Leveraging VR and Force-Haptic Feedback for an Effective Training with Robots

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Abstract: The utilization of robots for numerous tasks is what defines automation in the industrial sector in the era we are going through for multiple fields, including insect farming. As an outcome of this progression, human-robot collaboration is becoming increasingly prevalent. Industrial workers must receive adequate training in order to guarantee optimal operational efficiency and reduce potential risks connected with the use of high-value machinery like robots given the precise and delicate handling requirements of these machines. Accordingly, we propose a framework that integrates Virtual Reality (VR) technologies with force and haptic feedback equipment. This framework aims to simulate real-world scenarios and human-robot collaboration tasks, with the goal of familiarizing users with the aforementioned technologies, overcoming risks that may arise, and enhancing the effectiveness of their training. The proposed framework was designed in regard to insect farming automation domain with the objective of facilitating human-robot collaboration for workers in this field. An experiment was designed and conducted to measure the efficiency and the impact of the proposed framework by analyzing the questionnaires given to participants to extract valuable insights.

1 INTRODUCTION

Due to globalization and the growing demand for distinctive products, new challenges have emerged in the industrial sector. Industries, in order to maintain their competitiveness in the mass production model, needed to redesign their manufacturing system (Bragança et al., 2019). Therefore, the operation of robots became a key component by automating a variety of tasks and thus handling the constant increase of demand which also corresponds to the rising of annual revenue. Consequently, a necessity for humans to engage in collaborative efforts with robots at an industrial level to boost overall productivity and enhance efficiency has emerged. Thereby, the concept of Industry 4.0 was introduced (Robla-Gómez et al., 2017).

Industry 4.0 is envisioned as the fourth Industrial revolution that signifies today's industrial sector considering that technological leaps have a tremendous impact on the growth and evolution of Industries. The first field of mechanization (1st industrial revolution), the immense usage of electricity (2nd industrial revolution) and widespread digitalization (3rd industrial revolution) characterized the industrial sector in the past years (Lasi et al., 2014). The progression of technology and artificial intelligence entered the capability of automation and more robust decision-making mechanisms for industries, empowered with real-time performance management systems, leading to Industry 4.0 (Aoun et al., 2021).

Companies are progressively employing sensors and wireless technologies to gather data on the entire lifecycle of a product achieving smart manufacturing. These mechanisms are increasingly used to accumulate data that contribute to product design and manufacturing. In addition, the utilization of big data analytics is also used to identify causes of failure as well as to optimize product performance and enrich production efficiency (Kusiak, 2017). A key challenge for smart manufacturing is to connect the physical and virtual spaces. The rapid evolution of simulations, data communication, and cutting-edge technologies created a new era in the interactions between

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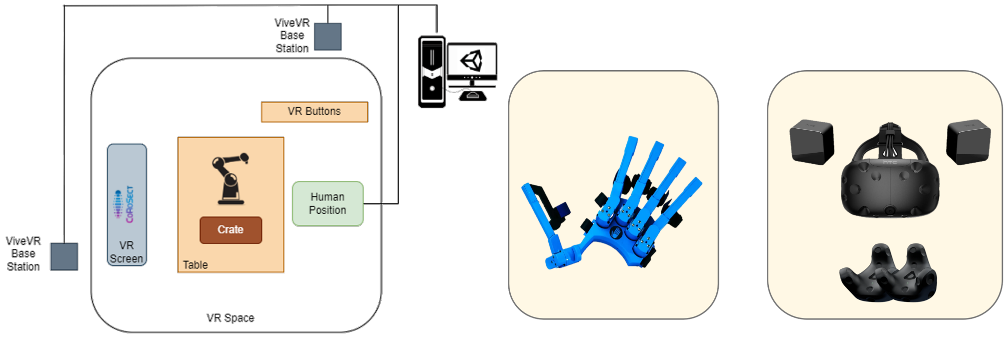

(a) Spatial Setup (b) SenseGlove (b) HTC Vive VR and Vive Trackers

Figure 1: (a) Spatial Setup (b) SenseGlove (c) HTC Vive VR Headset and two Vive Trackers.

physical and virtual spaces (Tao et al., 2019). Digital Twins integrate the physical and virtual data throughout a product lifecycle. When combined with analysis results of the collected data, can be used to improve the performance of a process in the physical space, hence is a vital feature of Industry 4.0 (Qi and Tao, 2018).

