



The effect of Constraint based Multi-modal Virtual Assembly on Student's Learning

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**Abstract:** In this article we propose Virtual Reality Training System (VRTS), a computer generated environment for assembly. VRTS provides training to students to assemble a three phase step down transformer on one hand and renders multimodal information about objects that enhances students' theoretical knowledge on the other hand. The system is cost effective, does not need complex set up and its implementation in real educational environments is easy. Low cost ARToolkit markers are utilized to have real time interaction. The analysis reveals that mean learning of students who got training in VRTS students is 81.5% as compared to 35.75% of those who did not get training in VRTS. Similarly experimental results show that students who used VRTS are more confident in performing the same task in real world as compared to students who did not received training through VRTS.

**Keywords:** Virtual Assembly Environment, Multi-Modality, Constraint Based Assembly, Virtual Environment

1. **INTRODUCTION**

Practical and hands on experience is one of the most important requirements of knowledge acquisition in theoretical as well in technical education. It is essential for building students' concepts and consolidation of their mental model about a certain phenomenon. To carry out practical work laboratories are needed but different issues such as cost, space constraints, availability, and need of up to date technology limits its large scale use in school education. The recent progress in 3D graphics, computational capability of personal computers and the advent of cost effective trackers have enabled Virtual Environments (VEs) to replace or at least complement the real world laboratories. VEs are very flexible where repetitive tasks can be performed without any cost or danger. Similarly users' tasks performance data can be easily captured and analyzed using virtual environments.

Some work has already been done in various fields of education like chemistry and physics (Kaufmann and Meyer 2008, Savage *et al.* 2009), engineering (Messner *et al.* 2003, Sampaio *et al.* 2006, Schofield 2012), biology (Mikropoulos *et al.* 2003, Minogue *et al.* 2006), and math's (Pasqualotti and Freitas 2002, Wang *et al.* 2009). Majority of these environments are two dimensional using control boxes and menus for interaction that have less resemblance with real world tasks. In contrast some environments are three dimensional which are realistic and provide more user immersion but their associated cost, availability, and need of experts for maintenance limit their wide spread use in educational institutes (Merchant *et al.* 2014). Most of the researchers proposed desktop based VR systems in school education because of their inexpensive nature (Mikropoulos and Natsis 2011).

In this paper we present a desktop based 3D virtual reality training system for training students of polytechnic institutions. The system trains students in the assembly of a transformer. VRTS permits to increase theoretical and technical learning of students, improve their confidence along with success in real situation. In section two we describe related work, section three discusses VRTS, and section 4 elaborates experimentation, evaluation and result analysis. At the end in section five conclusion is presented.

2. **RELATED WORK**

Now-a-days active research is going on to deploy virtual reality systems in the field of education. (Ng *et al.* 2000) based on their research proposed/created a VE that trains users in cable routing and designing in electromechanical products (Ng *et al.* 2000). The system is immersive but the expensive Head Mounted Display and the use of 3D mouse restricts its applicability in education. Angelov *et al.* (Angelov and Styczynski 2007) have created a synthetic 3D world for training workers about power system operations. Virtual Reality Interactive Learning Environment (ViRILE) was designed to train students of chemical engineering about the working of a polymerization plant (Schofield 2012). For interaction, the system uses menus and controls through mouse and keyboard making it less realistic. The simulation of the building of a wall was presented in (Sampaio *et al.* 2006). The system was unrealistic because of the 2D interaction.

Similarly virtual environments, for teaching planetary concepts such as the phenomena of Earth-Sun movements, day-night cycle and seasons change have been developed (Chen *et al.* 2007, Bakas and Mikropoulos 2003, Gazit *et al.* 2006). Interaction with

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these VEs is made using mouse and keyboard making the systems not much realistic. Virtual Geometry Learning System (VGLS) allows learners to acquire knowledge about the composition, shape, motion change, and folding and unfolding of basic geometric objects (Bakas and Mikropoulos 2003). A desktop based 3D virtual chemistry laboratory (VCL) for intermediate level chemistry experiments was presented by (Ali *et al.*, 2014). The VCL contains virtual chemicals and related apparatuses to perform certain experiments. Interaction with the environment is made using Wiimote which is relatively a costly device. Similarly Model ChemLab is also a VE for the simulation of chemical reactions. Menus and dialogue boxes were used for interaction with objects in the environment due to which the system is less realistic. To analyze the effect of VEs on students understanding regarding the structure and function of animal cell, a desktop based semi-immersive environment was designed by (Minogue *et al.* 2006).

