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Development of Virtual Reality Robotics Laboratory Simulation

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Dr. Reg Pecen is currently a Quanta Endowed Professor of the Department of Engineering Technology at Sam Houston State University in Huntsville, Texas. Dr. Pecen was formerly a professor and program chairs of Electrical Engineering Technology and Graduate (MS and Doctoral) Programs in the Department of Technology at the University of Northern Iowa (UNI). Dr. Pecen served as 2nd President and Professor at North American University in Houston, TX from July 2012 through December 2016. He also served as a Chair of Energy Conservation and Conversion Division at American Society of Engineering Education (ASEE). Dr. Pecen holds a B.S in EE and an M.S. in Controls and Computer Engineering from the Istanbul Technical University, an M.S. in EE from the University of Colorado at Boulder, and a Ph.D. in Electrical Engineering from the University of Wyoming (UW, 1997). He served as a graduate assistant and faculty at UW, and South Dakota State University. He served on UNI Energy and Environment Council, College Diversity Committee, University Diversity Advisory Board, and Graduate College Diversity Task Force Committees. His research interests, grants, and more than 50 publications are in the areas of AC/DC Power System Interactions, distributed energy systems, power quality, and grid-connected renewable energy applications including solar and wind power systems. He is a senior member of IEEE, member of ASEE, Tau Beta Pi National Engineering Honor Society, and ATMAE. Dr. Pecen was recognized as an Honored Teacher/Researcher in ”Who's Who among America's Teachers” in 2004-2009. Dr. Pecen is a recipient of 2010 Diversity Matters Award at the University of Northern Iowa for his efforts on promoting diversity and international education at UNI. He is also a recipient of 2011 UNI C.A.R.E Sustainability Award for the recognition of applied research and development of renewable energy applications at UNI and Iowa in general. Dr. Pecen established solar electric boat R & D center at UNI where dozens of students were given opportunities to design solar powered boats. UNI solar electric boat team with Dr. Pecen's supervision won two times a third place overall in World Championship on solar electric boating, an international competition promoting clean transportation technologies in US waters. He was recognized as an Advisor of the Year Award nominee among 8 other UNI faculty members in 2010-2011 academic year Leadership Award Ceremony. Dr. Pecen received a Milestone Award for outstanding mentoring of graduate students at UNI, and recognition from UNI Graduate College for acknowledging the milestone that has been achieved in successfully chairing ten or more graduate student culminating projects, theses, or dissertations, in 2011 and 2005.

He was also nominated for 2004 UNI Book and Supply Outstanding Teaching Award, March 2004, and nominated for 2006, and 2007 Russ Nielson Service Awards, UNI. Dr. Pecen is an Engineering Technology Editor of American Journal of Undergraduate Research (AJUR). He has been serving as a reviewer on the IEEE Transactions on Electronics Packaging Manufacturing since 2001. Dr. Pecen has served on ASEE Engineering Technology Division (ETD) in Annual ASEE Conferences as a reviewer, session moderator, and co-moderator since 2002. He served as a Chair-Elect on ASEE ECC Division in 2011. He also served as a program chair on ASEE ECCD in 2010. He is also serving on advisory boards of International Sustainable World Project Olympiad (isweep.org) and International Hydrogen Energy Congress. Dr. Pecen received a certificate of appreciation from IEEE Power Electronics Society in recognition of valuable contributions to the Solar Splash as 2011 and 2012 Event Coordinator. Dr. Pecen was formerly a board member of Iowa Alliance for Wind Innovation and Novel Development (www.iawind.org/board.php) and also represented UNI at Iowa Wind Energy Association (IWEA). Dr. Pecen taught Building Operator Certificate (BOC) classes for the Midwest Energy Efficiency Alliance (MEEA) since 2007 at Iowa, Kansas, Michigan, Illinois, Minnesota, and Missouri as well as the SPEER in Texas and Oklahoma to promote energy efficiency in industrial and commercial environments.

Dr. Pecen was recognized by State of Iowa Senate on June 22, 2012 for his excellent service and contribution to state of Iowa for development of clean and renewable energy and promoting diversity and international education since 1998.

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Dr. Suleiman M Obeidat, Sam Houston State University

Dr. Suleiman Obeidat received his Ph. D. in Industrial Engineering from University of Oklahoma in 2008. Dr. Obeidat joined the Engineering Technology Department at Sam Houston State University in Fall 2021. Dr. Obeidat teaches different courses such as Product Design and Solid Modeling, Materials and Manufacturing, Mechanics for Technologists, Quality Assurance and Manufacturing Processes. Dr. Obeidat's research focuses on additive manufacturing and inspection of machined surfaces using Coordinate machines (CMM). Dr. Obeidat is a reviewer for different journals in manufacturing and inspection.

