An immersive virtual reality platform for enablement and assessment of human-robot interactions for intelligent asset management

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Abstract: Human-robot collaboration (HRC) is at the heart of intelligent automation and is essential for increasing efficiencies in industrial systems by combining the strength, dexterity and precision of robots with the intelligence and adaptation skills of humans. HRC is enabled by Human-Robot Interaction (HRI) in which humans and robots co-work on a task communicating and physically interacting with each other. However, the principles of HRI are neither well understood nor well established and detailed investigation is difficult because real-life experimentation involving human and industrial robot interactions carry the risk of detrimental encounters. This paper presents an opportunity to investigate and assess human-robot interactions for collaboration efficacy and safety within a realistic Virtual Reality (VR) environment. A simple maintenance activity involving the assembly of two blocks was designed with two scenarios: manual assembly; robot assisted assembly.

1. Introduction

The collaboration between humans and robots can enhance the efficiency of partly automated maintenance activities by combining the performance and precision of...
robots fulfilling repetitive tasks with the human skills of dexterity and creative problem solving. Therefore, human-robot interaction (HRI) will be essential for increasing the efficiency of asset lifecycle and management activities (Rückert et al., 2020). The field of HRI focuses on understanding robotic behaviours and systems that are related to interaction with humans through communication. However, the principles of HRI are at present poorly understood. For instance, robots are commonly placed in cages in order to reduce the risk of harmful human-robot encounters. The ISO 15066 standard provides safety guidance for collaborative robot application but still refers to a previous standard (ISO 10218-2) for verification and validation. There is an opportunity to use virtual reality (VR) scenarios to investigate interaction strategies with virtual industrial robots in a safe environment. Within the virtual reality environment, the user is able to perform a set of actions, which can involve manipulation of the environment and the creation of new objects. Processes for the maintenance of assets, while being a target for automation are still likely to require human input in the near future; the proposed platform will aid the further understanding of how humans and robots can safely cooperate in the completion of asset maintenance tasks.

2. Related Research

Industrial robots are part of many modern manufacturing systems. HRI becomes an important issue when humans and robots share the same workspace. Especially in assembly line production systems, robots are utilised to support human workers executing tasks requiring high precision or the handling of heavy loads (Bicchi, et al., 2008). The latter is a common application in automotive assembly lines, where industrial robots carry heavy and unhandy loads such as car seats for the human operator, who can move the seats almost without restrictions (Krüger, et al., 2009). In general, HRI safety incorporates the human operator’s protection, which has unconditional priority; and the safety of the robotic structure. Nevertheless, the latter has an impact on the robot’s reaction to collisions, which can have many strategies with various levels of effectiveness for a given task (Haddadin et al., 2008). Haddadin et al. (2008) investigate the scenario in which a collision is unavoidable or has already happened. Haddadin et al. (2008) focus on the detection of collisions and have developed strategies to prevent serious injuries, such as switching the robot to a “zero gravity” torque control mode to reduce impact forces. With regards to human-robot interaction, Richer and Drury (2006) developed a framework in order to characterise HRI platforms based on video games. The framework was used to evaluate and compare HRI systems, with multiple input and output devices and limited immersiveness. The work of Sosa et al. (2015) demonstrates an approach with a robot utilising a decision making process for navigating around obstacles. In this research, the robot does not incorporate any autonomous features and is fully guided by the humans during the collaborative task. Additionally Guerra-Zubiaga et al. (2021) provide a narrative on the capture of tacit knowledge to aid the further development of platforms that support human-robot interaction.
3. Methodology

An outline schematic of the proposed VR platform was developed and is shown in Figure 1. The two actors in the schematic are the human, who will interact with the virtual robot while performing a manual task and the computer, which will provide the immersive virtual environment to enable and assess HRI.

The two scenarios are as follows:

1. **Manual assembly task:** This scenario requires the operator to assemble two blocks manually in the virtual environment. The idea is to grip each block using the handheld VR controllers that symbolise the operator’s hands in the virtual environment, positioning and orientating the blocks for assembly using the visual markers on the blocks and mating the two blocks together to complete the assembly (Figure 2).

2. **Robot assisted assembly task:** This scenario is similar to the first one with the difference being that there is an industrial robot arm placed in the centre of the work table to assist in the assembly task. In order to complete the task, the human operator must pick up any one of the two blocks and wait for the robot to react. The robot arm will pick up the other part and orient it in the correct position for the human to clearly see the visual markers. The human is always the first mover while the robot is always a follower reacting to the human’s actions.