The Quantum Atom, an Educational VE, to visualize various states of hydrogen atom was developed by (Kontogeorgiou *et al.* 2008) but did not allow direct interaction with objects. Real Time Relativity (RTR) presented by (Savage *et al.* 2009) is a 3D simulation software for physics that provides interactive game-based experience. Similarly Physics Playground, an Augmented Reality application for physics experiments in the field of mechanics (Kaufmann and Meyer 2008). Another work on physics education is that of (Dede *et al.* 1999) and (Bowen *et al.* 1993). The environment possesses synthetic objects permitting the students to carry out interactions with these objects. The use of Head Mounted Display and other 3D trackers make the environment expensive. Virtual Assembly Environment (VAE), was designed by (Zhang *et al.* 2007) 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. An Immersive Virtual Planning and Training System (I-VAPTS) was designed for training and guiding workers in a pump assembly process (Yao *et al.* 2006). Dataglove and three dimensional mouse were utilized for interaction and Head Mounted Display for visualization.



Fig. 1. Samples of markers used for interaction

The interfaces, interaction techniques or the whole system as described above have so many issues. For

example some of them are very cumbersome with large size and cabling and requires lots of power for operation. Similarly some of these systems are very expensive or even not easily available in the market. In addition majority of the state-of-art systems provide simple simulation but lacks interactivity.

### 3. THE PROPOSED SYSTEM

In this section we are going to present in detail the proposed VRTS which actually a desktop type three dimensional virtual environment that we developed for the students of polytechnic institutions to carry out their practical work of power transformer assembly. The VRTS is actually a room where every part of the transformer such as tank, iron-core, coils, bushes and bolts have been loaded using OpenGL loader and placed at some specific locations in the environment (as shown in Fig.2). We have used 3D Studio Max for designing the transformer parts with high quality due to which they are very realistic. In addition the VRTS provides a very natural and intuitive way of interaction using ARToolkit markers which are special black and white landmarks. These markers are very cost effective and have six degree of freedom.

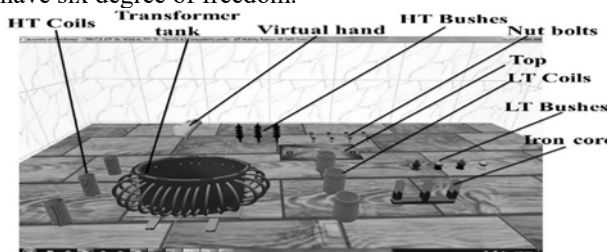


Fig. 2. Screen shot of VRTS environment

#### 3.1 VRTS architecture

The architecture of VRTS is shown in Fig.3 which depicts its various modules and the way it works.

##### 3.1.1 CAD 3D Models

To design the components of transformer, we used a designing tool called 3D Studio Max 2009, later on the designed components were converted into a format (i.e .obj) suitable for OpenGL loader. The new format also included other details such as color, material and texture information. The OpenGL loader is then used to load the .obj file into the VE.

##### 3.1.2 OpenGL Loader

The OpenGL loader is responsible to load the .obj file of each object into the virtual environment and put them at their defined locations.

##### 3.1.3 Computer Vision Module (CVM)

This module (CVM) is responsible for interaction with VRTS which is composed of 3 parts: (i) ARToolkit markers (ii) ARToolkit library and (iii) a video camera. An ARToolkit marker is square in shape having black borders with interior white region. It is easily detected by video cameras that use visible light when printed on paper. For marker detection in the video stream the

program developed with the help of AR Toolit Library is used. After the detection of a marker, position and orientation are calculated which is given to the core module of VRTS in the next.

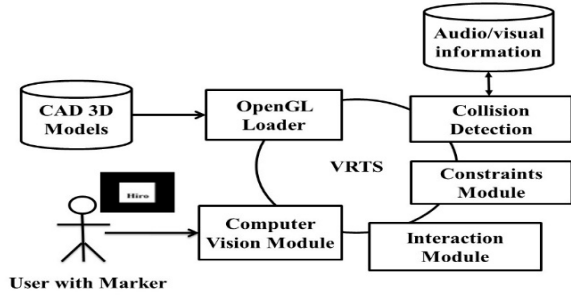


Fig. 3. Illustration of the various modules of VRTS

3.1.4 Module for User Interaction (MUI)

MUI is responsible to control lots of operations such as navigation, detection of collision, selection and manipulation in the VE.