Industry 4.0 is characterized by humans and robots having the same goal and following a sequence of shared actions to achieve it (Weiss et al., 2021). For the collaborative assignments between humans and robots, humans need to be trained to ensure smooth cooperation. Stemming from the unfamiliarity of humans with robots, which are expensive equipment requiring precise manipulation and to mitigate risks pertaining to the safety of humans during their cooperation, proper and efficient training is mandatory.

Robots have already become a key component of Industry 4.0 and have replaced many procedures that have so far been performed manually and started to move out of laboratory and manufacturing environments into more complex human working environments (Bauer et al., 2008). Collaboration between humans and robots became an efficient way for enterprises to increase their productivity level while reducing production costs and thereby increasing their annual revenue (Matheson et al., 2019). Collaborative robots, often referring as cobots (Colgate et al., 1996), are designed with the purpose of working simultaneously with human workers to perform a specific task in a much more productive and safer environment.

On a robotic environment, a novel form of training, overcoming risks associated with real equipment to ensure the safety of the trainee, occurs. Human-robot collaboration can be dangerous due to the high-speed movements and massive forces generated by industrial robots (Oyekan et al., 2019). Therefore, digital training emerged through technologies such as Virtual Reality (VR), force and haptic feedback, and digital twins. In particular, digital twin, which is a virtual replica of real-life objects that simulate their behavior, not only enhances the training process but also can enable the integration of cyber-physical systems (Hochhalter et al., 2014).

Based on a comprehensive review of several training mechanisms that utilize VR technologies, this paper proposes an innovative and efficient training framework in a robotic environment. Contrary to the majority of VR training techniques that integrate VR controllers of the respective VR headset, this framework leverages force and haptic feedback gloves, and more specifically Sense Glove, to enable the user's interactions within the virtual environment. These gloves not only give the ability to the user to observe his own hands in the VR but also provide realistic manipulation within the environment by applying force and haptic feedback when an interaction with a VR object occurs, which is not possible to be achieved by utilizing only the controllers of a VR headset. Additionally, cases, where force-feedback gloves were integrated, are mainly involved healthcare and military domains while the presented framework provides a novel and innovative industrial robotic environment and training workflow where the user can freely manipulate the robot with his hands and be trained through this procedure by manually programming a VR industrial robot.

Taking into account that the simplest way to program a robot is its manual movement with hands, this framework allows the user not only to observe a VR environment that utilizes a 7 joints Kuka Robot but also to interact with virtual objects and the robot itself by integrating Force and Haptic Feedback gloves, with the purpose of his efficient training. Thereby, the proposed VR training framework overcomes any potential issues regarding highly expensive equipment (i.e. Kuka robot) and gives the ability to users with no prior robotic knowledge, to learn the kinematics and limitations of the robot's joints, to understand how the robot needs to be moved to perform a specific task and thus to achieve appropriate training. After the VR training is completed the user will be able to interact with the real robot more efficiently and safely.

To evaluate the realism of the VR environment and hand interactions with the robot, an experiment was conducted in which the participants needed to set the robot for a specific task in an insect farm robotic environment. After the completion of the task, questionnaires were given to the participants to evaluate the realism of the experience of the VR environment, the movement of the robot by their own hands and the training framework workflow. Statistical Analysis and correlation methods were performed to extract valuable insights along with Cronbach alpha test to ensure the reliability of the questionnaires and the overall contribution of the proposed haptic-based VR framework and its impact on an effective and safer human-robot collaboration environment.

2 RELATED WORK

Virtual Reality technology has immense significance in various domains such as gaming, education, healthcare, and industry. It revolutionizes the user experience by providing the ability of transferring to a computer-generated simulation place while also redefining the traditional training methods in a safer and more efficient manner.