4. Results and Validation

The two scenarios were tested with users (humans) holding the two controllers, one in each hand, and wearing the headset to immerse themselves in the virtual assembly environment. Within the virtual environment, they see the assembly work table in
front of them with the two blocks placed on the table ready for assembly. In the robot assisted assembly scenario, the users also see the industrial robot arm placed in the centre of the table in between the two blocks. The results are in the form of expert feedback received in running the two scenarios.

4.1 Validation

Validation was undertaken to assess the usefulness of the developed platform for enabling HRC. The chosen validation methodology is illustrated in Figure 3. The methodology consisted of the four steps: Introduction; Testing; Questionnaire; Evaluation - undertaken by subjects with an academic background in manufacturing and basic knowledge of virtual reality. In the introduction phase, the subjects were introduced to the platform hardware and the associated controls. A VR environment was created so subjects could familiarise themselves with the immersive virtual setting. In the testing phase, the subjects completed the assembly task in scenario 1. They performed the task multiple times, ascertaining the quickest way to assemble the blocks correctly. Then the subjects performed the same assembly task in scenario 2 assisted by the virtual robot arm (Figure 4). In the questionnaire phase, the subjects were asked to provide feedback on the entire VR platform experience. The questionnaire was aimed towards obtaining feedback concerning ergonomics, intuitiveness, possible enhancements and the usefulness of the VR platform for enabling HRC. In the evaluation phase, the feedback from the subjects was analysed to assess the platform’s ability to enable HRC and to obtain areas of improvement for the platform.

Figure 3: Validation methodology

Figure 4: Robot assisted assembly.
4.2 Results

The platform evaluation questionnaire was undertaken by fifteen subjects drawn from manufacturing industry and academia. Over 80% of the subjects rated the VR platform as good, ‘very intuitive’, ‘quite close to reality’ and rated the ergonomics between average and good. All subjects encountered no problems during the robot assisted assembly with most stating that they felt safe and that the robot was interacting with them as expected. Their awareness for the robot’s movement increased with multiple repetitions of the scenario.

These results indicate that the developed platform could work as a tool for training an operator on a previously unknown task, raising their awareness and teaching them how to fulfil the task in an environment where the operator would feel safe with the robot. A few subjects reported problems with the physics engine (e.g. assembly became stuck in the table, inaccurate collisions) and the object grabbing accuracy and implied towards making the assembly environment closer to a real manufacturing setting with richer graphics.

5. Discussion

The main objective of this research was to develop a VR platform for HRC to provide a safe environment for investigating human-robot interactions and to give an indication of human perception should co-working between humans and robots become a possibility in real world manufacturing. This objective was achieved by building the platform and embedding it with assembly scenarios that facilitated a comparison between a completely manual task and a robot assisted task. The platform was tested by fifteen subjects and their feedback was obtained to assess the feasibility of the platform to enable HRC in the future. The results obtained were primarily positive indicating that the platform, once fully developed to the standards expected by industry, would be a useful tool for the manufacturing industry to acclimatise its workforce to HRC scenarios. In the VR platform, industrial robots can be selected from a wide variety of 3D models, task parameters can be changed and workers can run through the various task scenarios. The effects of these on the collaboration can be visualised within a few minutes in VR while doing this in the real-world would be impractical with the time, effort and costs involved. the overall VR experience was perceived by most as quite close to reality, more than 50% of the subjects considered the platform as a toy rather than an industrial tool. This could be due to the close association of virtual reality to games and the perception of games as a medium of entertainment rather than a medium of training. Inclusion of more real-life scenarios, with higher fidelity graphics, may help in achieving the appropriate user perceptions.
6. Conclusion

This paper presents an immersive virtual reality platform to enable and assess the potential of human-robot collaboration in manufacturing. The platform was developed in Unity 3D and was delivered using the HTC Vive headset. Even with simple and unsophisticated scenarios, the differences between manual and robot-assisted tasks were perceivable, which meant that this platform could be used for acclimatisation of workers in future manufacturing scenarios, where co-working of humans and robots is anticipated to be the norm. The main contributions to knowledge as a result of this work are: (1) development of an immersive VR platform to enable and assess the potential of human-robot collaboration for the manufacturing industry, (2) development of interaction methodologies between humans and virtual robots in a virtual setting that eliminates the risk of experimenting with people and real robots, (3) creating an integrated development environment within Unity3D that combines game development with human action recognition enabling first-person interactivity between the human and game elements within a manufacturing context.

References


