Can Virtual Reality Enhance User Performance and Experience by Reducing an Individual's Cognitive Workload?

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Abstract

Recent developments in Virtual Reality (VR) technology has prompted the manufacturing industry and software vendors to investigate VR's potential for process enhancement. In this paper, we present a study to investigate whether using VR could reduce an individual's cognitive workload during the process of programming an industrial robot. The rationale of the study and the design of the experiment are discussed first. The results, including time taken to accomplish the given tasks and the quality of the path plans, are presented, along with the results from a user experience survey. We conclude this paper with the discussion of the findings and the plan for future study.

Introduction

Path planning of the end effector is one key step for programming an industrial robot. It can be done either by synchronous, manual programming on a physical robot using a teach pedant, or by asynchronous, semi-automated programming through a CAD/CAM-like software. For the novice user, moving the end effector of the robot through the teach pedant is more intuitive, but very slow and tedious due to the built-in protection mechanism (Quarta et al., 2017). After the user becomes familiar with the basic of robotic operations, the programming of an industrial robot is often moved to the offline, computer-assisted planning environment. The program interface, similar to that of modern solid modeling packages, allows the user to register the end effector's corresponding positions and orientation sequentially, refer to the workpiece geometry if necessary, and verify the program through simulation and collision detection (Laumond, 1998; Takakura, Murakami, & Ohnishi, 1989).

Nevertheless, for asynchronous computer-assisted programming, the programmer (or process planner) is operating under a higher cognitive workload (Dadi, Goodrum, Taylor, & Carswell, 2014; Eberts & Salvendy, 1986). In a setting using 3D CAD/CAM systems with a two-dimensional screen, the user must often perform mental rotations and rely on hand-eye coordination to interpret the images on the computer screen. To address such a concern, Chang and Devine (2018) suggested that the use of virtual reality (VR) might significantly reduce the cognitive workload mentioned. The recent breakthrough of VR hardware and software could grant the user an immersive visual experience, allowing him or her to navigate the virtual space by using the controller's gesture, or simply by "walking" around.

To better understand such a phenomenon, we conducted an experiment to compare the user's performance of completing a robotic path planning task in both a conventional desktop setting and a setting with the VR add-on. Figure 1 depicts the path planning workflows in these two settings. The second half of both workflows, e.g. the design iteration to address the program problems found in computer simulation and dry-run on the physical robot, is the same. The main difference is the front-end conceptualization of the path. In the conventional setting, the user might spend time to take measurements at the robot cell, use the teach pedant to get some ideas, and jot down a note before starting from scratch with the path planning software. In the VR-assisted setting, however, the user could utilize the drag-and-drop function to create a draft path and refine it later in the desktop planning environment.

The intent of this study is to identify possible benefits and threats of introducing the VR-assisted approach to the curriculum, thus to improve students' learning outcome and experience. In this pilot study, overall program quality (e.g. does the program cause the robot to complete the required task?) and speed of completion are measured as they may provide a big picture of how an individual's task performance may be affected by different settings (McMorris, Sproule, Turner, & Hale, 2011). With the expected reduction of mental rotation and hand-eye coordination, the VR interface or VR-assisted workflow might affect an individual's task speed and accuracy (Gerhardt-Powals, 1996). Our research questions are whether the VR-assisted approach could (1) improve the user's task performance, in terms of programming quality and speed of completion, (2) enhance the overall experience of programming due to a lower cognitive workload.

