due its high cost and complex nature. Yao et al. [22] presented an immersive virtual assembly planning and training system (I-VAPTS) in order to train and guide workers in a pump assembly process. Data glove and 3D mouse were used for interaction and HMD for display. The system cost was very high. According to Bryson [23], the complications associated with glove devices are imprecise measurements and need of standard gestural lexis.

Dunne et al. [24] presented the Pulse!! The Virtual Clinical Learning Lab for teaching and training in medical education. Using mouse and keyboard user could navigate in the environment. The environment was 3D but used 2D mouse and keyboard for interaction. The system could provide only textual information about the patient. Virtual Body Structures-Auxiliary Teaching System (VBS-ATS) designed by Huang et al. [25] is an interactive Web-based 3D system for teaching human physiology in medical. It provides two versions i.e. desktop for single user and projection-based VR for multiple users. User could navigate in the environment, rotate, and zoom in and out the objects. A 3D ear model of the central and inside of the ear is presented by Nicholson et al. [26]. The model is 3D in nature but interaction with it is carried out using the 2D mouse. There is no interaction with the individual parts of the ear. The system gives only the textual information to the user.

Mikropoulos et al. [27] presented the creation and assessment of 3D biological virtual learning environment. Here traditional 2D Mouse is used for interaction.

In Shima et al. [28] 3D Webmaster software (3DWS) is used for the development of Virtual Reality Biology Simulations (VRBS) program. The system is used to educate middle school students. The VRBS studies the structure and working of eye. Here keyboard is the only way of interaction. Bakas et al. [29] created a learning environment to educate the students about the universe and planets. This system doesn't support 3D interaction with objects, all is made through mouse and menus.

The devices used for interaction with these systems have many problems such as cost, availability, weight and size, need of electric charge, cabling and space constraints. Also most of the existing systems are not the virtual worlds but the simulation software. This paper presents a realistic 3D virtual environment called VRTS that uses ARToolKit marker for interaction. The ARToolKit markers are printed patterns (see Fig. 1) that can work as low cost, flexible and real-time positional and orientation input device.

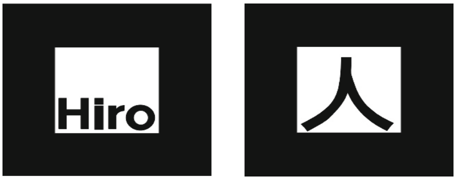

Fig. 1. ARToolKit markers' patterns

Marker has many advantages, such as tracking in 3D space, fast detection, wireless nature, can be used anywhere and need not be built into objects, wide range of movements and styles of interactions, no hardware cost, easy calibration, and supported by specific software [30].

3 Virtual Reality Training System

We have developed a 3D Virtual Reality Training System (VRTS). It is a desktop based virtual environment that is used to train students in assembly of 3phase step-down transformer. The VRTS is a room like structure and contains all 3D components of the transformer as shown in Fig. 2. These component are designed in 3d studio max and loaded and placed in the virtual environment. The high quality of these models increases the realism of the environment. Just like a real environment the user can navigate, select and manipulate the objects. Whenever a user selects an object he/she is provided various audio/visual information about that object i.e. name, properties and function of the object. Interaction with VRTS is made via the ARToolKit [9] markers which are printed patterns. These markers provide 6 degree of freedom.

3.1 Software Architecture of VRTS

The complete model of the system is shown in Fig. 3. This model represents the working mechanism of VRTS, and consists of the following principle modules.

