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Haptically Enabled Interactive Virtual Reality Prototype for General Assembly

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ABSTRACT
Desktop computers based virtual training systems are attracting paramount attention from manufacturing industries due to their potential advantages over the conventional training practices. Significant cost savings can be realized due to the shorter training-scenarios development times and reuse of existing engineering models. In addition, by using computer based virtual reality (VR) training systems, the time span from the product design to commercial production can be shortened due to non-reliance on hardware parts. Within the aforementioned conceptual framework, a haptically enabled interactive and immersive virtual reality (HIIVR) system is presented. Unlike existing VR systems, the presented idea tries to imitate real physical training scenarios by providing comprehensive user interaction, constrained within the physical limitations of the real world imposed by the haptics devices within the virtual environment. As a result, in contrast to the existing VR systems, capable of providing knowledge generally about assembly sequences only, the proposed system helps in procedural learning and procedural skill development as well, due to its high physically interactive nature.

KEYWORDS: Haptics, virtual assembly, interactive and immersive

1 INTRODUCTION
Assembly is one of the most studied processes in manufacturing and number of computer based VR systems has been proposed and developed such as [1, 2]. The system in [2] is currently used by car manufacturing companies, such as Volvo and SAAB. Such VR systems are effective if the knowledge required to be transferred is just assembly sequence. However, knowledge transfer regarding the procedural learning and to develop cognitive skills becomes very hard, due to the limited user interactivity and immersion. Keeping in mind, the shortcomings of aforementioned VR systems, a complete interactive and immersive VR system is presented. The system is designed to imitate the real physical training environments within the context of visualization and physical limitations. Head Mounted Displays (HMDs) are used for immersive visualization equipped with 6DOF trackers to keep the virtual view synchronized with the human vision, PHANTOM® devices are used to impose physical movement constraints. In addition, 5DT® data gloves are used to provide human hand representation within the virtual world.

The aim of the proposed system is to support the learning process of general assembly operators. In particular, these users will be able to repeat their learning practices until they are proficient with their assembly tasks and sequences. Their levels of proficiency can be measured by quantifiable data such as the percentage of correct tools/parts selected and the time they took to complete the specified tasks. Consequently, the proposed training environment is designed to achieve the following goals: (1) providing an interactive training platform where users can explore their targeted assembly sequences through experiential learning in 3D virtual space. Users are able to interact with these virtual objects directly and experience the effects of their interactions. The effects are likely to include visual, audio and haptic feedback. Through direct manipulation, implicit and explicit learning modes can be induced [6]. Implicit learning is "the induction of an underlying representation that mirrors the structure intrinsic to the environment" [7]. On the other hand, explicit learning is characterized by the formation and
refinement of mental models [5]. An additional consequence of direct manipulation of virtual objects is that users' motivation is increased and concepts become more readily internalized [8]. (2) Conducting of empirical studies to determine the effectiveness of such training environments in terms of enhanced learning processes and increased understanding compared to conventional instructor-based face-to-face methods. The empirical studies will emphasize the testing of the level of knowledge retention. The questions used in the empirical studies will be situated in actual assembly line situations where users are expected to apply their knowledge of the assembly sequences. Because the purpose of the system is to help users participate in assembly training rather than in learning how to use the system itself it is pertinent to design an engaging interface so that the system is easy and pleasurable to use. A pleasant experience will help to attract users back to the environments, resulting in more learning experiences and familiarity with the learning context. As such, the user interface should be simple enough for users to operate without lengthy training or instructions by "leaving more unsaid" [9].

The overall HIIVR system architecture uses a modular approach where different software modules process information independently. This modular approach makes HIIVR system highly scalable as new modules can be added into the system or discarded at anytime with minor changes in the central processing module. Furthermore, independent processing modules take advantage of the current multi-core architectures of the computer processors by running operations in parallel if processes are completely independent. Moreover, the functional aspects of the HIIVR system are event-driven where communications between system modules are encapsulated as events that are propagated to the appropriate destinations. This event-driven approach provides a framework of assessment and evaluation of the user's performance. It also portrays an outlook similar to computer games, keeping the user motivated to keep progressing throughout the simulation. This event-driven system design considers the repository, object interaction and user interface aspects of the system. The repository is needed to provide storage and retrieval of geometric models representing virtual worlds and assembly parts as well as the information models encapsulating relevant assembly sequences.