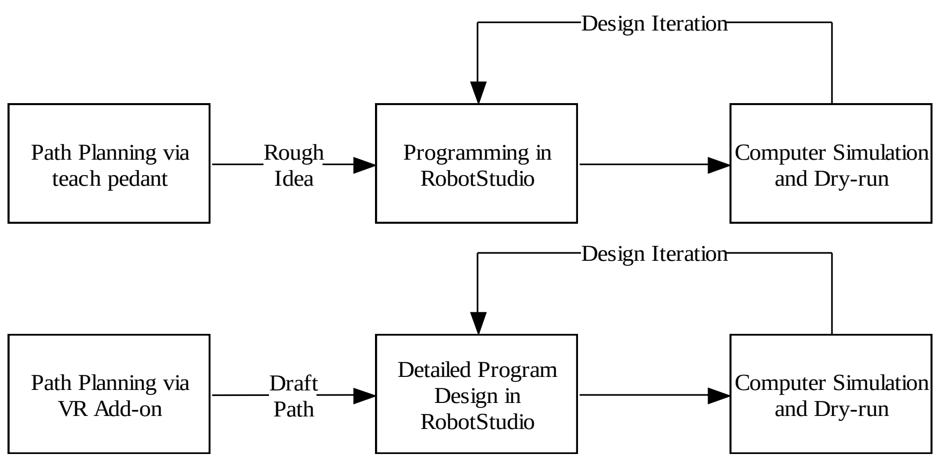

Figure 1. The plan-build-test workflow for robotic path planning; the top is for the conventional setting, while the bottom is for the VR-assisted setting.

Methodology

Nine participants were recruited from the undergraduate students enrolled in TEC 234 Robotic Systems Integration class offered in Spring 2019 at Illinois State University. There were eight males and one female, no minorities, all in junior or senior standing, and all Engineering Technology majors. Prior to the actual experiment, a 12-minute training video on how to use the VR add-on with a VR helmet, in this case the Oculus Rift, was provided for participants one week ahead of time as a self-paced tutorial, and the participants got the opportunity to familiarize with the functions of the VR add-on on the day of experiment.

The path planning task used for the experiment is shown in Figure 2. The goal of the task to be performed is to program the 6-axis robot, an ABB IRB 140 model, to:

- Use the 3-jaw gripper end effector to pick up a yellow disk from the left base
- Move the yellow disk toward the RFID scanner and scan the tag at the bottom of the disk
- Place the yellow disk on the right base

Each participant was asked to perform the task first in the conventional, desktop ABB RobotStudio suite, and repeat the same task with the help of the VR add-on. An undergraduate teaching assistant was asked to help conducting the experiment, providing a quick review of the VR add-on's function as well as standing by for Q&A and troubleshooting. At the end of the experiment, each participant completed a self-reporting survey to describe their experience with the VR add-on, in terms of completing the same task in the conventional or the VR-assisted setting, and the likelihood for them to adopt the VR add-on for the planning stage of their final class project if given the opportunity.

