Designing an Interactive Serious Game to Investigate Acceptability of Human-Robot Collaboration in Manufacturing

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ABSTRACT

This paper presents in brief a novel 3D interactive serious game that simulates in real-time collaborative manufacturing tasks between industrial robotic manipulators and humans. The use case scenario incorporates a human and a robot working in close proximity (collaborative handling of carbon fabric composite parts), while sharing their workspaces. The Virtual Environment (VE) is original and comprises a shop-floor environment, an industrial robot, an avatar and several auxiliary parts and objects. A Kinect sensor and a Head Mounted Display (HMD) are employed for interaction, immersion and skeletal tracking of the user motion. Particular emphasis is given to the various interaction techniques used to facilitate implementation of virtual Human-Robot (H-R) collaboration. The short-term aim of the research was to build this system as a platform for experimentation of several H-R interaction techniques, as well as of the fluency of H-R collaboration inside the VE. The medium-term goal is to investigate users' enhanced experience and behaviour inside the virtual world while cooperating with the robot; the system can be used to investigate the acceptability of H-R collaboration in regard to safety issues, by fostering human's awareness of the robot motion. Ultimately, the long-term goal of this research is to consider safety-based robot motion programming, based on motion awareness and anticipation of intention by both human and robot.

Keywords: Human-Robot Collaboration, Serious Game, Virtual Reality, Situation Awareness, Safety.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; H.5.m [Information Interfaces and Presentation]: Miscellaneous—Human Robot Collaboration

1 INTRODUCTION

The necessity of collaboration and work-space sharing between industrial robots and humans while executing manufacturing tasks is emerging in modern manufacturing systems, and can lead workers to perform more "value-added work" [1]. The key aim of this cooperation is to enhance workers' abilities with the strength, and accuracy of robots. Robots are already assisting humans in assembly lines, especially in automotive and aerospace industry [2], [3], or even provide domiciliary help to the elderly, e.g. the Giraff [4] robot. Still, H-R collaboration remains under-exploited due to safety concerns.

However, no matter how physically-safe collaborative robots are, they are not always welcomed by humans. To assure acceptability of H-R collaboration, all important "mental" safety issues must be successfully dealt with. Mental safety can be defined as the enhanced users' vigilance and awareness of the robot motion, that will not cause fear, shock or surprise [5].

In general, recent research literature focuses more on Augmented Reality techniques and interfaces to enrich with information the H-R communication and collaboration [6-9]. Very few researchers tackle mental safety issues and acceptance of H-R collaboration using immersive and interactive VR systems. For instance, [10] presented an immersive VE to study users' perception of robots during collaboration tasks, as well as the acceptability of H-R collaboration. Other recent H-R interaction studies have shown that a fluent collaboration requires awareness and anticipation of intention by both human and robotic agents [11]. To enable and facilitate this awareness and anticipation, it is important that both humans and robots communicate their status, location and intent [1]. In such cases, interactive VEs and serious games can provide enhanced training at all three levels of situation awareness (perception, comprehension and projection).

This paper presents in short an overview of the developed serious game, the interaction techniques that were employed, and a brief discussion concerning user's experience in the collaborative virtual world. H-R collaboration safety issues, such as contacts and collisions are mainly tackled through visual stimuli and sound alarms. The approach followed is that warning stimuli inside a VE that offers immersion and real-time interaction can provide to the user augmented situational awareness and enhanced perception of the robot's motion. The main goal of the research is to investigate users' enhanced experience and behaviour inside the virtual world, while cooperating with a robot, whilst the overall long-term goal is to investigate the acceptability of H-R collaboration.

2 SYSTEM SETUP AND IMPLEMENTATION

The developed serious game ("beWare of the Robot" v.1.3) is a standalone Windows application implemented in the Unity™ 3D game engine platform. Two main 3D user interfaces are employed: (i) a Microsoft Kinect™ sensor is used as an input device for skeletal tracking and travelling of the user, and, (ii) a stereoscopic HMD (Oculus Rift or eMagin Z800) is used as an output device for 3D visual display, and as an input device for head motion tracking. The VE and its components were developed using Rhinoceros™ and 3ds Max™ software, for 3D model creation, and the avatar's biped design. For further details on the system setup see [12].