The VRTS contains a virtual hand that represents user in environment. Movements of virtual hand along x, y and z axes are controlled through movement ARToolkit marker in the real world. Whenever user wants to move the virtual hand to a certain position/place in virtual environment he/she simply moves the marker in that specific direction.

For navigation, selection and manipulation in VRTS, we make use of ARToolKit markers. The virtual hand follows the movement of the real world marker. If only navigation or object identification is desired then a single marker is used (Fig.4 (a)). Whenever there is collision between an object and the virtual hand and a single marker is visible, the audio/visual information corresponding to the object is given to the user as feedback. When 2<sup>nd</sup> marker becomes visible to the camera and there exists collision between the virtual and an object, the object is attached to virtual hand and follows its movements (see Fig.4 (b)).

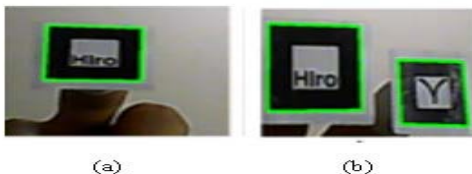


Fig. 4. Illustration of markers for interaction (a) One marker visibility (b) Two markers visibility

The invisibility of the 2<sup>nd</sup> marker will cause the release of object.

3.1.5 Collision detection

Collision detection is one of the important challenges in complex virtual assembly environments for which various algorithms are used. In VRTS the system computes the distance between the centers of virtual hand (VH) and other objects. If this distance

becomes less than the specified threshold K then collision is detected (see in Equation (3)).

$$|C_i(x, y, z) - C_j(x, y, z)| \leq K_{i,j}(x, y, z), \forall i, j = 0, 1, 2, \dots, n \quad i \neq j \quad \text{Equation (3)}$$

Where  $C_i$  and  $C_j$  represent positions of object  $i$ , and  $j$  respectively.

$K = ((d_{ix} + d_{jx}), (d_{iy} + d_{jy}), (d_{iz} + d_{jz})) + w$   
 Here  $d_{ix} + d_{jx}$ ,  $d_{iy} + d_{jy}$  and  $d_{iz} + d_{jz}$  represent the distance between object  $i$  and  $j$  in x, y and z axes respectively (see Fig. 5(a) & 5(b)). In addition,  $W$  is an offset value. The system performs various actions whenever collision is detected. In case of collision between virtual hand and an object, the audio/visual information related to the object is rendered by the system or the object is selected.

3.1.6 Constraints

VRTS is a constraint based virtual environment where various constraints are implemented in order to minimize errors in the assembly task. There are numerous constraints such as the system does not allow users to put (HT/LT) coils before placing the iron-core in the tank. Similarly the system does not permit them to place two LT or HT coils in the same leg of the iron-core. These constraints helps the user to put the objects at their correct places.

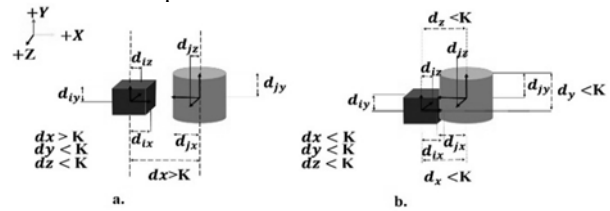


Fig. 5. Illustration of collision occurrence (a). No collision (b). Collision



Fig.6. Rendering information in text while selecting object

3.1.7 Multi-modal feedback

Audio/visual information are provided by VRTS to user as cognitive aids. The purpose of utilizing these aids is to increase user knowledge regarding the system and objects. Whenever the virtual hand collides with an object, its corresponding information both in audio/textual forms are given to the user (see Fig. 6). We use separate databases to store audio and visual information.

**4. EXPERIMENT AND EVALUATION**

To examine the impact of VRTS on students’ knowledge enhancement, we performed objective and subjective evaluation.