2 HIIVR SYSTEM ARCHITECTURE

The overall system could be divided into two broad classes i.e. software modules and hardware equipments. Hardware part of the system includes I/O devices such as Phantom® haptic device, 5DT® data glove, Flock of Birds® and visualization equipments such as Emagin's Z800 HMD or Stereo projectors. Software part of the system is responsible of providing interactive functionality to the user. Within the context of software development a modular approach is used. Modular approach provides computationally stable and superior performance with current multi-core computer architectures. Furthermore, modular approach makes the system highly scalable as new modules with enhanced capabilities can be plugged in at any time and older modules can be discarded if required. The overall architecture of HIIVR system can be represented by a block diagram in Figure 1.

![HIIVR System Architecture](image)

The core challenge faced in designing and developing HIIVR system is the integration of third-party libraries written for different VR/AR devices and applications. It is necessary for supporting the myriad of user interactions that are part of an effective virtual training environment. In order to overcome this challenge, a central information processing module is developed to enable these different devices to communicate with one
another as well as different information processing software modules in the virtual training environment in a manner that achieves robustness and software modularity.

2.1 Hardware Modules

The hardware modules used to provide complete immersive and interactive training environment can be divided into two broad categories, that is the devices to provide immersion and the devices responsible for interaction. For display purposes, two different stereoscopic modes are provided that are stereo projection system mode and HMD mode. The display of graphical user interface (GUI) of the HIIVR system can be selected in any of the aforementioned display modes. Both of the modes provide depth perception to the user however HMDs are capable of providing better immersion to the user but suffers with shortcomings [4]. For the developed setup of HIIVR, NEC® stereo projection system and eMagin®'s Z800 HMD is used.

For interaction purpose devices used are:

5DT® Data Glove: used to mimic the real human hand interaction within the virtual world by providing graphical representation of the human hand. The functionality of data glove also propagates human hand gestures from real world to the virtual world providing the perception of real hand manipulation within the virtual environment. It also helps to recognize different hand gestures that may require during the assembly operation.

Phantom® Haptic Device: used to interact/manipulate virtual objects within the virtual world while providing physical force feedbacks depending on the physical properties of the virtual objects. It also provides tracking capabilities within the device's working envelop. In the developed system the user's hand equipped with data glove is attached to the haptic device for hand movement tracking within the virtual environment as can be seen in Figure 2. Haptic device is the most crucial part of the HIIVR system as it helps to imitate the real physical training environments. It also provides physical movement constraints during the simulation so as to imitate the real physical movements while performing real assembly process.

Flock of Birds® tracker: used to track the position and orientation of the HMD in order to provide a realistic visualization by synchronizing the view of virtual environment with the user's direction of view as can be seen in Figure 2.

2.2 Software Modules

Software training environment consists of different information processing modules separated on the basis of information availability to the user and interaction required form the user. The software modules developed within the functionality of HIIVR system are:

Information processing module is responsible of processing information related to assembly sequence and to keep track of assembly operations performed by the user. The information accumulated during the free play assembly operation, presented in section 2.1, is stored in a log book to assist in evaluating the user efficiency and skills. During the free play the features that are given attention to for assessment and evaluation purposes are time taken by the user to complete/ partial task, number of attempts made before completing individual assembly operation successfully, assembly sequence mistakes and incorrect operations involving fitting of objects at wrong location.

Registration Engine is responsible for registering the graphical information and engineering data in an appropriate format to make it accessible whenever required. In HIIVR system math data is kept in VRML-97/2 format converted from GM standard JT format. It is also responsible for keeping the graphical data in an appropriate format that can minimize the access time and to keep the data manipulation costs less for easy graphical manipulation. Consequently, maintaining an acceptable frame rate for better visualization to decrease stress on user's eyes.

Physics Engine is responsible of the physical properties of the virtual objects and the virtual environment. Physical properties of the objects within the virtual environment, such as friction, weight, bounce, and gravity.

Data Acquisition Engine is responsible for acquisition of information from hardware devices such as haptic devices, data glove and trackers. Required data is acquired mostly according to a timer usually running at 0.01 seconds interval. However sometime data acquisition is event driven, i.e. data is acquired from some specific device at the occurrence of some specific event such as collision of two virtual objects.

Collision Detection engine is responsible for most of the force feedback signals that are generated during any specific assembly operations. It is an essential part of different assembly operations that require any sort of fitting of two different virtual objects. In HIIVR case SmartCollision® Library [3] is used.
**Evaluation Module** is required to assess the performance of the user during any specific training procedure within any specific training environment and scenario. The evaluation module records the information related to the time taken by the user to complete assembly operation successfully, number of times some operation is repeated before successful completion and number of operations performed not in sync with the pre-optimized assembly sequence. Furthermore to check the quality of the assembly process a number of control points are added into the virtual environment which triggers the information regarding the quality of the assembly that has been performed by the user.