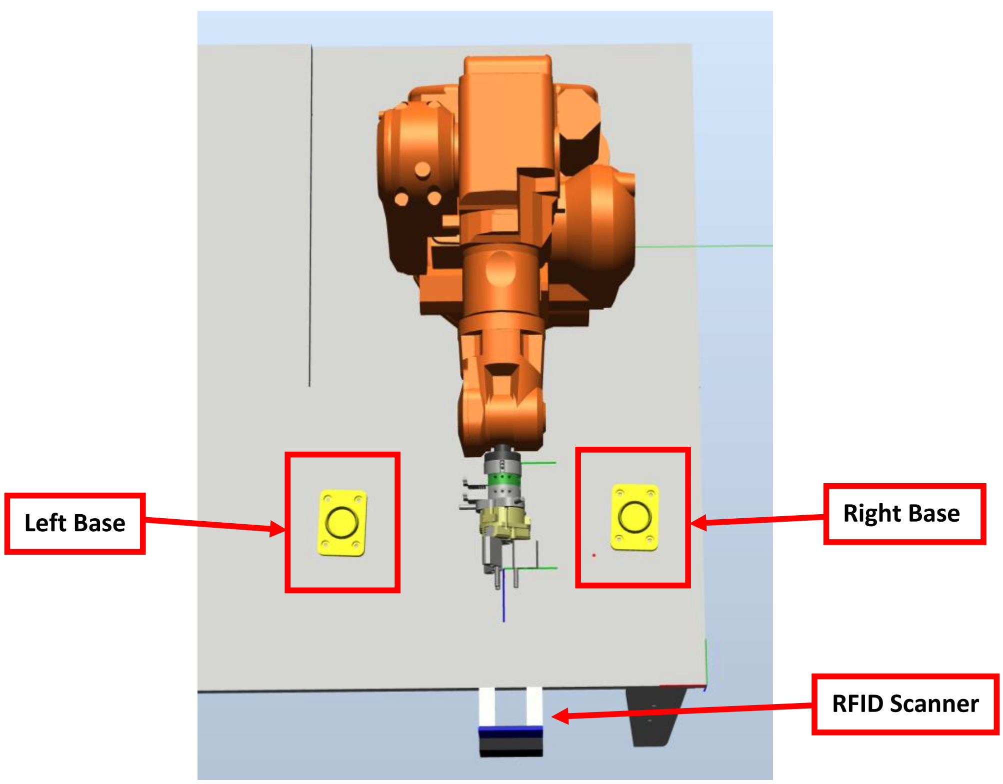

Figure 2. Top view of the path planning task

It is worth noting that we did not investigate the possible impact of cybersickness on participants' performance. Cybersickness, or simulator sickness (Davis, Nesbitt, & Nalivaiko, 2015; Johnson, 2005) is caused by perceived discrepancies between the simulator's motion and actual movement, especially after extended usage. By carefully planning the user's starting position and orientation in the VR environment, participants in the experiment were able to begin interacting with the virtual robot without teleporting or uncoordinated body movement, thus avoid being affected by cybersickness.

Results and Discussion

An example path created in RobotStudio by one of the participants is shown in Figure 3. Starting from the robot's default (home) position, the yellow dashed lines and arrows illustrated how the robot's end effector will be moved in the space to complete the task. The draft path created with the VR add-on is similar conceptually but might not be as precise due to accuracy limits of current VR technology (Borrego, Latorre, Alcañiz, & Llorens, 2018; Niehorster, Li, & Lappe, 2017).

Each participant's task performance was measured by the time taken to complete the task, and the overall quality (score) of the completed robot program. The results of both the VR and conventional programming activities is shown in Table 1. The time taken to complete the task was measured in minutes; in the conventional setting the time from the start of the task to the submission of the file was calculated. In the VR-assisted setting, the time from the beginning to the end of the task recorded by the experiment proctor was calculated. The score relating to the program quality was determined by the instructor of TEC 234, who is the subject matter expert, using a grading rubric similar to other rubrics used throughout the course. The score was based on a 10-point scale, where 1 was the lowest quality and 10 was the highest.

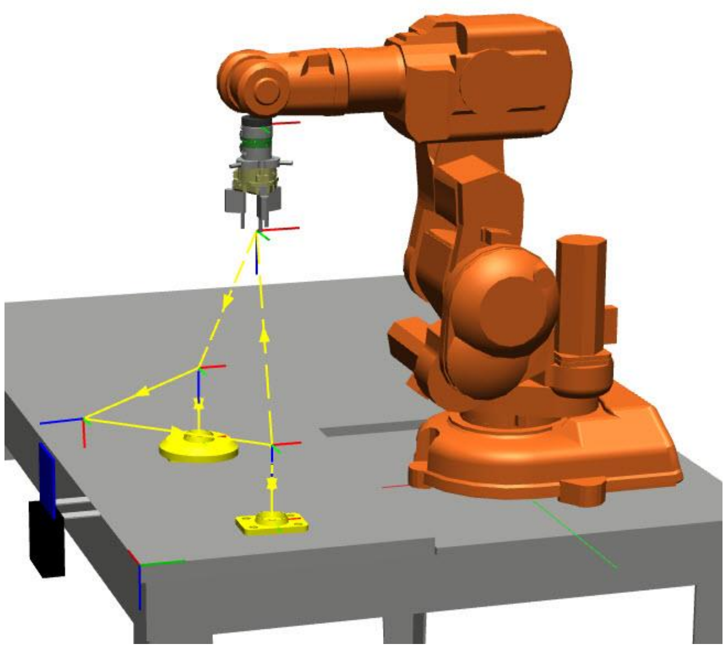

Figure 3. An example path of the end effector

Participant	Time taken – Desktop (mins)	Time taken – VR add-on (mins)	Score – Desktop (out of 10 points)	Score – VR add-on (out of 10 points)
1	20	12.05	5	6
2	55	7.95	9	9
3	43	10.25	8	8
4	37	13.75	10	10
5	50	6.22	7	6
6	32	14.85	8	9
7	81	16.45	3	2
8	44	16.95	9	7
9	75	11.50	8	9
Average	**48.6 (σ = 19.6)**	**12.2 (σ = 3.7)**	**7.4 (σ = 2.2)**	**7.3 (σ = 2.4)**