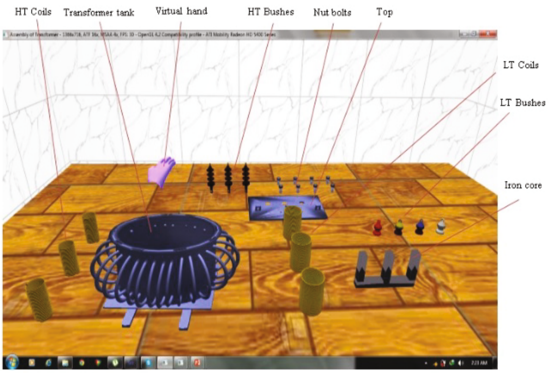

Fig. 2. Overview of the VRTS environment

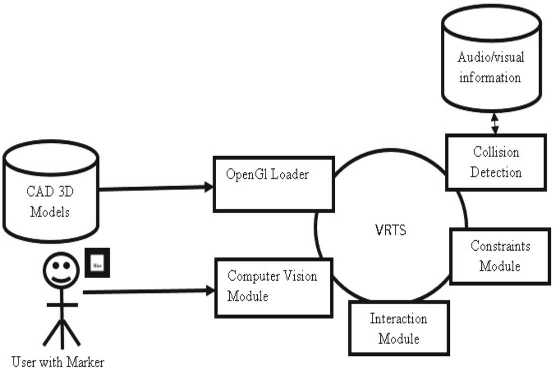

Fig. 3. Software architecture of VRTS

CAD 3D MODELS. The whole environment and all the parts of 3 phase step down transformer were first designed in 3D Studio Max 2009 package. These high quality objects were then translated to .obj file format along with color, material and texture information. The .obj file is then exported to OpenGl Loader software.

OpenGl Loader. This module is used to translate the .obj file into the VR environment. It places all the objects at specific positions in the VR environment.

Computer Vision Module (CVM). In order to make the VRTS system simple, realistic, and reduce its cost and complexity so that it can easily be adopted and used in many organization, we use computer vision based interaction system. This system has three main components: (i) ARToolKit markers (ii) ARToolKit library and (iii) a video camera. ARToolKit markers are special black and white markers printed on a paper that can be detected by a normal camera. The algorithm developed using ARToolKit library is responsible for analyzing the input stream taken by the video camera to detect the marker. Once the marker is detected, its position and orientation is estimated and then passed to the main VRTS module.

- 3D Pointer Mapping The 3D pointer is a virtual hand in the virtual environment which represents the presence of the user and is used for interaction with the VE (see Fig. 2). The physical pose of the marker in the real environment is mapped into the pose of the 3D pointer in the VE.

The User Interaction Module (UIM). UIM controls different operations in the virtual environment. It allows the 3D pointer (virtual hand) to navigate and interact with virtual environment. It controls the collision detection of virtual hand with objects, inter-object collision detection, object selection, and manipulation in the virtual environment.

- Navigation
  The user (represented by the virtual hand) can move (navigate) freely in all directions in the VR environment. The virtual hand is mapped with the marker, whenever user moves the Marker using his hand in the real environment, the virtual hand follows its motion in the virtual environment dynamically in real time. The camera also moves along with the virtual hand in the virtual environment.

- Selection and Manipulation Module
  Selection and manipulation are the most important operations in any virtual environment. The object is first selected by the virtual hand in order to perform some manipulation operations. The manipulation may consist of making some change in the behavior of the object e.g. changing the position of the object. ARToolKit marker is used for navigation, identification and selection of objects in the virtual environment. The virtual hand follows the movement of the real world marker. A single marker is simply used for the free navigation and identification of objects in the virtual environment(Fig. 4 (a)). If an object collides/intersects with the virtual hand while the user has a single visible marker, the audio/visual information related to that object are provided. If the second maker is also made visible to the camera and the virtual hand collides/intersects with an object, then the virtual hand picks/grabs that object (see Fig. 4 (b)). So in this way user can select, move, and rotate the object dynamically. To release the object, simply make the second marker invisible to camera. The Fig. 5 shows the algorithm for interaction using the markers.

Collision Detection. Collision detection is the most important issue in complex virtual assembly environments. Different types of techniques are used for collision detection. VRTS measures collision by calculating the distance between the centers of objects. The system performs different actions when the collision occurs in the virtual environment. If the virtual hand collides with an object, the audio/visual information related to the object is provided by the system or

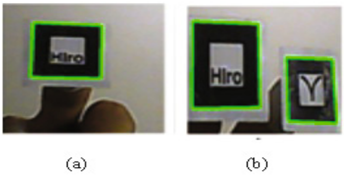

Fig. 4. Interaction via ARToolKit markers (a) Single marker (b) Two markers both visible