3 **FUNCTIONAL SPECIFICATIONS OF HIIVR SYSTEM**

The functional specification of the HIIVR system is categorized into two information processing blocks which are Training Interface and Interaction Interface. First block is responsible for providing different modes of training scenarios whereas the second processing block takes care of the user interaction with the first processing block.

3.1 **Training Interface**

Training interface consists of user selectable difficulty levels and training modes. Provided training modes require different interaction levels from the user. In general less difficult training mode requires less interaction or input from the user and provides more visual and audio feedbacks to guide the user through the simulation. In contrast as difficulty level increases, user interactivity increases and feedbacks decreases so as to provide grounds for assessment and evaluation of the knowledge transfer to the user. In HIIVR system, assessment and evaluation phase is linked only to the last mode of difficulty as it provides the true representation of users understanding learning of the assembly process. The four training modes that are currently developed in HIIVR system are:

- **Process demonstration:** The user is shown the complete process of assembly operation prior to any user interaction to give a clear idea about the assembly operations involved and the pre-optimized assembly sequence.
- **Guided assembly:** The user is provided with step by step visual information to perform complete assembly task. This mode helps the user to understand the assembly process and in understanding the used interface/interaction of the environment. To teach the assembly sequence properly, the environment restricts the operations by enabling only the operations that are required in a step by step mode.
- **Unguided assembly:** In this mode user is assisted with different operations only if required by the user or if software judges that the user is facing difficulty in some specific task/operation. Furthermore, for any wrong operation, e.g. attaching a part at the wrong location or going for an operation not according the pre optimized sequence, the software prompts a visual feedback to keep the user on track.
- **Free play:** This mode provides complete free hand to the user and allows the user to perform any assembly operation and in any sequence. However, the operations will be restricted if the assembly operations involve fitting of the two objects that are not meant to be fitted together due to the physical shape restrictions. This mode is also used to assess the skill levels of the user by tracking all mistakes and out of sequence assembly operations. Time taken by the user is also recorded to get an idea about the comfortability and understanding of the user about the assembly operation.

3.2 **Interaction Interface**

The user interaction can be defined in terms of the I/O devices that user uses to interact with the virtual training environment and triggers different events pre-embedded into the system.
In general user wears the data glove attached to the haptic device as can be seen in Figure 2. The data glove provides the visualization of virtual hand within the virtual environment whereas the haptic device provides the force sensation to the user as well as the tracking information that is the location and orientation of the hand. The user is able to grasp and manipulate the objects by touching them and making a predefined hand gesture. While the objects are in user's grasp can be dragged throughout the virtual environment, however with physical constraints, i.e. not being able to pass through other objects. The user is then supposed to assemble the objects by fitting them to appropriate locations. To be able to fit the object, the user has to perform alignment of the objects according to the fitting space, as the physical constraints imposed by the haptic device restrict the assembly operation to be fulfilled otherwise. The user is also provided with the visual and audio feedbacks to inform about different events that occur during the operation such as completion of any specific assembly operation. A simple example of the aforementioned operation can be visualized by the Figure 3 to 4, where user is required to fit the screws in the holes.

4 EXPERIMENTAL SETUP

For demonstration purposes a simple assembly training scenario is presented in Figures 3 to 4. Presented assembly scenario requires the user to fit two parts into each other as is clear from Figure 3 and Figure 4. The blue color represents the part is being selected by the user and is been dragged using haptic device with attached data glove. The red hand represents by the hand of the user in the virtual world.

In the presented training scenario user can complete the assembly process only if he/she fulfill the physical geometric constraints such as aligning the gaps and fitting areas properly. Once the two bigger parts are assembled as in Figure 4 the user is required to fit a screw into the appropriate place to keep the assembled parts attached as shown in Figure 4. After the first screw is assembled the user has to rotate the environment using key control provided. At this stage the assembly process is shown in Figure 4. It
is quite apparent, by looking at the assembled parts from the back side, that parts and screws are fitted very nicely. As mentioned in section 2.2 control points that are added prior to the training provides information about the quality of the fitting of different parts.

Figure 4. An example of HIIVR's training scenario: Second Step

5 CONCLUSION

A prototype of HEIIVR system is presented. The system is designed in a way to imitate real world assembly practices to support the learning process of general assembly operators. The proposed system provides highly interactive and immersive virtual training environment where operator can perform the assembly operations with physical restriction imposed by haptic device to deliver feeling of real world environment. Due to the HEIIVR system's highly interactive nature, it provides both, assembly sequence information and procedural information.

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