In healthcare, for instance, VR aids in patient therapy and surgeon training. Previous work indicated that simulation-based training can remarkably decrease the mistakes of healthcare workers as well as improve patient safety (Salas et al., 2005). VR-based training is a promising area that can assess task-specific clinical skills and simulate multifarious medical procedures and clinical cases (O'Connor, 2019). These cases include orthopedic surgery (Laith K Hasan and Petrigliano, 2021), neuroradiology procedures (Magnus Sundgot Schneider et al., 2023), gunshot wounds (Dascal et al., 2017), and mental diseases such as schizophrenia by creating a VR experience that puts participants on a city bus with additional surroundings like sights and sounds (Mantovani et al., 2003). Consequently, a healthcare VR training program that gives the ability to the trainee to interact realistically with the necessary equipment overcomes substantial risks and provides the essential skills before being applied to a real patient.

An efficient training mechanism in the VR is comprised of multiple critical elements. The most vital component is the VR Headset which corresponds to the display quality and the tracking motion of the user's head to provide the ultimate experience. At present, the most popular VR hardware devices are Oculus VR (Yao et al., 2014), HTC Vive, Valve Index (Valve, 2019), and Samsung HMD Odyssey (Samsung, 2021; Yildirim, 2020). The most important features that categorize VR headsets are the display quality, the motion tracking, and the VR controllers' response. For instance, research indicates that an increased level of visual realism improves the sense of presence (Bowman and McMahan, 2007). All the aforementioned VR headsets achieve a high level of image quality using LCD and AMOLED displays to provide an excellent three-dimensional environment with a remarkable tracking system and are equipped with VR controllers (Angelov et al., 2020).

Furthermore, in all training procedures, the trainee's hands must be visible within the the VR to accomplish the desired educational level of the user performing a specific task. VR controllers which are available with most VR headsets, provide this capability but they lack of realistic interactions since they exclusively map the user's hand with the controller and failing to deliver a sufficient hand simulation within the VR.

On the contrary, force and haptic feedback gloves leverage a realistic user interaction in VR. In (Whitmire et al., 2018), a haptic revolver was introduced that offers the user's ability to interact with surfaces and perform tasks such as picking and placing of objects. Nevertheless, it does not provide the mapping of fingers on the VR and is more similar to a VR controller equipped with a haptic capability. Moreover, research efforts in (Kim et al., 2017) led to the development of a low-cost portable hand haptic system designed as an Arduino-based sensor architecture for each finger. Similar work was presented in (Martinez-Hernandez and Al, 2022) in which researchers proposed a wearable fingertip device for sliding and vibration feedback in VR. The corresponding device comprised an array of servo motors and 3D-printed components. However, these research focus on applications outside of training workflows, and not in cases where the movement of the hands must be precise by applying the corresponding force-feedback such as in industrial robotic domains. It is notable that in the literature these gloves are mostly employed preliminarily in healthcare domains while it could be very beneficial to be integrated into an industrial robotic field to simulate realistic worker training for programming robotic tasks.

In (Pérez et al., 2019), researchers proposed a system utilizing a VR interface connected to the robot controller providing the ability to control the virtual robot. This system can be used for training, simulation, and integrated robot control all in a cost-effective

Figure 2: Virtual Environment for Training.

manner. They employed HTC Vive headset and utilized its controllers for the interaction with VR buttons that move the robot. It must be noted that the HTC Vive controllers cannot simulate the haptic experience in a realistic way.

Similarly, (Garcia et al., 2019) proposed Virtual and Augmented Reality as means of optimizing training time and cost reduction. The application created with Unity Pro enhanced the familiarization of their system and procedures. META2 Development Kit was selected as equipment, which is an Augmented reality device. Again in that situation, emphasis was not given to the haptic experience.