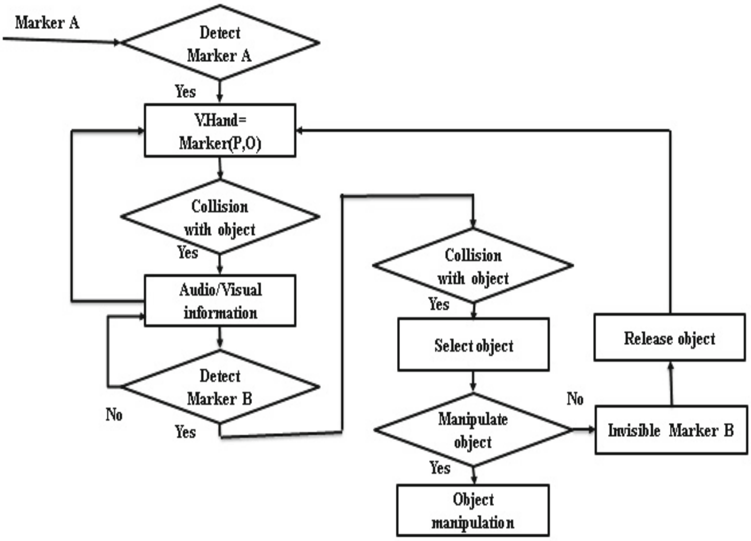

Fig. 5. Flow diagram for object selection and manipulation using markers

the object is selected. If a selected object collides with any other object in the environment, the object blocks moving further.

Audio and Visual Information. The system provides audio/visual information as cognitive aids to the user. The objective of using audio/visual information is to enhance the user learning about the system and the objects. When the virtual hand touches an object in the virtual environment, the object related information both in audio/textual forms are provided to the user (see Fig. 6). These information are stored in audio/textual databases.

4 Experiments and Evaluation

In order to investigate the effects of using VRTS on students learning, we performed subjective evaluation.

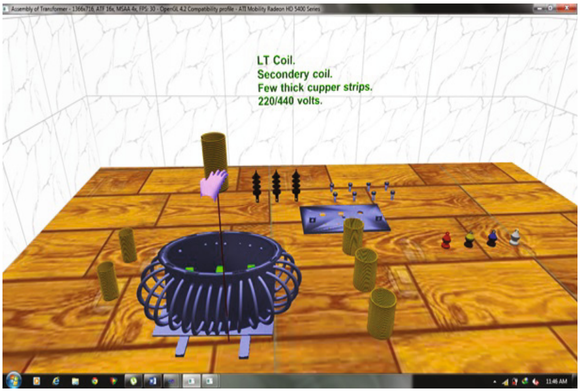

Fig. 6. Textual information of the selected object

4.1 Protocol and Task

For VRTS evaluation 40 students participated in the experiments. They were the 3rd year students of electrical diploma for associate engineers of a polytechnic college. They were in the same class and had ages from 19 to 22 years. The 3phase step down transformer was included in their course. They were taught using the traditional classroom method by the same teacher. These students were divided into two groups (i.e. G1, G2) each containing 20 participants. The students in G1 used the VRTS while those in G2 did not. As all the participants had no prior experience of VR systems, therefore, they were briefed about the use of the VRTS. For example, they were taught that how they will navigate in the environments. Similarly, they were also guided about the selection and manipulation of objects. Then each participant was asked to work in the VRTS. They had to assemble the transformer (see Fig. 7. a user during the experiment using VRTS). Each participant filled a questionnaire after getting experience in VRTS. Then both G1 and G2 were taken to a workshop where they had to perform the assembly of the 3phase transformer. Here the data of the students performance were collected again through a questionnaire.

5 Result Analysis

In this section we present the analysis of the questionnaire filled by students in G1 (group 1). There were four questions in this questionnaire. The objective of these questions was to evaluate the following aspects of VRTS:

- The role of VRTS in technical skills learning.
- Realism of the system.
- Ease of interaction.
- Its role in students confidence building in real situations.

The students had to answer these questions on a scale of 1 to 5. Where 1= low and 5 = very high level. The analysis of these responses is given below.

