Haptically Enabled Interactive and Immersive Virtual Assembly

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Abstract

Virtual training systems are attracting paramount attention from the manufacturing industries due to their potential advantages over the conventional training practices such as general assembly. Within this virtual training realm for general assembly, a haptically enabled interactive and immersive virtual reality (HIVEx) system is presented. The idea is to imitate real assembly training scenarios by providing comprehensive user interaction as well as by enforcing physical constraints within the virtual environment through the use of haptics technology. The developed system employs a modular system approach providing flexibility of reconfiguration and scalability as well as better utilization of the current multi-core computer architecture. The user interacts with the system using haptics device and data glove while fully immersed into the virtual environment with depth perception. An evaluation module, incorporated into the system, automatically logs and evaluates the information through the simulation providing user performance and improvements over time. A ruggedized portable version of the system is also developed and presented with full system capabilities allowing easy relocation with different factory environments. A number of training scenarios has been developed with varying degree of complexity to exploit the potential of the presented system. The presented system can be employed for teaching and training of existing assembly processes as well as the design of new optimised assembly operations. Furthermore, the presented system can assist in optimizing existing practices by evaluating the effectiveness and the level of knowledge transfer involved in the process. Within the aforementioned conceptual framework, a working prototype is developed.

Keywords: Haptics, virtual assembly, training.

Introduction

In recent times, lot of focus has been targeted to overcome problems and deficits in the automotive and aerospace industries such as integration in international markets, product complexity, increasing number of product variants, reduction in product development time and cost. In order to stay competitive on international market spectrum; companies must be capable of producing higher quality new products in shorter times with broader variety and minimum costs. In this regard virtual prototyping and assembly is becoming an interesting strategy for product development with aforementioned variants. Automotive industries are considered to be the leaders in applying virtual reality (VR) for real-world, non-trivial problems. Although, a number of commercial 3D engineering tools for digital mock-ups exist, however all of them lack in intuitive direct manipulation of the digital mock-up and interaction by the users.

Assembly is one of the most studied processes in manufacturing and a number of computer based VR systems has been proposed, developed (Vizendo; A. Boud 1999; F. Crison 2005; L. Malmsköld 2006) and adopted by the 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 math 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 for training. The system demonstrated in (Vizendo) is currently used by car manufacturing companies, such as Volvo and SAAB, to train assembly operations. Such VR systems are effective if the knowledge required to be transferred is just process sequence such as assembly sequence. However, knowledge transfer for procedural and cognitive learning as well as skills development is very limited, due to the lack of user interactivity and immersion. Keeping in mind, the short comings of aforementioned VR systems, a complete interactive and immersive VR system (HIVEx) is presented. 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 in the virtual environment. Consequently, in contrast to the existing VR systems that are capable of providing knowledge generally about assembly sequences only, the proposed system helps in cognitive learning and procedural skill development as well due to its high physically interactive nature. The system is designed to imitate the real physical training environments within the context of visualization and physical limitations.

The aim of the proposed system is to support the learning process of general assembly operators as well as provide an intuitive training platform to enable assembly operators to perform their learning practices, repeatedly, until they are proficient with their assembly tasks and sequences. Their levels of proficiency could be measured by quantifiable data such as the percentage of correct tools/parts selected and the time they took to complete the specified tasks. The proposed training environment is designed to achieve the following two explicit 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 (S. G. Schär 1996). Implicit learning is "the induction of an underlying representation that mirrors the structure intrinsic to the environment" (A. S. Reber 1989). On the other hand, explicit learning is characterized by the formation and refinement of mental models (G. Schär 2001). An additional consequence of direct manipulation of virtual objects is that users' motivation is increased and concepts become more readily internalized (T. Koschmann 1995).

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" (J. S. Brown and P. Duguid 1996).

HIVEx System Architecture

The overall HIVEx system architecture uses a modular approach where different software modules process information independently. This modular approach makes HIVEx 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 HIVEx 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.

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.