**4.1 Protocol and Task**

To evaluate our proposed system of virtual assembly (i.e VRTS), forty students took part in experiments. They were enrolled in a polytechnic college for electrical diploma for associate engineers. Their ages were in the range of 19 to 22 and were in the same class. One of their courses contained the topic of 3phase step down transformer which they had studied. The same instructor had taught them using the conventional classroom approach. The forty students were put in 2 groups. The first group was given the name G1 while the 2<sup>nd</sup> group was named as G2. In addition each was composed of twenty students. The member students of G1 performed the assembly task using VRTS while students in G2 were taught through conventional class room approach. None of the students in G1 had any previous experience of interaction with virtual reality systems, hence they were provided a briefing regarding the usage of VRTS. After the briefing, each participant was assigned to perform two tasks in our proposed assembly environment. The first task was to interact with different parts of the transformer to acquire knowledge about them. The second task was to carry out assembly of the transformer. The students in G1 after performing these two tasks in VRTS then filled a questionnaire. Later on the two groups were taken to a workshop where the experimenter asked them to recognize different components of the transformer and their functionality. In addition they recorded their knowledge regarding the placement/assembly of each component of the transformer. For this purpose the experimenter used another questionnaire.

**4.2 Result Analysis**

The questionnaire responded by the students placed in G1 is analyzed in this subsection. The purpose of these questions was to examine the role of the proposed system on students’ knowledge gaining, confidence building and success in real situation, realism and interaction easiness. The requirement for the students was to respond to questions on the Likert scale from 1 to 5. In this Likert scale 1 represent low level while 5 is equal to very high level.

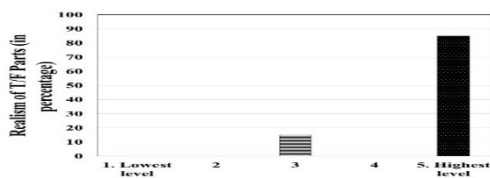


Fig. 7. Realism of transformer parts in VRTS

**4.2.1 Realism**

Here Realism of the overall system, individual parts and its role in students learning was evaluated. For the first question in this sub-category whose aim is to measure realism of the components of transformer, 85% students went for the highest level of realism as shown in (Fig.7). Furthermore, the 2<sup>nd</sup> question in this subcategory is aimed to measure that how much the assembly process in VE resembles the real assembly. In response to this question we observed that 78% students marked the higher levels (Fig.8). Similarly, 80% students as shown in (Fig.9), went for the highest option for the question regarding the realism of the overall system.

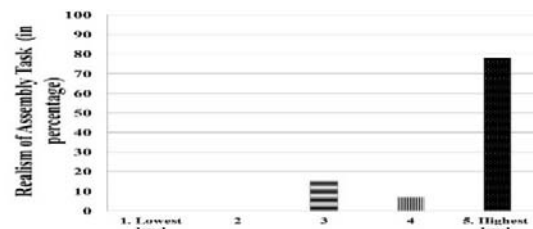


Fig. 8. Realism of assembly task in VRTS

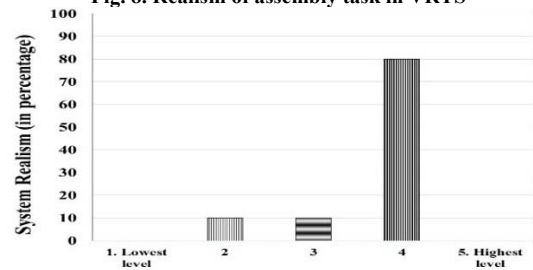


Fig. 9. Realism of VRTS

**4.2.2 Easiness in interaction**

Interaction with the system is done through fiducial markers by wearing them on the fingers of a hand. The movement and visibility of markers permit users to select and manipulate objects in VRTS. Based on the simplicity and easiness of the approach, 60% students opted for the highest options (Fig.10). In the start majority of the students were feeling nervous because of the novel interaction interface but they were comfortable with it after some time. The question that how much natural the selection and manipulation was in VRTS was?, got 60% score for higher scale (Fig.11.12)

**4.2.3 Confidence**

The student were very confident and carried out the task excellently. 80% students opted the highest level for confidence (Fig.13). Similarly, 60% students marked the highest level regarding the usefulness of VRTS in technical education (Fig.14). It is worth mentioning that there was another questionnaire to which students of both groups responded once they completed the session in the workshop. This questionnaire was actually filled by the experimenter by asking questions from the

students. Here the students were required to describe each object pointed by the experimenter in terms of its name, structure, functionality, target place and its relationship with other objects. Analysis of the questionnaire revealed that students (G1) who got training in VRTS were far better in learning (obtained average of 81.5%) as compared to those (G2 only got an average of 35.75%.) who were taught using the conventional approach (as shown in Fig.15).