Lain Edward Sowell, Sam Houston State University

My name Is Lain Sowell, I am currently a student at Sam Houston State University. I am working on a VR robotic arm project that I started in the summer of 2021. My personal goals are to find a career in computer software, and to develop new technologies to improve everyday life. Although I haven't gotten to these goals yet, I've made great achievements such as becoming the secretary of the VR club at Sam Houston State University, working on and completing a project that could be used to train people in using the Fanuc robotic arm. To accomplish the goals I listed, I have developed the necessary skills that will be required, such as programing in Java and c#, getting certified in Auto cad, working with the game engine Unity, communication skills, and outreach.

Introduction

One of the important engineering courses at the University is learning a robotic arm as part of the coursework. In this regard, colleges employ various equipment to teach students how to conduct a safe starting sequence of the robotic arm, execute basic manual controls through various tasks such as picking up an object and dropping in a bin or placing on an assembly line, program automatic operations, and turn off the equipment safely. Although every student must learn these basic operations, the limited space in the laboratory or financial challenges allow colleges to educate with a smaller number of equipment than the class size. Moreover, spring 2020 semester required all educational institutions to conduct their classes remotely due to the global pandemic. Therefore, development of a virtual reality simulated robotic arm was important for effective learning remotely and experience hands on operation to train muscle memory.

The advancement of novel technology in virtual reality (VR) in the game industry and medical fields [1]–[5] enabled users to experience immersive environments to simulate real life like scenarios. Additionally, clinical studies have shown significant improvement in human health recovery with the assisted VR motor trainings [6]. Virtual environments can serve as a mediator between the human operator and the robotic arms to improve perception of the equipment. In this study we explore the effectiveness of a VR simulated Fanuc robotic arm as a remote learning tool. We replicated the existing robotics laboratory in the VR environment to provide realistic experience to the students in the course.

Related Work

Commonly used desktop computer tethered VR head mount [7], which makes it unpractical for mobile operation unless the student uses it behind their computer desks. Additionally, tethered VR equipment such as Oculus Rift S and HTC Vive are significantly more expensive compared to Oculus Quest. Moreover, Abtahi et al [8] discussed that the head mounted display, compared to desktop VR provides users higher sense of spatial presence and immersion.

Virtual reality interfaces provide intuitive immersive experiences for mapping a user's motion actions and observations, hence develop muscle memory. Additionally, non-expert users of robotic arms are more efficient [9] with VR interface compared to the keyboards that are typically provided with the teaching pendants. For instance, the da Vinci Robot System is an immersive haptic surgery simulated system that demonstrated increased learning and retention for novice and experienced users[10]. However, to reduce bias and increase the analysis accuracy, we replicated the operation of pendant to the original.

This research has shown that the VR robotic operations have increased the effectiveness of the VR technology in various industries. In this regard, the development of engaged educational materials to support both instructors and students need in almost every lab-based classes.

Methods

There are certain steps to start the FANUC robot arm such as E-Stops in the teach pendant and in the standard operator panel for safety reasons. In addition, the teach pendant has DEADMAN switch, which must be always pressed while programming the arm – error pops up if the switch is released. There are three modes in the operator panel – Auto, T1 and T2. To enable control from teach pendant the mode select switch must be in T1 mode, which restricts the jog and program testing speed. Once the controller powers up, and control stays with the teach pendant, now it can be programmed to perform certain task. There are different coordinate systems for the FANUC robot, but we mainly use “joint” and “world”. During “joint” mode, the 6 joints of FANUC arm combine to make the move, while in “world” mode it works with x, y and z axis and rotation around them.

The participating students completed two tasks: Task 1-Start up sequence of the robotic arm per manufacturer’s instruction manual, and Task 2: - Pick up an object and place it in the designated bin. For data collection and analysis for independent sample t tests and a paired t test, we divided the participating groups as follows: VR – student group that participated in the immersive portion of the experimental test, which comprises of Tasks 1 and 2; IP – student group that participated physically in person for both tasks; VRIP – student group that completed the task in VR and IP; IPNVR – student group that completed the task IP but not in VR as shown on Figure 1.