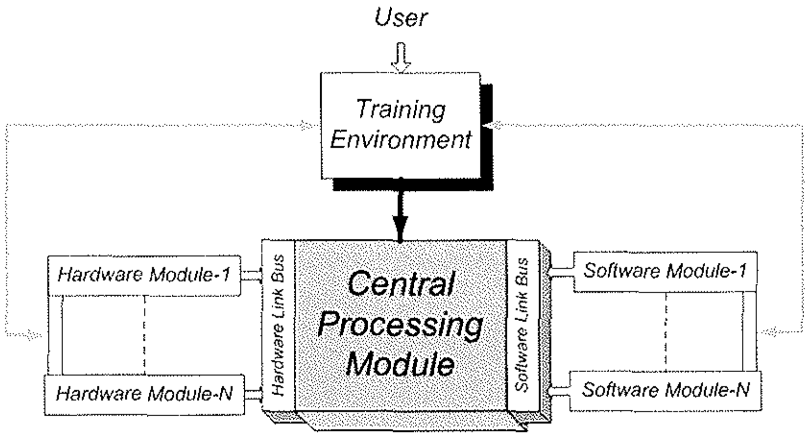

Fig 1. HIVEx System Architecture

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 HIVEx system can be represented by a block diagram in Figure 1.

The core challenge faced in designing and developing HIVEx 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.

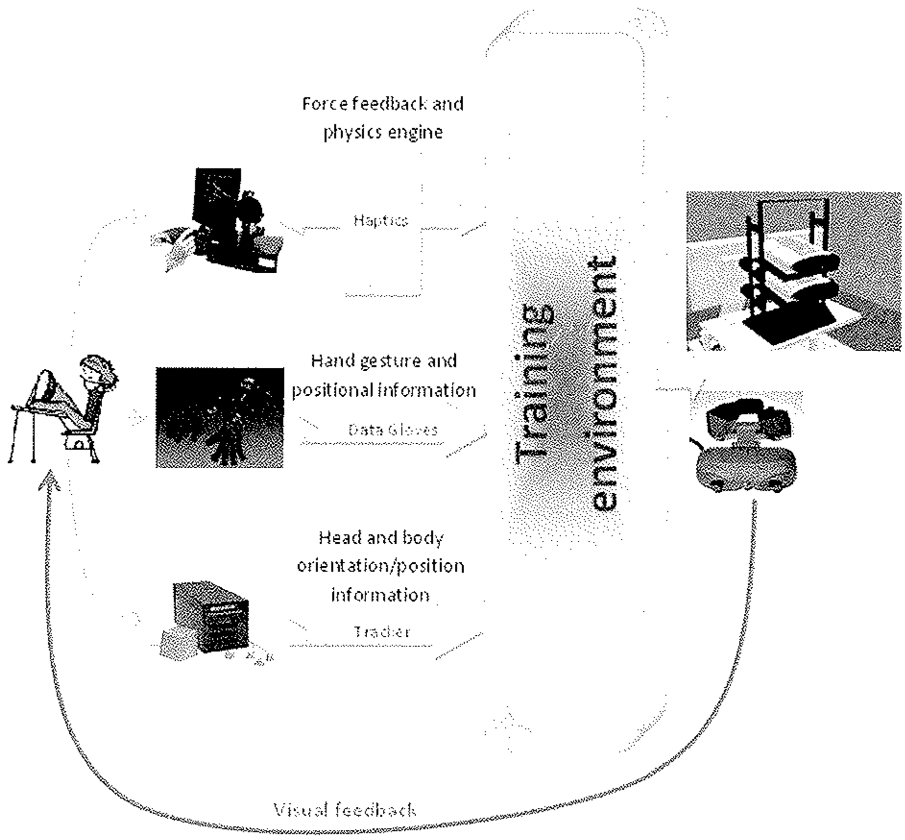

Fig 2. Hardware interaction involved in HIVEx System

Hardware Modules

The hardware modules used to provide complete immersive and interactive training environment can be divided into two broad categories that are 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 HIVEx 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 (Baber 2001). For the developed setup of HIVEx, NEC® stereo projection system and eMagin's Z800 HMD is used. The overall HIVEx system's hardware setup can be visualized by Figure 2.

The devices used for user interaction 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 3 (a). Haptic device is the most crucial part of the HIVEx 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 3(b).

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 HIVEx system are Information processing module, Registration Engine, Physics Engine, Data Acquisition Engine, Collision Detection engine, Evaluation Module.

Functional Specifications of HIVEx System

The functional specification of the HIVEx 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.

