



A Tale of the Robot: Will Virtual Reality Enhance Student Learning of Industrial Robotics?

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Abstract

This work in progress paper describes an ongoing research project examining the feasibility of using consumer-graded virtual reality devices during the design verification stage of industrial robot programming. Modern industrial robot programming is often performed offline using graphics-based programming and simulation software. This computer aided design environment provides experienced robot programmers cost effective features to streamline the acquisition of work information, generate and debug the robot programs, and visually verify the code through simulation before sending to the actual robot for execution. However, these features might not benefit novice learners who do not fully understand robot programming. The cognitive workload resulting from eye-hand coordination (mouse movement corresponding to on-screen pointer action for object manipulation) and mental rotations (three dimensional object rotation in mental space) could distract the learners from paying attention to program errors such as object collisions or sudden robot movement due to robot axis singularity. The robot simulation might turn out to be just another video game to novice learners, and misconceptions can be formed easily.

In this study, we propose to use virtual reality (VR) as a tool during the robot cell design verification process to determine if the use of VR technology can improve the learner's performance. The findings from the preliminary usage of VR devices for robot cell design verification are reported. The project is currently in the initial stage where frequent student learning problem areas caused by overlooking of the simulation results will be identified as the baseline. Later project stages will involve the development of a learning assessment tool. Next a clean virtual environment will be created to remove the distraction from the robot programming software, and specific tasks correlated to common program errors will be designed. Finally a full experience will be conducted and analyzed to see if there is a significant difference of learning performance between the VR and non-VR (desktop) environments. A theoretical framework will also be established to help explain the results. We conclude the paper with a summary and the outlook for future works.

Introduction

Computer-based simulations have been used to study the behavior and performance of actual or theoretical systems. With the advance of visual computing technology, STEM educators are able to use graphic intensive computer simulation to offer learners different learning experiences. These mathematical driven images or models provide the learners visual cues in addition to the numbers [1], and help construct the necessary cognitive models that enable the learner's deep learning [2]. For example, time-based two-dimensional images can be used to explain how the fluid flows under different conditions [3], [4]; three-dimensional models can be used to illustrate the chemical structure of DNA [5]. The learner can also interact with

these images or models to pick up essential knowledge or information from the prescribed responses [6]. Furthermore, simulation has been used to verify the learner's design approach and prompt the learner with important feedback [7].

In addition to the reported successes of simulation in STEM education, the use of simulated-based learning also brings new challenges to both instructors and learners. First of all, to reduce the cognitive workload of novice learners, the instructors might choose to start the learning process from a simplified task or system [2]. This might give the learner misconceptions of the task and system, and therefore wrongly assume and overlook important factors [8]. Secondly, while simulation provides means to manipulate variables that cannot be easily controlled in a real system, learners might choose to learn through trial-and-error, instead of mentally connecting the theory behind the scene with the tasks [9]. Finally, the presentation of the graphic results are still mainly accomplished using two-dimensional screens, and the interaction with the model is mainly with two-dimensional devices such as computer mice or touch screens. The eye-hand coordination [10] and mental rotation ability [11], [12] associated with the learner might limit his or her understanding of simulation results.

One example of the phenomenon mentioned is the learning of industrial robot programming in a computer simulated environment. The programming of industrial robots used to be performed through manual coding on a teach pendant connected to the robot controller (online teach programming). Depending on the tasks to be performed, once the coordinates and orientations of the robot arm's end effector were determined, robot paths could be created by specifying the tool tip's travel speeds and other motion parameters. Such an approach however was very slow, labor intensive and can be tedious, especially for complex programs. With technology breakthroughs in computing, the programming of industrial robots today is often performed offline on desktop computers. In an environment similar to modern 3D CAD/CAM software, the human programmer interprets and analyzes the presented geometry in virtual space, develops specific fabrication strategies, and details the action of the robot accordingly.