2.1 Use Case

The use case scenario represents H-R collaborative handling tasks during tape-laying for building aerospace parts, in a composites hand layout work-cell. A Stäubli™ RX90L robotic manipulator

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picks and transfers carbon patches towards the user. The user is represented in the VE by a realistic avatar which reproduces the tracked user movements. The user, who stands near the robot, has to take the patch from the robot (see Figure 1) and to properly place it in the appropriate position inside the metallic die located in front of him. Afterwards, the robot proceeds to feed the next patch, and the process is repeated until all different patches are correctly placed. When the user enters the robot's workspace, the red transparent volume that represents this workspace starts blinking to alert the user. When the user's body is in very close proximity with the robot's forearm, a sound alarm is turned on, to warn the user of the robot's proximity and a possible collision. The robot speed is reduced accordingly by a percentage that is subject to investigation.

Figure 1: The avatar picking the patch from the robotic arm.

2.2 Interaction Techniques

"BeWare of the Robot" employs a wide variety of natural interaction techniques (schemes) for selection, manipulation, travel, and system control. Collision detection is mostly implemented using sphere, box and cylinder covering techniques, for events-triggering, manipulation and system control. Ray-casting technique is used for selection, parenting tasks, and for system control. Ray-casting scripts are attached to the avatar's index fingers and the robot end-effector. The direct tracked virtual hand technique is used for manipulation and activation of controls. Travel is implemented with simple physical motions (real walking technique), since contactless body tracking is used. Metaphors or "magic" techniques are only employed when the user grabs the patch and when he/she lays the patch onto the die.

3 User Experience and Discussion

The line adopted in this work is that immersive serious games and interactive VEs simulating H-R collaboration are a suitable tool to foster situation awareness, since they can provide enhanced training at all three levels of situation awareness (perception, comprehension and projection). Human performance in training VEs highly depends on the degree of presence that the user experiences [13]. In this work, both involvement and immersion are thought to be necessary for experiencing presence. Preliminary results published in [12] revealed that the system scored great in "presence by involvement" and in immersion issues. Users experience a high level of involvement and immersion, and therefore, presence. The inclusion of a realistic avatar, combined with reliable skeletal tracking, strengthens the sense of presence.

Furthermore, visual and audio warning stimuli (alarms) might be argued to be unrealistic or even to compromise physical fidelity; however such exaggerated triggers can prove very effective for tasks that are characterized by a significant perceptual component. The data collected, see [12] for details, showed that a vast majority of users favourably accepted use of these alarms for the robot's workspace awareness and vigilance of the robot motion. 3D sound also boosted spatial perception of the moving robot.

As to Kinect's™ tracking limitations and problems that were observed at the initial experiments of this research [12], they have been successfully tackled by minor changes in the scene setup, so that users do not turn their bodies by more than 60 degrees to the Kinect sensor axis.

4 Conclusion and Future Work

This paper presented a concise overview of the virtual serious game "beWare of the Robot", some functional details of the VE and the main interaction techniques used. The developed VE reproduces simple H-R collaborative manufacturing tasks and offers to the user a first-person enhanced interactive experience that would be difficult and dangerous to be naturally performed in the real world involving a real robot.

The short term goal of the research has already been reached. The VE offers a wide field of experimentation as a platform for studying different H-R interaction techniques and 3D user interfaces, as well as their effect on the fluency of H-R collaboration. The employment of different interaction techniques and the combination of multiple tracking devices is primarily what distinguishes this work.

Furthermore, given that mental safety is of utmost priority in H-R collaboration, preliminary findings show that users experience augmented situational awareness and enhanced perception of the robot's motion. This is attributed to involvement and real-time interaction offered by the VE as well as by special warning stimuli.

The next step is to conduct further user experiments both in virtual and in real situations. Additional user studies on robot speed adjustment and smart user-avoiding kinematics are being planned. Ultimately, the system could serve as an offline platform for safety-based robot motion programming as well as user training in collaborative H-R manufacturing cells

Acknowledgments

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II Investing in knowledge society through the European Social Fund. The authors would also like to thank Dimitrios Batras, MSc, for his generous help during the initial development of the application.

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