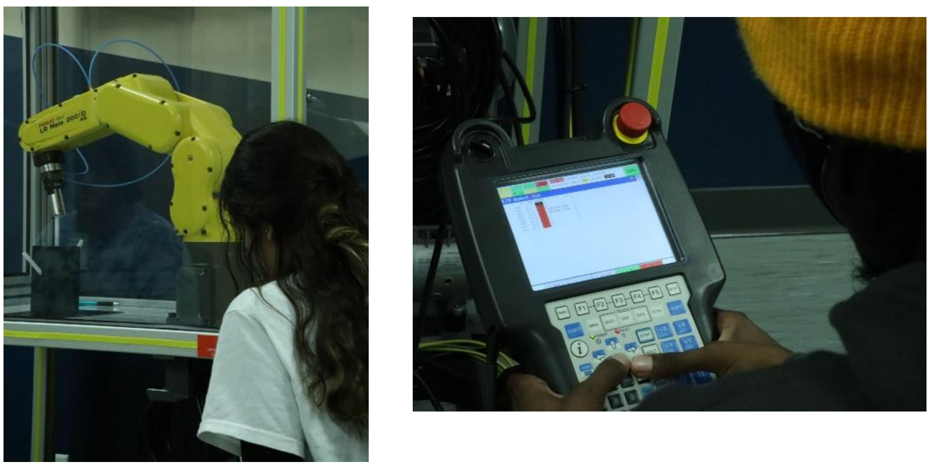


Figure 1. Teach pendant control participation In Person

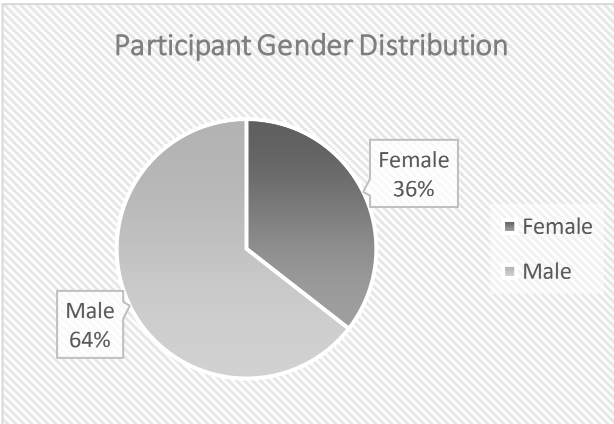
The VR group never received any instructions on how to perform either Task 1 or Task 2. Instead, we provided the Oculus Quest head mount for the participants to independently lean the robotic arm with trial and error. The purpose of this is to explore how effective is the VR versus the in-person instruction or a tutorial manual.

Generic start up sequence for the robotic arm begins with the user turning the mode switch key on the startup panel to the desired operational mode, which in our case is labeled T1 mode. Then the student needs to toggle the power switch to turn on the robot. Once the robot is powered up and ready to begin, the student must access pendants menu to select the I/O functions with the arrow keys on the pendant. This will activate the toggle to turn the tool on and off for the task.

The jogging allows the user to operate the robot with a series of buttons, instead of having to program the sequence. When in Jogging mode, the buttons that are used for operation our colored blue and located on the right side of the pendent, and each one is labeled with the axis they control. Each row of these buttons controls a different joint on the robot. Using these controls, the students can maneuver the robot to pick up an object vertically.

Data Analysis

Total number of 45 randomly selected students, whose 36% were female and 64% male (Female = 16, Male =29), from both engineering and non-engineering disciplines participated in the study (Figure 2a). Fifteen of the participating students conducted a paired sample t Test and the rest (Figure 2b) were shuffled for independent sample t Test to investigate the effectiveness of the VR application to learn Robotic Arm.



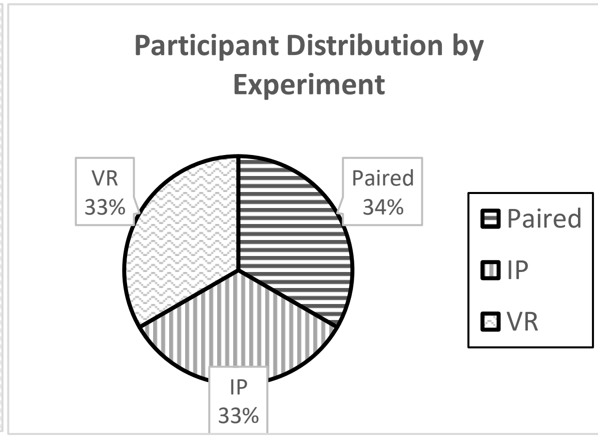


Figure 2a. Sixty four percent of Male and thirty six percent of Female participated in the study

Figure 2b. Number of participants in each category (VR, IP, and Paired)

For the paired sample t Test, 15 students received a head mounted device (Oculus Quest) to independently conduct Task 1, which is the start up sequence with no additional verbal assistance. Moreover, this group did not receive any instructional manual as a reference.

