An Immersive Virtual Reality Training System for Mechanical Assembly

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Abstract: Given the growing evolution of technology, machinery and manufacturing techniques, conventional methodologies for training the workforce are not enough for the current needs. Therefore methodologies capable to accelerate the training process and able to train the trainee in a wide range of scenarios are claimed for the industrial sector.

Virtual reality offers an alternative that has been successfully implemented in other industries, and virtual reality based training systems have numerous advantages over the conventional methodologies, making it a very good option. Based on that premise, this paper explores the implementation of an immersive training system for mechanical assembly based on virtual reality for improving the training process. This system was proved to be as effective as the conventional methodology.

Key–Words: Training System, Virtual Reality, Manufacturing, Mechanical Assembly

1 Introduction

In the industry, all employees that carry out specific tasks within the production process are required to perform them properly so that productive levels are as high as possible and the product quality is maintained or even increased. To do so, the employees have to go through a training process for each specific task; this is the reason why training is such an important process. (Something about new employees that are not familiarized with the new tasks)

Some of these tasks or operations present many problems for the training, which are inherent to their nature. Some of them can be dangerous to the employee and other people around, where any mistake could result into harm to their own integrity. Other operations are very expensive, so the training process can be very restricted in terms of the types and the number of trainings that a trainee can realize.

Even if the tasks to be trained are not considerably dangerous or expensive, their training process is quite expensive if traditional methodologies are used. On one hand, traditional methodologies often require an experienced trainer responsible of transferring the knowledge and skills to the trainee and also of supervising and evaluating his performance, who could be performing other productive activities, and on the other hand, this methodology requires the use of resources as machinery and materials that are frequently damaged, destroyed or worn out. Another major disadvantage of the traditional methods is the difficulty to quantitatively measure the evolution and performance of the trainee; these metrics are generally qualitative and arise from the discretion of the expert.

To improve this situation, other alternatives for training the workforce may be considered, and one of the most promising alternatives that arise is the use of virtual reality for such purposes.

Some studies have shown that the use of simulators and other training techniques based on virtual reality are effective in transferring knowledge and skills, as mentioned in [6], and even industries such as aerospace, aeronautics and medical, where human life is at stake, make use of these techniques for the training of pilots and surgeons.

The use of virtual reality in the training field provides numerous advantages over conventional methods not only when training in processes with high risk or cost, but also in more common applications, as it represents significant reductions in time and resources. The use of virtual reality, computational in nature, enables simultaneous control of several metrics such as time or error rate, save user profiles as well as historical data as the learning curve [1]. A system based on virtual reality is a collaborative and interactive tool, where an expert can evaluate the trainee's progress through reports generated by the system, as well as interact with him even from distant places. In addition, a virtual reality system can simulate scenarios that in reality would be very difficult or impossible to train, i.e. training pilots how to perform an emergency landing.

Nowadays, the manufacturing industry claims for effective alternatives to improve the training process. For that reason, a training system for mechanical assembly using virtual reality will be presented in the following sections. This system includes an architecture that integrates interaction and visualization devices in order to achieve a higher level of immersion.

2 Related Works

Virtual environments have been widely adopted for training purposes with excellent results; in addition, virtual reality has taken a bigger role in computer graphics and is the subject of several studies aiming to improve the capabilities of current simulators to have higher levels of immersion and interactivity.

Virtual environments for mechanical assembly training, and generally all simulators must have a high level of immersion to achieve greater effectiveness in the process of learning or skills acquisition. Some studies like [11] show the key features for simulators to achieve high levels of immersion, and [5] mentions some of the generalities of these applications in assembly processes.

Another wide range of studies focus on interaction devices, which are essential components of simulators, as mentioned in [9]. These interaction devices are mainly intended for user tracking, stereoscopic vision and haptics, and allow more natural forms of interaction with the virtual environments, opposed to conventional I/O devices.

Several virtual reality systems have been proposed for applications such as mechanical design studies [2], evaluation of assemblies [10] and [7] and assembly path planning [8] among others. An important part of the study of these systems has focused on the following aspects: (i) in the development of new algorithms for collision detection, seeking greater accuracy and efficiency, so they can run in real time, (ii) in the CAD modeling of the parts used in the environment, to which is added weight and physical properties such as roughness of the material to make more realistic simulations and (iii) in the development of interfaces for interaction with virtual environments Some of these studies are [3] and [4].

