Immersive virtual environment for industrial robotics manipulation training

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Abstract: A virtual reality environment consisting of a 6 degrees of freedom (DOFs) industrial robotic arm and a hand-manipulation interaction interface has been presented in this study. The main aim of this study has been set to fulfill the needs of industrial robotics users in order to provide better user experience as well as to minimize the costs due to any manipulation errors which might cause damages to the robotics elements or the operator and/or non-optimized operation procedure. Therefore, the presented system has been designed and constructed for practical applications and training purpose. A commercial head-mounted display, HTC Vive, has been used with a portable hand-gesture-capturing device, Leap Motion. The operator has been told to manipulate the robotic arm with his hand following the operation procedures in an immersive virtual environment. Some add-on assistive functions have been integrated into the system, such as acoustic and visual warming signals, vibration-based haptic feedback, simulated hazards testing, etc. During the training process, the trajectory and relevant parameters of the robotic arm are recorded. After model computation and data conversion, the virtual manipulation may be sent as executable command to the robotics controller for real robotic arm operation in the factory. This system has been evaluated by industrial vendors and ergonomists considering its functionalities as well as usability. Results based on expert evaluation have shown a convincing implementation of the presented system for industrial use.

Keywords: virtual environment (VE), immersion, human-computer interaction (HCI), robotics arm training, gesture manipulation, motion capturing

1. Introduction

Modern development and advances in technology have transformed the traditional labor-workforce-centric industry into a high-tech-centric industry. Many manufacturers have started introducing industrial robots in their production line, R&D projects, logistics, and other sectors for various purposes. For instance, we may rely on industrial robotic workforce in the assembly line for achieving mass-production goals with long operation hours, high consistency, low human errors, and other advantages especially in some specific industry sectors. From some low-complexity tasks the industrial robots originally were designed to ease the workload or risk of a human workforce, the modern industrial robots aim to replace or even to improve the precision and quality of highly sophisticated tasks done by a human operator. A high-complexity task may be accomplished with the collaboration of a human operator and a high-end industrial robotic arm. For teaching the robots how to execute its assignments, a human operator needs to train the robots carefully and precisely. Normally such training procedures are not rated as intuitively nor easily. For instance, we may imagine that the computer vision is somewhat different from the human vision. The mechanisms and coordinates of a robotic arm might differ from the human capability. Therefore, there has been a need and trend of intuitive and easy-to-operate human-robot interaction.

Recent bloom and progress of virtual reality (VR) technology has enabled enormous applications and advances in various sectors such as in education, entertainment, defense industry, medicine, science, research, etc. VR technology has integrated with many advanced hardware facilities and been applied and focused on human-computer interaction and multimedia designs and development (Burdea 1993, Walter 1996, Sherman 2002). Traditionally, a human operator uses a “teaching box” (like a remote control or a gamepad) for training a robotic arm to follow certain motion trajectories through a computer software interface. Imaging the modern application and trendy medium of a head-mounted display (HMD) to be implemented in such a training system, we may face a new type of communication interface while integrating the physical environment with the virtual assistive information in a more intuitive perspective and based on a real-time structure.

In this study, we aim to use the virtual integration method to let the physical robotic arm (such as its appearance, function, instruction, physics, etc.) be output to the display of a HMD and a computer medium. HMD equipped and/or integrated with wireless hand gesture capturing device, are linked to the VR software and simultaneously receiving simulated manipulations of the virtual arm, motions, hazards or assistive information, a vivid complex virtual environment as the reality. Therefore we could provide an immersive virtual environment as in the real physical environment for training purposes, so that the physical arm does not need to be operated in a real and critical environment nor the human operator needs to work in a dangerous situation.

2. Method

2.1 VR software setup

3D virtual objects and scenarios implemented in this VR training system have been constructed and designed using various software tools such as Autodesk 3dsMAX, Goggle SketchUp, Unity, Blender, and Solidworks. Unity has been used as the universal and final rendering platform and real-time engine. Fig. 1 shows the 6 DOFs industrial robotic arm in Unity implemented in this system.