Student’s performance improved with once they got familiarity with the system after sufficient interaction. Based on the results it is clear that VRTS is more beneficial for students learning, confidence building and increasing their practical skills. It will be of great help if deployed in technical institutions in support to the conventional teaching approach.

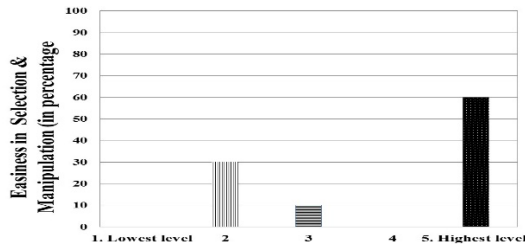


Fig.10. Easiness in selection and manipulation with VRTS

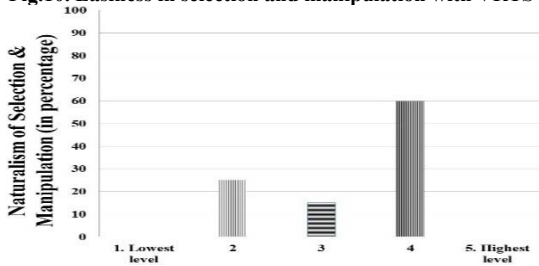


Fig.11. Naturalism of selection and manipulation with VRTS

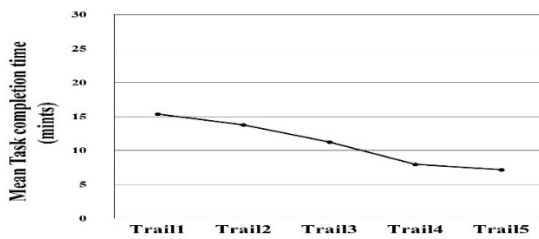


Fig.12. Students’ performance with VRTS

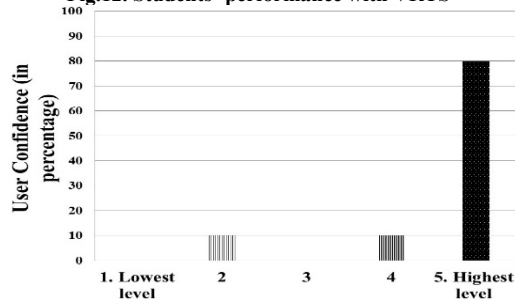


Fig. 23. Confidence level of students in VRTS

5. **CONCLUSION**

We proposed a new system of computer based learning known as VRTS to train students of institutions providing technical education. The selected training task was the assembly of three phase step down transformer. The proposed VRTS visualized the synthetic objects providing a high degree of realism. The use of ARToolkit markers with VRTS made the interaction very easy. The audio visual information corresponding to each component were given to the users. The VRTS guiding functionality allowed the students to carry out the assembly in a step by step manner. The analysis revealed that mean learning score of untrained students is 35.75% while that of students who got training through VRTS is 81.5%.

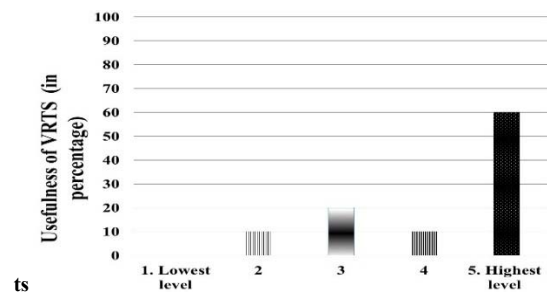


Fig.14. Usefulness of the proposed VE

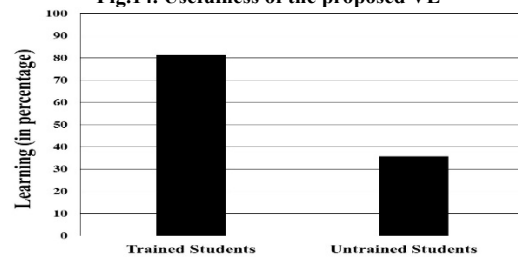


Fig. 15. Learning of students in different conditions

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