Figure 1 shows a screenshot of programming a robot using ABB's RobotStudio. This example shows a virtual material handling stacking products on a wooden pallet. The graphical workbench in the middle allows the user to specify the robot's motion in a 3D work cell, while the corresponding program code is presented simultaneously. For experienced programmers, such a computer simulated programming environment is very efficient and cost effective. Compared to the work needed for manual programming on the robot's teach pendant, the mathematics behind the simulated environment provides necessary precision and accuracy, thus greatly simplifies the task. The tool paths can be easily revised, and the embedded simulation engine provides visual inspection of process detail, including the detection of any possible collisions between the workpiece, the robot, and other items in the work cell.

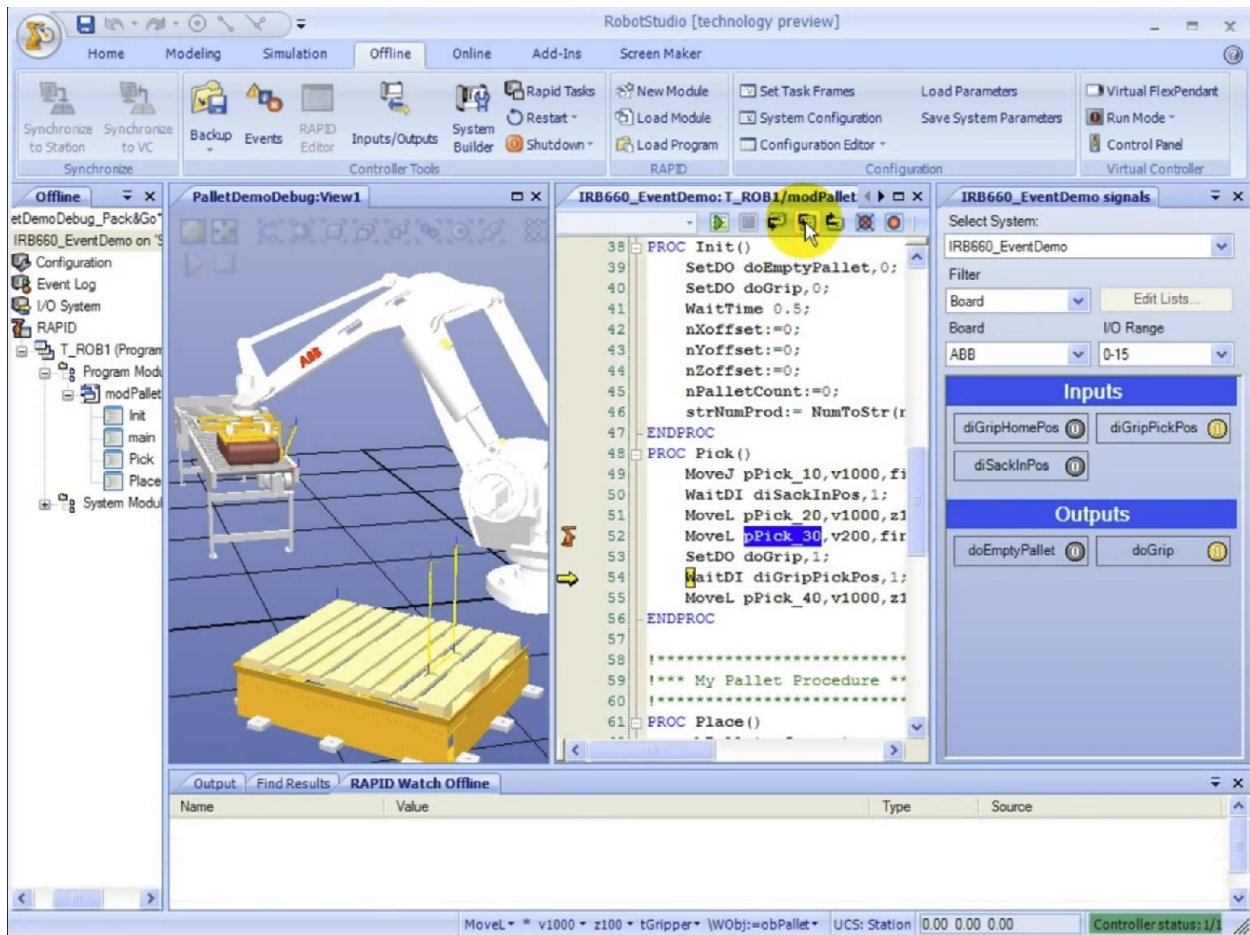


Figure 1 ABB RobotStudio software suite for offline robot programming [13]