Fig. 7. A user during the experiment using VRTS

The first questions was related to realism for which 85% students selected the highest level (see Fig. 8).The next question which was related to the easiness of interaction in VRTS which got the 60% vote for the highest option (see Fig. 9). Similarly, 80% students selected the highest level for confidence (they got using VRTS) of VRTS, in technical education (see Fig. 10). The second part of the questionnaire was filled by both the groups (G1 and G2) during their session in the workshop (real situation). The data recorded in the second section were consist of their ability to perform the assembly task in the real environment. Comparing the VRTS trained group (G1) with untrained group (G2) we observed a great difference in their success rate graph (see Fig. 11). Here the mean learning score of G1 is 81.5% while that of G2 is only 35.75%.

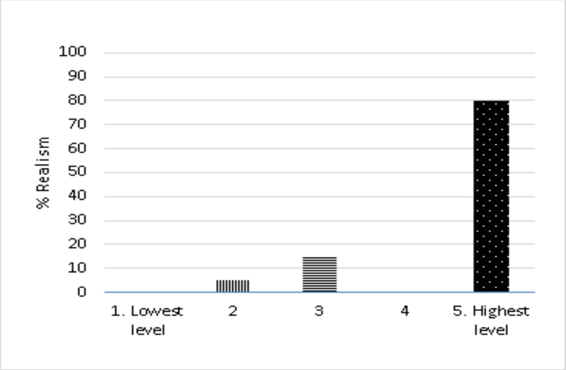

Fig. 8. Realism in VRTS

The result shows that the VRTS system is more helpful in students learning, confidence building, and improving their practical skills if it is employed in technical colleges as a supplement with the traditional teaching methodology.

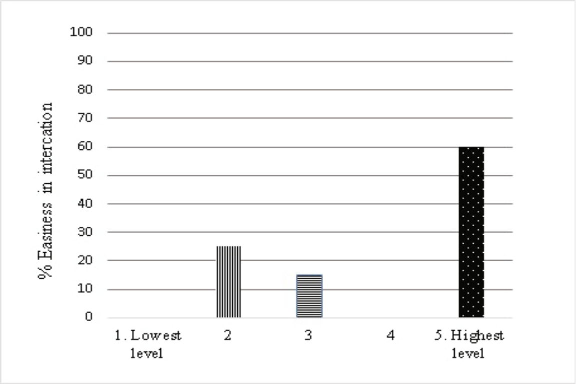

Fig. 9. Easiness in interaction

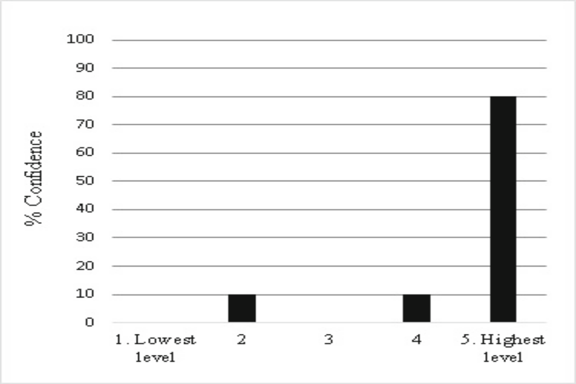

Fig. 10. Confidence building in VRTS

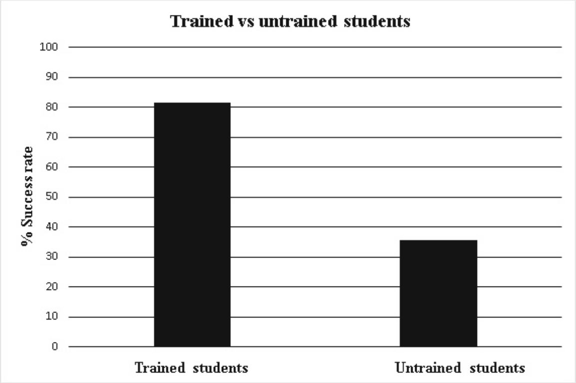

Fig. 11. Comparison of trained vs. untrained students

6 Conclusion and Future Work

In this paper we presented a novel learning system called Virtual Reality Training System (VRTS) for polytechnic colleges students in assembling a 3 phase transformer. VRTS is a Virtual Reality environment where we visualized the 3 phase transformer parts through 3D objects. The user could easily interact with VRTS through fiducial markers. The audio visual information about each object/part of transformer were given to its users. The system improved the practical skills of students in technical education. The analysis showed that the average success rate of untrained users is 35.75% while that of trained (using VRTS) students is 81.5%.

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