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 rises, user interactivity increases and feedbacks decreases so as to provide grounds for assessment and evaluation of the knowledge transfer to the user. In HIVEx 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 HIVEx system are Process Demonstration, Guided Assembly, Unguided Assembly and Free Play.

Fig 3. HIVEx System's hardware setup

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. An overview of the user interaction with the virtual training environment through different devices can be presented by a visual representation as shown in Figure 3.

In general user wears the data glove attached to the haptic device as can be seen in Figure 3. 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 of the hand, i.e. 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 moved throughout the virtual environment, however with physical constraints restricting any passing 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 4 and 5 where user is required to fit the screws.

Experimental Setup

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

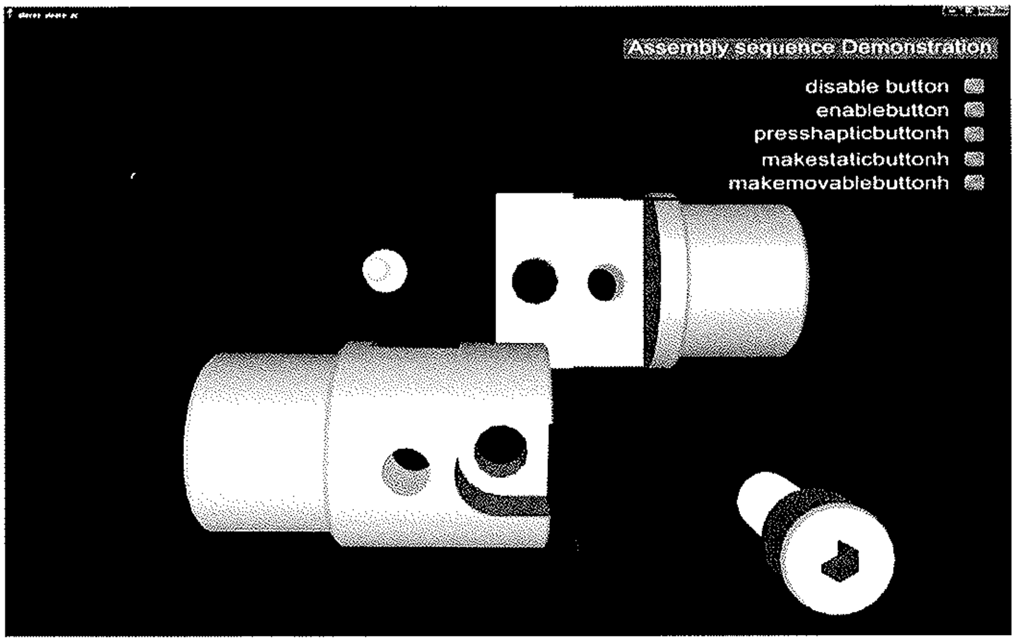

Fig 4. An example of HIVEx's training scenario

In the presented training scenario user can complete the assembly process only if he/she fulfil the physical geometric constraints such as aligning the gaps and fitting areas properly. Once the two bigger parts are assembled as shown in Figure 5 the user is required to fit a screw to keep the assembled parts attached. After the first screw is assembled the user has to rotate the environment using key control provided. It is quite apparent, by looking at the assembled parts from the back side, that parts and screws are fitted very nicely. Control points are added, prior to the training, providing information about the quality of the final assembly of different parts. Assembly process for this particular scenario completes by adding the last screw into the previously assembled parts as shown in Figure 5.