The majority of the research for Virtual Training employed the controllers of each Virtual Headset for the appropriate training. However, this training process lacks intrinsically since the trainee is not capable of manipulating machines realistically, but only limited to the controllers. Our proposed framework utilizes not only VR for training but also force and haptic feedback gloves enabling trainees to interact with and manipulate realistically with VR objects in a more intuitive manner. Particularly, Sense Gloves were utilized for the force and haptic feedback capability combined with the HTC Vive VR headset along with Vive trackers to map the hands into the VR environment. Thereby, the proposed framework contributes an industry learning mechanism providing the ability for the trainee to freely view the Virtual Environment, interact with his own hands as if it was a real physical environment, learn from it and kinestheticaly interact with the VR robot and subsequently learn how to program a robot efficiently.

3 THE PROPOSED FRAMEWORK

The proposed framework was developed by leveraging the capabilities of the open-source game development engine, Unity3D. Unity3D offers numerous features that facilitate the integration of multiple independent modules into a cohesive environment (Haas, 2014). Additionally, the framework leverages the support for force and haptic feed-back gloves, SenseGlove, which enables natural interaction in VR Environments and manipulation of VR objects.

Contrary to traditional controllers, SenseGlove provides users with the ability to feel the size, stiffness, and resistance, allowing a more realistic experience when pushing, holding, and touching virtual objects (SenseGlove, 2018). SenseGloves are exoskeleton gloves equipped with servo motors and tires that can block the movement of the fingers. Accordingly, whenever the user interacts with a virtual object, the servos actuators block the tires, preventing the user from closing his hand. Thereby they deliver the sense of touching the object while also applying the appropriate force and haptic feedback. Finally, a Vive Tracker was attached to each of the Gloves to deliver the capability of the free hand move within the VR environment.

The HTC Vive headset, which is also supported by Unity, is utilized in the framework to enable free viewing and movement within the VR environment (HTC, 2011). Moreover, two VR base stations are placed to enhance the motion track of the headset and the Sense Gloves. The complete hardware and spatial setup are illustrated in Figure 1.

3.1 Virtual Training Environment

The virtual environment has been developed with the intention of providing effective training to users regarding the automation in insect farming domain. This environment is a virtual training room that has been designed to simulate real-world scenarios . In particular, an industrial level robot, Kuka IIWA 7, was chosen to carry out robotic tasks in the VR training room, as depicted in Figure 2. A 3D crate containing animated worms and substrate was placed in front of the Kuka in which the robot assists in quality management tasks (i.e. scanning crate). In addition, the SenseGlove technology has been utilized to allow users to see a virtual representation of their hands. This technology also enables users to manipulate the Kuka robot freely within the designated area, while taking into account the robot's joint limitations.

Furthermore, a table with two VR buttons has

(a) Robot manipulation shown in Unity

(b) Robot manipulation shown in VR Headset

Figure 3: Kuka Robot Manipulation in VR.

been installed within the interaction VR area. The main objective of these buttons is to record the robot's movement and display it on the corresponding VR screen. Therefore, the users and their trainees can evaluate the task and identify the optimal robot manipulation movement for this specific task.

Overall, this virtual environment is designed to provide users with a practical and hands-on experience in a simulated training room. It incorporates cutting-edge technologies such as VR, SenseGlove, and a 3D model of the Kuka IIWA 7 robot to simulate real-world scenarios and enable users to acquire practical skills that can be applied in real-world situations. The corresponding robot is an exact representation of the real 7 joint Kuka one in Unity 3D by respecting its mass, torque, stiffness, acceleration and all the attributes that affect its movement.

3.2 Training Procedure

In numerous tasks, there may be a requirement for the manual movement of a robot, such as in the case of insect farming, where the robot must be manually moved to scan a crate of insects. This manual robotic movement is valuable for workers lacking prior expertise in robot manipulation, particularly in programming a robotic task. The robot records the user's manual movement and replicates the exact trajectory. A significant application of this method within insect farming is the visual inspection of the crate where a camera is attached to the robot's end-effector and must be positioned above the crate to capture images and perform the corresponding visual inspection (e.g. using AI algorithms).