Table 1. Paired Sample Statistics between VR and VRIP for Start Up Sequence

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
VR vs VRIP	VR	2.73	15	0.72	0.19
	IP	2.8	15	0.74	0.19

The paired sample test, analyzed in IBM's SPSS 27, outcome (Table 1) shows descriptives for paired sample t Test. The Table 2 shows that the p value = 0.78 was higher than the alpha level a=0.05, indicating that there is no significant difference between these two methodologies for the same people (pretest and posttest), although the VR group completed the start up sequence faster Mean VR = 2.73 < Mean IP =2.8.

Table 2. Paired Sample t Test for VR and VRIP for Start Up Sequence

Paired Samples Test										
		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
VR vs VRIP	VRtest - VRIPTest	-0.07	0.92	0.24	-0.58	0.44	-0.29	14	0.39	0.78

These two tables (Table 1 and 2) show that learning independently in engaged VR immersive Robotic Arm Lab activities is as good as completing the same activities in person. Descriptives and analysis outcomes are reported in Tables 3 and 4.

Table 3. Descriptives for VR vs IP groups

Group Statistics					
	GROUPS	N	Mean	Std. Deviation	Std. Error Mean
VR vs IP	VR	30	2.61	0.79	0.14
	IP	15	2.5	0.81	0.21

For independent sample t Test for Task 1, there were 30 VR participants (15 independent VR and 15 from paired VR, Figure 2b) that were compared to an independent in person (IP, Figure 2b) group (not part of the paired IP group).

Table 4. Independent Sample t-Test for VR vs IP Task 1

Independent Samples Test											
		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
VRvsIP	Equal variances assumed	0.11	0.75	0.45	43	0.33	0.66	0.11	0.25	-0.39	0.62
	Equal variances not assumed			0.44	27.48	0.33	0.66	0.11	0.25	-0.41	0.63

Tables 3 and 4 also show that there was not significant difference (p=0.66>alpha =0.05) between two groups (Table 4) although IP group's average time was faster (Table 2) compared to the VR group. This also tells us that the virtual reality learning with no instruction provided is as good learning as the conventional way of teaching the students with both oral instructions and providing the instructional manuals for reference.

Table 5 and 6 show the comparative analysis between two independents in person (IP) groups for Task 2. First IP group, VRIP, is from the paired group, where they have learned the controls of the robotic arm independently in VR. The second in person group (IPNVR) is an independent group of participants that completed the task without any interaction with the VR, however, they did receive oral instructions and the reference manual for their operation.

Table 5. Independent Sample t – Test for VRIP vs IPNVR

Group Statistics					
GROUPS		N	Mean	Std. Deviation	Std. Error Mean
VRIPvsIPNVR	VR	15	2.8	0.74	0.19
	IP	15	2.5	0.81	0.21

Descriptive statistics shows (Table 5) that the number of participants was equal N=15. Independent sample t-Test (Table 6) shows that there is no significant difference between groups, although IPNVR group were slightly faster (Mean IPNVR = 2.5 < Mean VRIP =2.8).

Table 6. Independent Sample t-Test for VR vs IP Task 1

Independent Samples Test VRIP vs IPNVR											
		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
VRIPvsIPNVR	Equal variances assumed	0.02	0.89	1.06	28	0.15	0.3	0.3	0.28	-0.28	0.88
	Equal variances not assumed			1.06	27.81	0.15	0.3	0.3	0.28	-0.28	0.88

We also conclude from table 6 that there is not significant difference (p=0.3 > alpha =0.05) between the two independent in person groups. One more time we see that the independent simulated learning in VR is equally effective as receiving in person instructions with the reference materials. The time difference between the VRIP and IPNVR group is 14 days, therefore, VRIP's retention of information, that is, controlling the robotic arm has been almost equal with the new IPNVR group that freshly received the traditional training on the robotic arm operation.

Next, we analyzed how the robotic arm operation differs between two instruction methods. To answer if there is any significant difference between an independent learning in VR vs conventional instruction in person, we conducted same statistical methods as before. We will discuss a paired sample t Test for the pretest and posttest for VR and IP, then we will analyze independent sample comparative means.