Nevertheless, such a simulated robot programming environment can be quite challenging to novice learners. In a teaching environment the tasks in the programming tasks are often simplified to reduce the cognitive workload of learning. Student attention is usually focused on the robot's movement of the end of arm tool, whether it is a drill, a spot welder, a spray gun, or the two-jaw gripper for material handling. The learners may underestimate the complexity of the overall robot task by overlooking the spatial constraints posed by workpiece fixtures, part feeders, and other physical items in the robot work cell. The knowledge gained from CNC turning or milling, while helpful, is not fully transferable to industrial robots. Where CNC milling machines typically have 3 axes of motion, the movement of a modern articulated robot is accomplished through 6 or more axes. The necessity of axis-singularity avoidance along the path trajectory [14], [15] and considerations regarding robot axis configurations can be confusing. Novice learners might not be able to pinpoint these issues from the simulation, or choose to ignore as they do not understand the seriousness of these problems in their program code.

To prevent possible damage to the actual robot caused by the programming errors, and rectify the learner's misconceptions, an immersive design verification environment might be appropriate. Research studies using immersive environments driven by virtual reality (VR), augmented reality (AR), or mixed reality (MR) for training purposes have been reported [16]–

[18]. These three-dimensional environments allow the learner to explore the space in a stereo setting echoing his or her physical experience. The head mounted display and surrounding sensors enable the learner to navigate the virtual space by walking around and turning his or her head to change the viewpoint, instead of using a computer mouse or touch screen to spin the world or turn target objects around. By reducing the cognitive load from hand-eye coordination and/or mental rotation for space navigation (e.g. object translate, rotate, and zoom in/out), the learner, especially the novice one, can start paying attention to the robot's movement and its interaction with the rest of the virtual world.

Milgram et al. categorized the immersive display systems into seven classes based on four MR attributes, namely the principal scene's source (real vs. computer generated world), the substrate's presentation (direct vs. scanned view), the user's motion perception (exocentric vs. egocentric reference), and the need of conformal mapping (1:1 vs. 1:k) [19]. At the "real environment" end of their reality-virtuality continuum stands AR, where the real world is the focus of the user experience, enhanced with virtual details. At the "virtual environment" of the continuum stands VR, where the user fully immerses into the computer-generated, synthetic experience. MR, in which the real and virtual world are overlaid and even intertwined, exists in various forms between AR and VR. Milgram et al. also proposed a three-dimensional taxonomy for mixing real and virtual worlds. Three dimensions, extent of world knowledge (EWK), reproduction fidelity (RF), and extent of presence metaphor (EPM) were used to construct a 3D space, where the relationship between different display types can be spatially recognized. The authors claimed that the proposed taxonomy would help the future endeavor in the area of VR, AR, and MR.

Since different classes of computer displays and their corresponding immersive environments could lead learners to different cognitive interpretations and conclusions, it is essential for instructors to consider the MR attributes proposed by Milgram et al. to choose the right display device(s) to match his or her pedagogy. In this project, we plan to investigate how the use of VR can affect the learner's behavior and performance during the design verification stage of industrial robot programming. Figure 2 illustrates the setup of the project.