The movements necessary for this task require precise and careful handling of the robot. A realistic and sufficient utilization of hand manipulation within the VR occurred. Therefore, Sense Glove was integrated in conjunction with the VR training framework which allows the user not only to perceive his hands on the VR but also touch and move the robot realistically by applying Force and Haptic Feedback technology. To achieve an effective training for this task, the user, wearing the aforementioned equipment, as depicted on Figure 4, manually moves and interacts with the robot in a natural manner, provided with the appropriate force feedback and hence be familiarized with its kinematics. Finally, using the VR recording button the user can record the robot's movement and display it on the screen for evaluation purposes.

Figure 4: Framework Setup.

Particularly, using the proposed framework, the user is first able to move freely within the VR environment and interact with both the robot and other components of the environment, as depicted on Figure 3. As the user gains confidence in manually moving the robot, he records the robot's movements using the green VR button and after completing the task, stops the recording by pressing the red one. The corresponding recorded movement is then displayed on the VR screen and is visible to the employee, as depicted on Figure 5. It can also be evaluated along with his trainee for its precision and accuracy and can be further analyzed to determine the most optimal movements for this assigned task.

For instance, in the terms of insect farming, the worker can be trained in this Virtual environment, to lower the end-effector of the Kuka Robot above the crate in order to perform its scanning to assist the quality management of insects prior to executing the task given the real robot.

3.3 Experiment

An experiment aimed to evaluate the realism and the efficiency of the proposed VR training environment and the manipulation of the Kuka Robot was conducted. The established setup was created according to Figure 1, in which the two HTC Vive Base Stations were positioned to configure the VR space and to track the movement of both the headset and the Sense Gloves (by utilizing two Vive Trackers attached to each hand). The application for the experiment was created in Unity, utilized the SteamVR plugin, and ran on the NVIDIA GeForce RTX 3090 GPU with 24GB memory to maximize frames per second (FPS) and to avoid potential motion sickness that the user might experience.

Figure 5: VR Screen to evaluate robot's recorded movement.

The experiment was conducted by involving 25 participants with no prior expertise in robot manipulation. Each participant was equipped with the necessary hardware and was initially asked to familiarize himself with the VR environment and freely move within this environment. Afterward, participants engaged in manual manipulation of the robot with their hands to learn the kinematics and limitations of each joint. Accordingly, each participant was assigned the same task which consisted of a sequence of actions. Particularly:

- Lower the robot's end-effector and position it above the crate
- Press the green button in order to record the upcoming movement
- Move the robot to scan the crate
- Press the red button to stop the recording

After the recording was stopped, the movement was displayed on the VR display in order to evaluate whether the corresponding robot manipulation was the optimal one for the given task. Otherwise, the participants had the option of pressing again the green button and repeating the procedure.

Following the completion of the experiment, a questionnaire was provided to each participant aimed to evaluate the realism of the experience in combination with the hand manipulation of the robot and to analyze valuable insights. The questionnaire items are detailed in Table 1.

Table 1: Questions.

Questions	
Q1	Do you have any prior experience with VR?
Q2	Were the SenseGlove easy to use?
Q3	Was the VR Headset easy to use?
Q4	Did you experience nausia or motion sickness? (1: Not at all)
Q5	How would you rate the force-feedback while interacting with the Kuka Robot?
Q6	Was the process of the training framework easy to undertand?
Q7	Was the VR interface easy to understand?
Q8	How impactful was moving the robot for your training?
Q9	How impactful was the recording process of robot movement?
Q10	How would you rate the realiability of the training framework?
Q11	Do you consider that this framework leads to a safer human robot collaboration scheme?
Q12	Do you consider the training framework to be useful tool in your work?
Q13	Would you recommend using a similar VR framework in other jobs similar to yours?

3.4 Results

The duration of the experiment was approximately 20 minutes per participant including the time required for wearing the essential equipment. Furthermore, detailed instructions were provided to users about the utilization of Sense Gloves and VR headset along with comprehensive guidance during the conduction of the experiment to ensure the proper execution of the procedures.