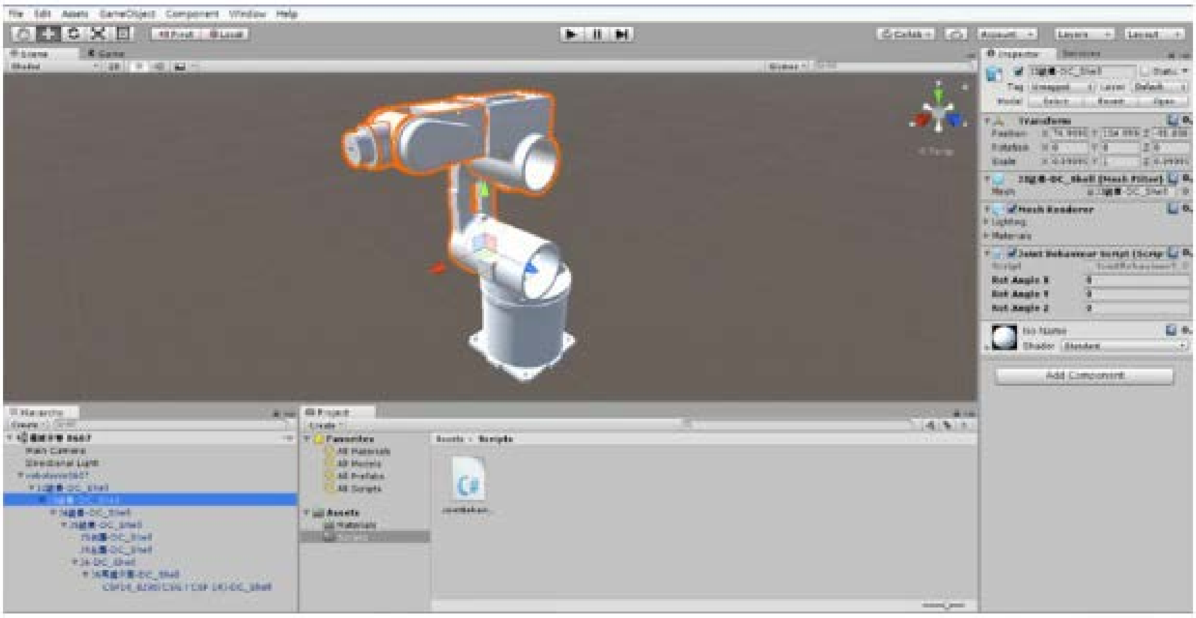

Figure 1: *The 6 DOFs robotic arm applied in this trajectory training system (J3 structure)*

2.2 Hardware setup

In the current version of the VR training system, HTC Vive has been used for our HMD medium and a room-scale VR has been constructed (as shown in Fig. 2a). A Leap Motion sensor module has been integrated with the VR program for detecting and capturing the hand gestures of a human operator. Fig. 2b shows the actual robotic arm used for the training and production purpose provided by the industrial collaborator in this project.