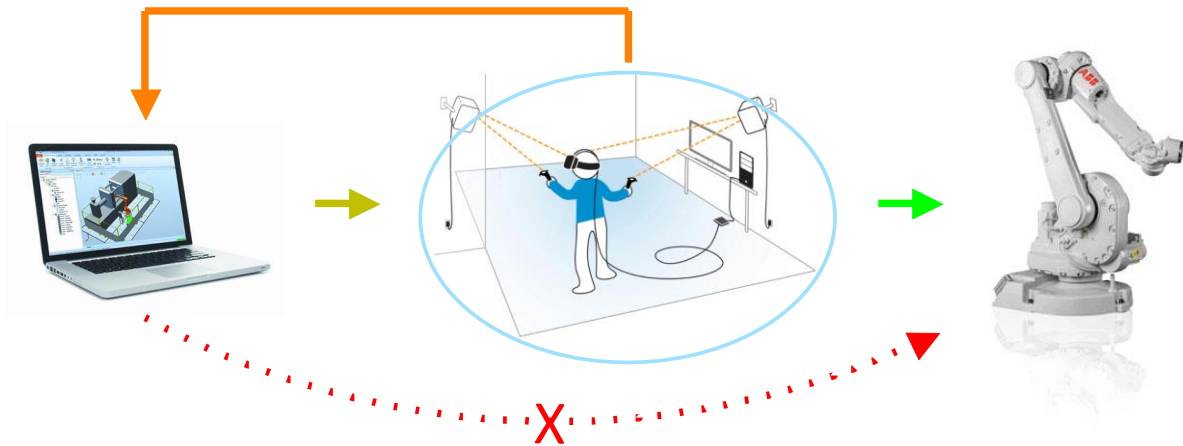


Figure 2 Project setup: From RobotStudio to VR inspection to ABB Robot

Conventionally the robot program was reviewed through desktop simulation prior to downloading it to the industrial robot for execution (red dotted line). We plan to use the virtual reality environment, circled in blue, as an intermediate stage to review the robot program before downloading it to the robot (green line). The olive-orange loop represents the iteration process of program revision, where the additional learning happens. VR was selected to drive the immersive environment instead of AR or MR because the VR environment can be controlled to a greater extent, displaying only content or information for performing cognitive tasks and/or measuring cognitive abilities. While AR or MR helps incorporate the physical surrounding for reference and comparison purposes, they can also introduce undesired cognitive workloads (e.g. distractions) from real-world surroundings.

Preliminary Findings

A preliminary study was conducted prior to the initiation of this project to help guide the determination of the project scope. A group of four student participants were asked to try the VR add-ons of ABB RobotStudio. The students used RobotStudio with and without VR tools to program an ABB robot to complete several tasks. The following is a summary of the preliminary findings:

- (1) All four participants agreed that the design verification process in ABB RobotStudio provided more usable “information” when the VR add-ons were used.
- (2) After some training, all four participants easily used VR space navigation including physically walking around, turning the head, and change body postures. They tended to walk “closer” to the virtual model or move back in order to “zoom in/out” in the immersive environment instead of using the VR system’s controllers.
- (3) The issues of object collision and robot's sudden movement became more "obvious" when using the VR interface.

From the results of preliminary study, it appears that further investigation on the VR's impact of learning performance in this application is warranted. The following section gives an overview of this proposed project.

Research Questions

This study seeks to contribute to the body of knowledge through our understanding of human-computer interaction with the VR applications in the design verification stage for industrial robot programming:

- (1) What are the common misconceptions in industrial robot programming caused by current desktop visualization formats commonly used for simulation?
- (2) Does VR improve a novice programmer's ability to identify robot program errors during simulation?
- (3) What is the theoretical basis for how VR interfaces might provide cognitive support or reduce cognitive workload in a robot programming environment?

Methodology

Figure 3 depicts the overall process of this project. A convenient sample strategy will be used, to recruit participants from TEC 392, the senior capstone course for Engineering Technology majors, and from TEC 234, the introduction course for Robotics.