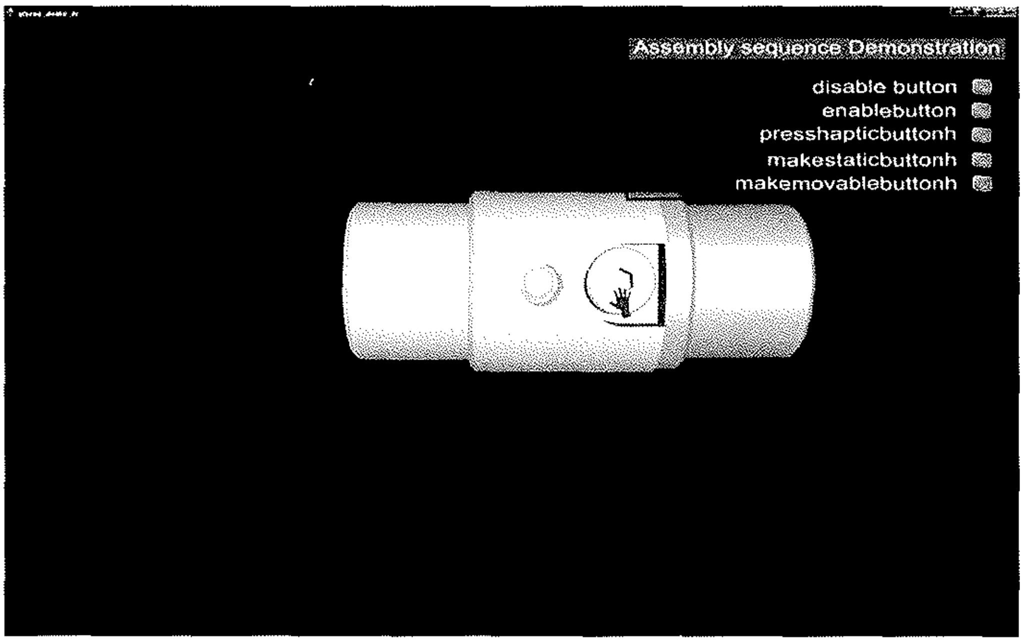

Fig 5. An example of HIVEx's training scenario: Final Step

An example of assembly training scenario with higher difficulty level is shown in Figure 6. In this training scenario user is required to assemble the complete radio encapsulating the assembly processes such as fitting the radio, attach four screws to fix the radio using a drill, attach the LCD panel and connect the power connector to complete the assembly process. All aforementioned assembly processes has to be performed in a particular order to be able to successfully complete the radio assembly process.

Portable System

In addition, despite of the hardware requirements and complexity of the training system, a portable version of the HIVEx system has also been developed as can be seen in Figure 7. This portable HIVEx system possesses similar capabilities as the desktop system and is fully self-contained. Special consideration has been taken into account to make the portable system highly ruggedized. The idea is to provide a mobile platform that could be used along the assembly line, providing number of training scenarios that could be used by assembly operators to enhance, refresh as well as learn new assembly operations that they have not come across before.

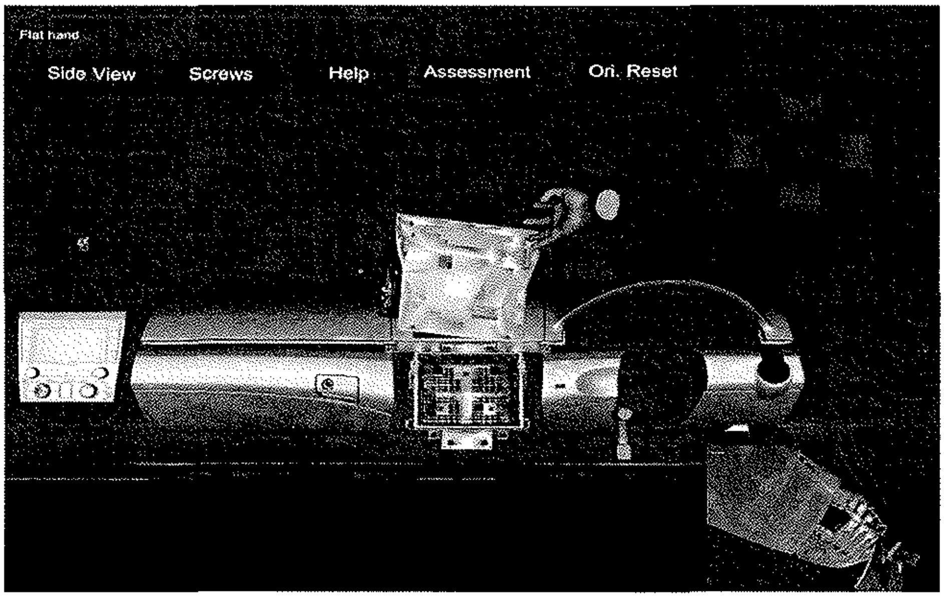

Fig 6. Example of HIVEx's training scenario with higher difficulty level

Conclusion

A prototype of HIVEx 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 HIVEx system's highly interactive nature, it provides both, assembly sequence information and procedural information.

Fig 7. Portable HIVEx System

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