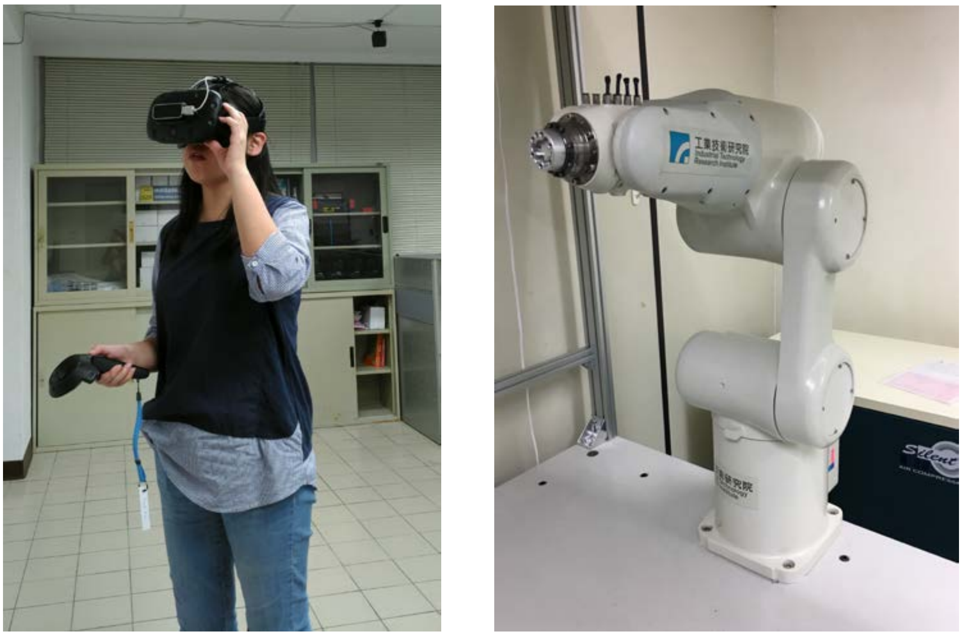

Figure 2: *(a) (left picture) A test subject wearing the HTC Vive in the VR training system*
(b) (right picture) The ITRI 6 DOFs robot

2.3 Hand motion (gesture) capturing

Current setup of hand gesture capturing is based on the joints coordinates detecting by the Leap Motion because of its convenience and the high precision is not targeted in the first training system. In Fig.3 it shows the commercial device used in this study and a demonstration of 3D coordinates capturing during the training process of a human operator.

Figure 3: *(left) Leap Motion sensor module.*
(right) While moving one's hand, the (X, Y, Z) coordinates of the thumb tip of the left hand has been recorded at a sampling rate of about 30 Hz.

3. Implementation results

Immersive Virtual Robotics Environment (IVRE) has been developed and constructed in this study. The flowchart of the VR training progress may be divided into three major procedures. In the first procedure, the training trajectory has been manipulated by the human operator in the VR environment. The continuous trajectory coordinates of relevant hand joints are detected and recorded. Meanwhile, the real-time coordinates are sent to the next procedure. Fig. 4 illustrates some demo trajectory patterns tested in the present IVRE system.

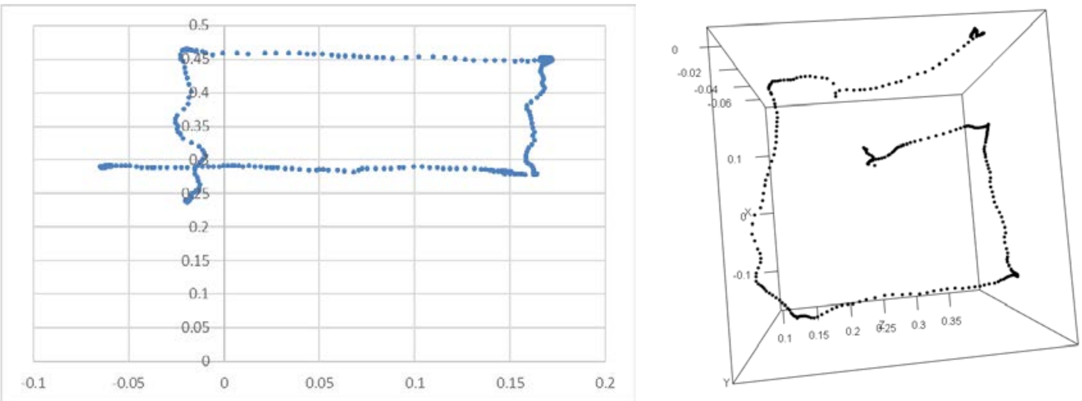

Figure 4: *(left) 2D graphical representation of a rectangular trajectory record (unit in meter)*
(right) 3D graphical representation of a rectangular trajectory record (unit in meter)

In the next procedure, the 3D coordinates of hand joints sent to the motion controller unit of the physical robot have been computed and converted into six input parameters for the 6 DOFs robotic arm. The motion computation and mapping are done in a separate program as shown in the software interface in Fig. 5.