This proposal mainly focuses in the training of assembly operations in manufacturing, using innovative technologies as optical tracking and stereoscopic vision, resulting in a highly immersive system.

3 Materials and Methods

3.1 System Development

The core module of the assembly training system was developed using *Panda3D*, an open source 3D game and simulation engine developed by Disney and maintained by Carnegie Mellon University's Entertainment Technology Center, and *Python 2.7* as a programming language. This module is called the Assembly Trainer, and is the responsible of the entire logic of the system, it loads all the 3D models, detects and manages the collisions, controls the assembly sequence and manages the data that comes in or out to other modules. The other modules are responsible of controlling each interaction device integrated with the system, those are, optical tracking and stereoscopic vision. A screenshot of the training system in 2D can be seen in Figure 1.

The module that controls the interaction of the system with the optical tracking device is called

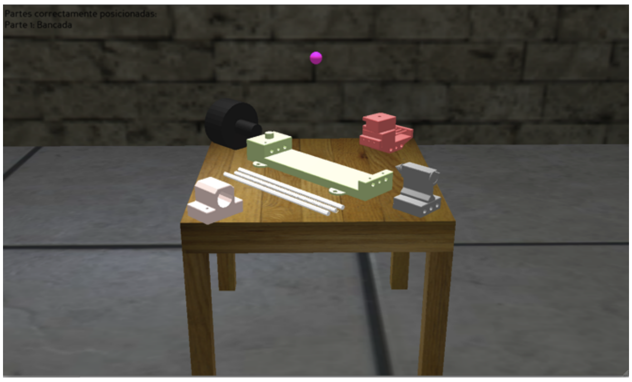

Figure 1: Screenshot of the training system for mechanical assembly. This is the initial state with all parts separated.

Input Manager, and communicates directly with the tracking controller to obtain the data and pass it to the Assembly Trainer.

The Stereoscopic Manager is the module responsible of displaying the 3D image; it creates the double window and controls the two cameras that capture the images from two different angles. The Figure 2 shows the architecture of the training system.

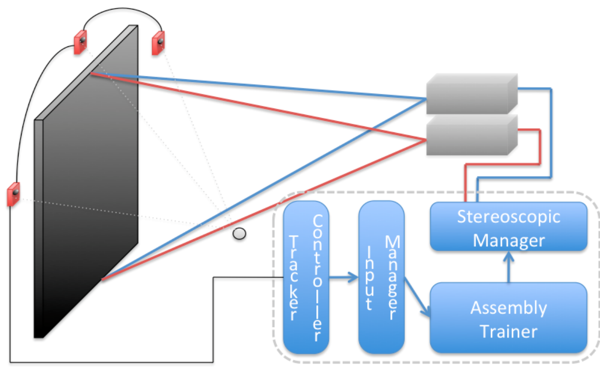

Figure 2: Architecture of the training system. The “Input Manager” controls the interaction with the optical tracker, while the “Stereoscopic Manager” is responsible for sending the corresponding images to the projectors.

The objective of the optical tracking system is to provide the user with a more natural way of interacting with the system. The tracker permanently captures the position of a marker, which is attached to a glove or wand and moves when the user makes movements with the hand. The marker moves a pointer in the virtual environment with which the user can select or grab objects, move them and place them into their final position.

The optical tracking system used is an OptiTrack FLEX: V100R2. The tracking system has 3 different cameras that capture the position of the marker from 3 different angles, and using that information it calculates the markers position in the workspace. This system has some development libraries that provide a bit of programming work. The Camera SDK (the SDK provided by the manufacturer) includes the necessary libraries for developing applications using the tracker in C++. Since the Assembly Trainer was developed in Python, an Interface for communicating C++ and Python had to be made.

Stereoscopic vision is one of the essential components for making virtual environments highly immersive. The human body, to capture 3D images, joins and processes the two different images captured by each eye; each one of those have a different perspective, depending on the intraocular separation, which is usually 65mm, and analysing the disparity or parallelism of the images the brain is capable of reconstruct the depth.

The stereoscopic system used is based on the principle of linear polarization to separate the two images; this method provides very high quality 3D vision. A computer with a dual video output is required, each one of these video outputs is connected to a different projector, which has a filter on the lens that polarizes the light, each one with a different angle, and reflected on a screen of a special material designed to maintain the lights polarity. The user, with the aid of special glasses with filters on each lens, is able to watch the corresponding image on each eye. The Figure 3 shows one of the participants performing a training session using the virtual reality system.