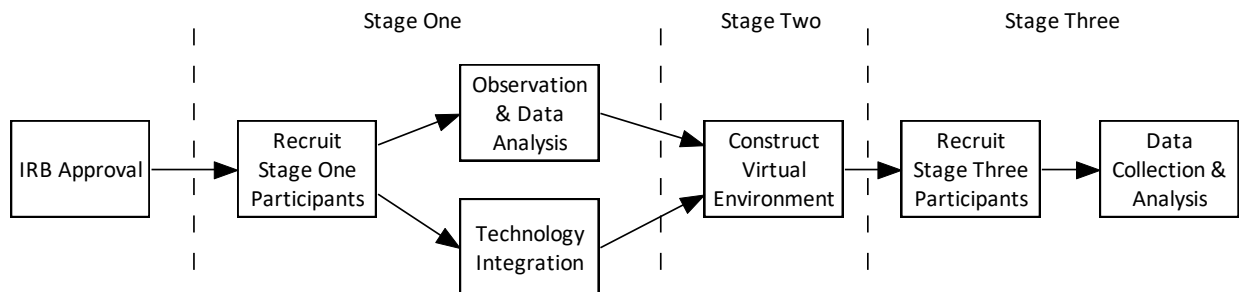


Figure 3 The project flowchart and key stages

Stage One

The goal of stage one is to understand how learners interact with different visual presentations during the design verification stage for robot programming (e.g. research objective #1). During the fall 2018 semester we will recruit participants from the senior capstone course. This group of participants has previously been exposed to the conventional way of creating robot programs, e.g. the red dotted line in Figure 2. Because the capstone project is ill-structured (open-ended), the participants will have to develop their own strategy to solve the problems. Their misconceptions therefore become more obvious and observable. We also plan to evaluate if the RobotStudio VR add-on is integrated appropriately, and see how the use of VR might alter

the participants' performance. Once the data has been collected and analyzed, an assessment tool for learner performance will be developed.

Stage Two

With the information from stage one, we will design a series of tasks and a corresponding virtual environment for experimentation purposes at stage three. Instead of using RobotStudio's VR add-ons, the focus of the customized virtual environment is to remove the possible distractions from the programming suite, and direct the participant's attention to the simulation itself. Unity [20] will be used as the rendering engine for two VR devices, HTC Vive and Oculus Rift. A workstation with a VR compatible graphic card will be used for testing at this stage.

Stage Three

The objective of this stage is to answer the last two research objectives, #2 and #3. Participants from both TEC 392 and TEC 234 will be recruited; participants from the former have been exposed previously to robot programming, while those from the latter course very likely have no experience in robot programming. The design of the experiment will utilize a 3x2 factorial design, with two independent variables, namely presentation format and navigation means, and one dependent variable, e.g. the learner's performance. The variable of presentation format has two levels, namely desktop and VR, while the variable of navigation means has three levels, namely computer mice, gaming controller (for Oculus Rift), and physical movement (for both Oculus Rift and HTC Vive). The learner's performance variable is a compound score consisted of speed and accuracy. Depending on the findings from Stage 1, the effect size will be calculated to determine the appropriate sample size.

Participants will utilize both RobotStudio and the created VR environment to evaluate the scripted robot simulation and identify the errors in programming. The assessment tool developed at stage one will be used to assess the learner's performance, and data will be collected; and the analysis will be performed using ANOVA to determine if a significance difference in learning performance improvement exists. In addition to collecting quantitative data through the learning performance assessment tool, we also plan to deploy post-experiment surveys for both stage one and three regarding the participants' background and perceptions. The self-reported data through the survey might help explain certain phenomenon observed during the course of experiment.

A research without a theoretical framework can at most be considered as a case study. For this reason, we intend to use cognitive workload analysis [21] and Dreyfus's model for adult skill acquisition [22], [23] to develop a theoretical model explaining what we find in both the desktop and VR learning environment in this application. The findings of these three stages can be used to determine the validity of the theoretical framework proposed. We also plan to utilize the three-dimensional taxonomy proposed by Milgram et al. [19] along with the research findings to point out the future research directions.

Conclusion

A project to understand the potential of virtual reality in enhancing student learning of industrial robotics has been proposed. We provided the justification of this research project and reported the findings from the preliminary study. An overview of the project was then given to inform readers of this ongoing research. We also discussed the expected outcomes and intended contribution of this paper to the body of knowledge in EDGD.

With the completion of this project, we will have a better understanding of how individuals interact with the immersive visual environment, and how individuals may perform differently with the assistance of VR technology. The findings, including the theoretical framework, can serve as the foundation to expand to other immersive visual computing technology such as AR or MR, and corresponding pedagogy and instructional material can be developed accordingly.

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