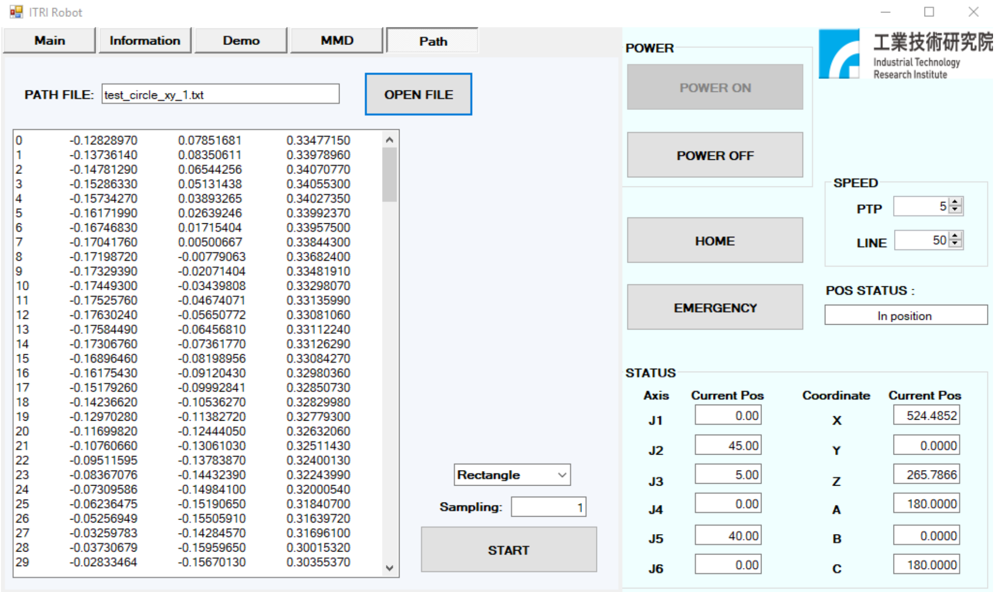

Figure 5: *The ITRI Robot motion control program: converting the trajectory 3D path (Xs, Ys, Zs) into corresponding joints parameters (each position) for operating the 6 DOFs robotic arm.*

And in the last procedure, the converted robotic parameters are feedback to the Unity VR environment for manipulating the virtual robotic arm accordingly as demonstrated in Fig. 6.

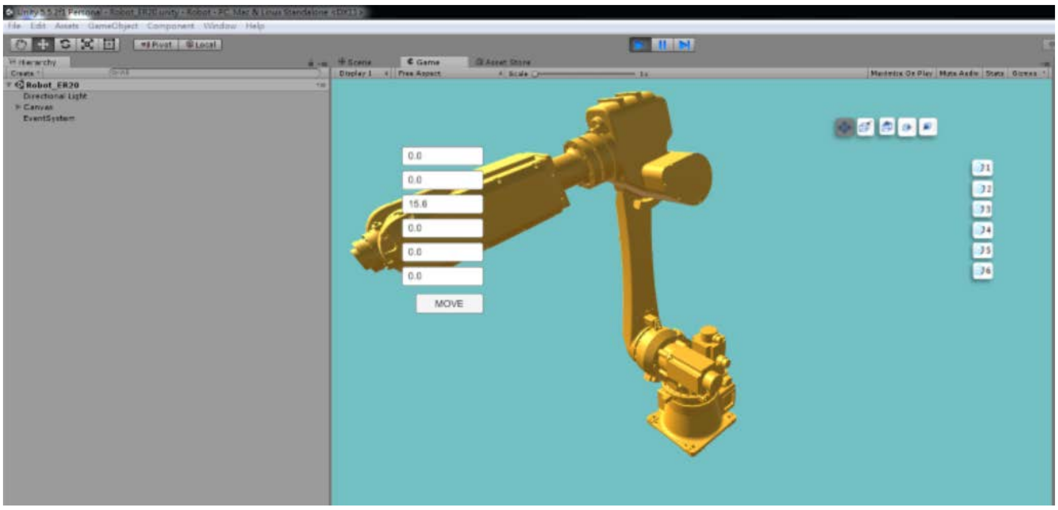

Figure 6: *The VR robotic arm in Unity is manipulated according to the motion converting computation following the moving trajectory of the human operator for training the robot.*

4. Discussion

The immersive virtual environment is a powerful tool for training or education purposes, as well as in the final operation, as the physical robotics does not need to be exposed to some potential damages as it will be simulated first in the virtual environment. Also for the human operator, one will not be exposed to a physical hazard during one's working process.

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