Table 7. Paired Sample Statistics between VR and VRIP for Robot Control

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
VR vs VRIP	VR	5.07	15	5.97	1.54
	VRIP	2.5	15	1.78	0.46

The paired sample test outcome (Table 7) shows descriptives for paired sample t Test. The Table 8 shows that the p value = 0.1 was higher than the alpha level a=0.05, indicating that there is no significant difference between these two methodologies for the same people (pretest and posttest), although the VRIP group completed the object pick up and bin drop operation faster Mean VRIP = 2.5 < Mean IP =5.07.

Table 8. Paired Sample t Test for VR and VRIP for Robot Control

Paired Samples Test										
		Paired Differences					t	df	Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				One-Sided p	Two-Sided p
					Lower	Upper				
VR vs VRIP	VRtest - VRIPTest	2.58	5.66	1.46	-0.56	5.71	1.76	14	0.05	0.1

Tables 1 and 2 show that learning independently in engaged VR immersive Robotic Arm Lab activities is as good as completing the same activities in person. For independent sample analysis between VR and IP for robotic arm control (Table 9 & 10) there were 30 VR and 15 IP participants (Table 9).

Table 9. Independent Sample t-Test for VR vs IP Task 2

Group Statistics					
	GROUPS	N	Mean	Std. Deviation	Std. Error Mean
VRvsIP	VR	30	4.01	4.48	0.82
	IP	15	4.75	2.57	0.66

Tables 9 and 10 also show that there was no significant difference (p=0.55>alpha =0.05) between two groups (Table 10) although IP group's average time was faster (Table 9) compared to the VR group. This also tells us that the virtual reality learning with no instruction provided is as good learning as the conventional way of teaching the students with both oral instructions and providing the instructional manuals for reference.

Table 10. Independent Sample t-Test for VR vs IP Task 2

Independent Samples Test											
		Levene's Test for Equality of Variances		t-test for Equality of Means							
		F	Sig.	t	df	Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						One-Sided p	Two-Sided p			Lower	Upper
VRvsIP	Equal variances assumed	0.74	0.39	-0.6	43	0.28	0.55	-0.75	1.25	-3.27	1.78
	Equal variances not assumed				42.02	0.24	0.48	-0.75	1.05	-2.87	1.38

Tables 11 and 12 show the comparative analysis between two independents in person (IP) groups for Task 2. First IP group, VRIP, is from the paired group, where they have learned the controls of the robotic arm independently in VR. The second in person group (IPNVR) is an independent group of participants that completed the task without any interaction with the VR, however, they did receive oral instructions and the reference manual for their operation.

Table 11. Independent Sample t – Test for VRIP vs IPNVR for Robot Control

Group Statistics					
GROUPS		N	Mean	Std. Deviation	Std. Error Mean
VRIPvsIPNVR	VR	15	2.5	1.78	0.46
	In Person	15	4.75	2.57	0.66

Descriptive statistics shows (Table 11) that the number of participants was equal N=15. Independent sample t-Test (Table 12) shows that there is a significant difference between groups (p=0.01<alpha = 0.05), illustrating that people in VR are significantly faster (Mean VRIP = 2.5 < Mean IPNVR =4.75).

Table 6. Independent Sample t-Test for VR vs IP Task 1

Independent Samples Test											
		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
VRIPvsIPNVR	Equal variances assumed	2.47	0.13	-2.79	28	0	**0.01**	-2.26	0.81	-3.91	-0.6
	Equal variances not assumed			-2.79	24.95	0	0.01	-2.26	0.81	-3.92	-0.59

These last two tables 11 and 12 showed that there is a significant difference (p=0.01 < alpha =0.05) between the two independent in person groups. Interestingly, we see that the independent simulated learning in VR is significantly more effective than receiving in person instructions with the reference materials. Similarly, the time difference between the VRIP and IPNVR group is 14 days, therefore, VRIP's retention of information, that is, controlling the robotic arm has been better with the new IPNVR group that freshly received the traditional training on the robotic arm operation.

Conclusion

This study investigated the effectiveness of VR independent learning for an engineering course. From number of analyses, we observed that the VR learning is as good as in person learning, where the students receive traditional instructions as well as reference materials. However, the last comparative test (Tables 11 and 12) resulted that the students that completed an independent VR simulated learning completed the robotic control operations significantly faster than the traditional way of learning. This suggests that incorporating a VR technology in STEM related disciplines, where hands on laboratory activities are needed, can be as good resource or even better than the traditional learning. Moving forward, we will be expanding this study to other courses as well as research questions.

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