The questionnaires provided to the participants consisted of a total of 13 inquiries, divided into two categories: five regarding the realisticness of the robotic manipulation and eight concerning the reliability of the training framework. Participants provided their feedback using a scale ranging from 1 to 5. The lowest value of the scale corresponded to 0% while the highest one represented 100%.

To ensure that the questionnaire produces accurate

Table 2: Evaluation of the manipulation's realism.

	Answer				
Question	**1 (Lowest)**	**2**	**3**	**4**	**5 (Highest)**
Q1	26.1%	**47.9%**	17.4%	8.6%	0%
Q2	0%	4.3%	21.7%	26.2%	**47.8%**
Q3	0%	0%	4.3%	39.1%	**56.6%**
Q4	**97.9%**	2.1%	0%	0%	0%
Q5	0%	3.4%	11.4%	**64.8%**	20.4%

Table 3: Reliability of the VR Training Framework.

	Answer				
Question	**1 (Lowest)**	**2**	**3**	**4**	**5 (Highest)**
Q6	0%	0%	0%	41.7%	**58.3%**
Q7	0%	0%	4.1%	29.2%	**66.7%**
Q8	0%	0%	20.8%	37.5%	**41.7%**
Q9	0%	0%	15.4%	30.4%	**54.2%**
Q10	0%	0%	0%	**58.3%**	41.7%
Q11	0%	0%	25%	**41.7%**	33.3%
Q12	0%	8.7%	8.7%	26.1%	**56.5%**
Q13	0%	4.2%	8.3%	20.8%	**66.7%**

and reliable results, it is essential to test its reliability. Therefore, Cronbach Alpha Test (Bland and Altman, 1997) was performed, particularly for questions 11, 12, and 13. The Cronbach Alpha between Q11 and Q12 is 0.749 and between Q12 and Q13 is 0.879 accordingly. Both indicate a good realiability and internal consistency.

Both the training framework and the robotic manipulation provided efficient and valuable outcomes. As illustrated in Table 2, most of the participants had no prior experience with Virtual Reality Technologies. Nevertheless, they found that SenseGlove utilization and VR headset were easy to use and 97.9% of them did not encounter any kind of nausea or motion sickness. The force and haptic feedback during interactions with the robot define the realisticness of the manipulation because it portrays the sense of touching and moving objects like in real world. The majority of the participants (precisely 85.2% of them), rated the force feedback with 4 and 5 indicating a highly realistic interaction with the robot.

Considering the competence and the impact of our proposed framework, the majority of the participants rated the training workflow with more than 75% by scoring 4 and 5 the corresponding questions, as illustrated in Table 3. As depicted in the descriptive statistics in Table 4 all the mean values regarding the competency of the framework are above 3 suggesting the efficiency of the proposed VR training mechanism. In particular, apart from Q5, all the variables have a score above 4. The reason behind this is that SenseGlove may not provide the corresponding feedback efficiency for creating the ultimate manipulation experience in VR. Nevertheless, the 3.83 mean score of the Sense Glove is significant enough and provides adequate training to inexperienced users as illustrated by the mean value of Q10. Consequently, all participants found our framework easy to understand while reliable to provide sufficient training to users lacking robotic expertise. Additionally, they rated both the provided robot task and recording procedure as intuitive for effective training.

Additionally, Pearson correlation (Sedgwick, 2012) was used to examine the relationship between the previous participant's experience with VR and Kuka Robot Manipulation to the reliability of the proposed framework. The Pearson correlation between the past VR experience (Q1) and the competence of the robotic movement (Q7) stands at 0.36 indicating a lack of relation between them. Moreover, it is noteworthy that the Pearson correlation between the past expertise with Kuka Robot and the training framework is 0.0017 confirming the independence of these variables.