3.2 Experimental Design

A series of test were conducted in order to validate the training system. All subjects selected as participants in both experimental and control groups were extracted from a single population, EAFIT university students that had no experience in mechanical assembly. All subjects had normal stereo perception and visual acuity, their ages ranged from 17 to 24 years, with an average age of 20.3 years.

At the beginning of the process, each participant, regardless of which group they belong to, had to perform the assembly task using the real components to determine its initial skills. Likewise,

Figure 3: One of the experimental subjects performing a training session, interacting via stereoscopic vision and optical tracking.

after completing the training, participants had to perform the assembly task again to determine their final skills. After the initial test, each subject went trough 5 training session with its corresponding training methodology; the experimental group used the training system based on virtual reality, while the control group trained with the conventional methodology using the real components of the machine. The training task consists in assembling a milling machine, which is disassembled at first.

4 Results

All learning curves were plotted with the data collected from all the training sessions of the subjects. The Figure 4 shows the learning curves of participants who were trained using the conventional methodology, and Figure 5 shows the learning curves of participants who were trained using the virtual reality system.

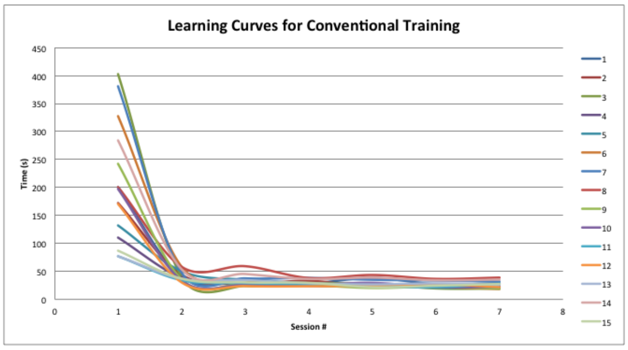

Figure 4: Learning curves for conventional training.

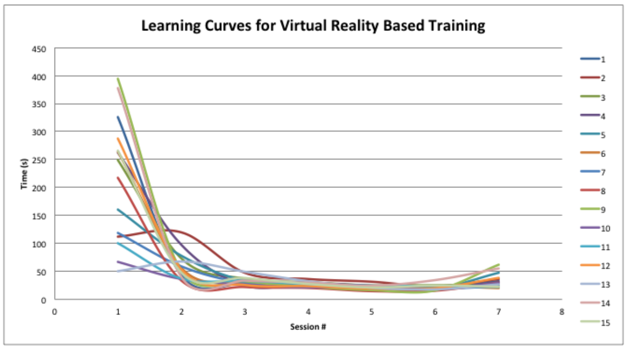

Figure 5: Learning curves for virtual reality based training.

At a glance, it can be seen that the curves of the experimental group are very similar to the curves of the control group. However, in order to determine if the virtual reality training system is as effective as the conventional methodology, both samples were statistically compared using a two-tailed t-student hypothesis test.

The variables compared between the two samples were the time reduction. The experimental group has an average time reduction X = 183.31 seconds with S12 = 10843.5, while the control group has an average time reduction Y = 178.27 with S22 = 11269.2. The conclusion of the hypothesis test with = 0.05 is that there is not enough evidence to state that the difference of the two means is different from zero, in other words, the hypothesis that the two means are equal cannot be rejected.

5 Conclusions

From the initially proposed objectives, and considering the results it is possible to conclude:

- In training systems based on virtual reality, interaction devices are key to achieve a high level of immersion, as they allow a more natural interaction with the system and thus, skills can be transferred more appropriately.
- Highly immersive systems are nearly as effective for training as conventional methodologies; therefore they can replace a mayor part of the training process, eliminating most of the disadvantages that conventional methodologies have.
- The training methodology based on virtual reality brings numerous benefits for the industry, and

more specifically for manufacturing sector, enabling a greater amount of trainings and being a very important option to solve the high cost of training problem.

6 Future Work

During development, several aspects that could be included in future work to improve the system and to apply the same concept in other industrial fields were identified, these include:

- In order to further increase the level of immersion of the system, a haptic device can be integrated, so that trainees can feel the forces there when performing trainings.
- Increasing the systems degrees of freedom by adding new markers or integrating it with an electromagnetic tracker, so that interactivity and realism may be augmented.
- Add more scenarios with more specific applications in the industry, such as assembly of parts in the automotive industry or other training applications such as welding.
- Develop a collaborative system, so several people can interact in different tasks simultaneously using an Internet connection.

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