Table 1. Time taken and program quality score of individual participants in conventional desktop setting and with the assistance of the VR add-on.

Table 1 shows that there was not much difference for either the individual participants' scores or the average scores of program quality between these two settings. This was expected because no feedback or grade was provided to the participants before they moved from the conventional setting to the VR-assisted setting. The quality score was a good indicator the participant's knowledge and skill level of path planning, which did not change significantly just because of the repetition of the task. Nevertheless, the individuals' time taken to complete the task varied greatly, and the difference between the average time taken in the conventional setting and the average time taken in the VR-setting was significant. While the difference could be due to the training effect, since the same task was performed twice on the same day, it also could suggest that the VR add-on might reduce the student's cognitive workload, allowing the participants to complete the task in a much shorter time.

While the participant's performance was evaluated separately based on program quality and time taken (e.g. speed of completion), these two measures can be combined into a global measurement to address the speed-accuracy trade-off. Chignell, Tong, Mizobuchi, and Walmsley (2014) proposed to use the negative standardization of variables with predetermined weights to calculate the participants' performance. We plan to adopt their approach in future work, including determining the appropriate weights for the contribution proportion of variables "program quality" and "time taken" toward the global score.

The result of the self-reporting survey is shown in Table 2. In the survey, the participants were asked to share their opinions regarding the conventional and VR programming exercises. A 1-to-5 Likert scale, where 1 was the poorest experience rating or the least likely, and 5 was the highest experience rating or most likely. On average the participants ranked their experience in the VR-assisted setting higher, and the likelihood to use VR for their final projects (if given the opportunity) was either 4 or 5 except for the first participant, whose program quality was not stellar. According to written comments from participant 1, he or she was expecting that that VR add-on would have all the functions of the desktop version (e.g. a direct mapping), while the current version of the VR tool was not yet on a par with that of the desktop version.

Another participant rated his or her experience of using the VR add-on lower than that of using the conventional approach was participant 4. This could due to his or her familiarity of the desktop setting, as shown in a 100% score on program quality, and thus could not find the added value of using the VR add-on. However, he or she recognized the usefulness of the VR add-on for the final project, with a likelihood of 4 out of 5.

Participant	Experience – Desktop	Experience – VR add-on	Likelihood to use VR for final projects
1	3	2	2
2	5	5	4
3	2	4	5
4	4	3	4
5	3	5	5
6	3	4	4
7	3	5	5
8	4	4	5
9	3	5	5
Average	**3.3**	**4.1**	**4.3**

Table 2. The result of the self-reported survey regarding the experience of using either approaches for path planning, and the likelihood to use VR for final projects.

Conclusion

A preliminary study was conducted to better understand if a VR add-on could enhance the user performance and experience by reducing the cognitive workload when programming an industrial robot. While the sample size is relatively small (nine to be exact), there was evidence that in the VR-assisted setting the time needed to complete the task was shorter, and the user experience rating of the VR tool was higher. Both observations could be attributed to the reduction of an individual's cognitive workload.

In the future, we plan to revise the experiment protocol to help differentiate the change of user performance and experience due to the factor of mental rotation or hand-eye coordination. Because an individual's cognitive workload depends on his or her working memory capacity, we plan to adopt Baddeley and Hitch's model (2011) to determine individuals' cognitive capacity prior to their participation of future experiments. In addition to randomly assigning the treatment sequence (conventional vs. VR-assisted) between two similar yet different tasks and increasing the sample size, we intend to measure each participant's mental rotation ability using a standardized instrument and limit their navigation approach in the virtual space.

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