The independence of these variables is vital for the realism and particularly for the impact of our framework since otherwise the efficiency of the proposed framework will be biased by users who already experienced similar technologies. On the contrary, the primary objective is to train inexperienced users to manipulate Kuka Robot by utilizing VR technologies. Therefore, it is concluded that the prior knowledge and manipulation of Kuka Robot and the prior experience with VR do not affect the intuition of the

Table 4: Descriptive Statistics.

	Count	**Mean**	**std**	**Min**	**25%**	**50%**	**75%**	**Max**
Q1	25	2.16	0.96	1	1.75	2	3	4
Q2	25	1.79	1.35	1	1	1	2	5
Q3	25	4	0.83	2	3.75	4	5	5
Q4	25	4.54	0.58	3	4	5	5	5
Q5	25	1.04	0.20	1	1	1	1	2
Q6	25	4.41	0.65	3	4	4.5	5	5
Q7	25	4.62	0.57	3	4	5	5	5
Q8	25	4.21	0.78	3	4	4	5	5
Q9	25	4.33	0.86	2	4	4	5	5
Q10	25	4.16	0.63	3	4	4	5	5
Q11	25	4.08	0.77	3	3.75	4	5	5
Q12	25	4.29	0.95	2	4	5	5	5
Q13	25	4.5	0.83	2	4	5	5	5

framework, hence the proposed training framework is highly valuable and efficient. Moreover, the Pearson Correlation comparing the reliability of the framework (Q10) and its impact on a safer human-robot collaboration environment (Q11) stands at 0.67 suggesting their notable relation between. Accordingly, apart from effective training, the proposed framework additionally results in a more secure human-robot collaboration scheme.

Consequently, this mechanism simulates efficiently the real movement and manipulation of the robot, thereby providing sufficient and secure training to new users in a robotic environment.

4 CONCLUSION AND FUTURE WORK

The presented framework provided an innovative training methodology, implemented in VR, able for the user to intrinsically interact with robots, to analyze and understand their kinematics and joint limitations and to overcome possible risks while operating real world robots. Therefore, it contributes to the effective training of employees in human-robot collaboration schemes and thus will ensure wariness when the actual task on the real robot has to occur.

The conduction of our experiment resulted in a highly realistic VR environment concerning the insect farming domain and a 7-joint Kuka IIWA robot while also providing a realistic simulation of the hand interaction and manipulation of the corresponding robot. Therefore, the proposed framework, leveraging VR with force and haptic feedback technologies, achieves effective training for non-expertise employees securely by overcoming any potential risks while handling highly expensive equipment i.e. robots. Additionally, the regular use of this mechanism will raise the confidence and the safety of the employees dealing and working with robots while reducing the uncertainty when the real robot task occurs. Consequently, it is a vital component for new robot users to simply learn how to program a robot task safely corresponding to their needs while they have been trained fundamentally in VR.

The majority of the Virtual Training methods utilize the controllers of the corresponding VR headset that they use resulting in a limitation of hands-on experience and real interactions within VR lacking an effective simulation in reality. On the contrary, our proposed framework that utilizes force and haptic feedback gloves overcomes this limitation and improves the realistic experience of the user. In the literature, only in a few cases, VR force-feedback gloves are integrated for training purposes and observed primarily in the healthcare domain. However, our training framework acts as an educational tool for inexperienced users (provides the ability to learn the kinematics and constraints of robotic joints) and is an innovative approach to program robotic tasks that could be further expanded as a digital twin of an actual robot.

For future work, robotic joint data will be gathered with their timing characteristics from the real robot to be transferred in the VR robotic digital twin in order to provide a more realistic experience. Having constructed the realistic digital twin of the Kuka robot, the proposed framework will be further utilized to program the actual robot by non-technical workers. Specifically, the ultimate goal is the robot's movement in the Virtual Environment to correspond to the movement of the real robot. By utilizing the VR training room, the user can analyze the recorded movements of the robot and determine the optimal trajectory path. Thereby, the user can transfer the corresponding movement to the physical robot by pressing a designated VR button. This process can enhance the existing human-robot collaboration schemes in terms of of human safety and robot integrity (avoiding damage).

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