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# An Augmented Reality System for Safe Human-Robot Collaboration*

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***Abstract*—Closer interaction in Human-Robot Collaboration (HRC) could result in increased worker efficiency in manufacturing situations. However, physical cages often limit this. Our research is investigating the potential for using Augmented Reality (AR) to visualise virtual safety zones, thus replacing real cages. This paper presents initial experiments towards addressing the issues of how to display the safety zones and what size they should be in relation to a robot arm in order to ensure safe working practices.**

***Index Terms*—augmented reality (AR), safety, human-robot collaboration (HRC)**

## I. Introduction

Industry standards and practices for human-robot collaboration (HRC) are based on the principle of separating operator and robot work areas and detecting separation violations using sensors or physical cages [10]. However, more flexibility and efficiency could potentially be achieved if there were closer cooperation between human and robot [3], [6]. Augmented Reality (AR) could be used to achieve this by adding virtual safety cages to an environment instead of real cages.

AR in HRC has been investigated in terms of human safety and overall system productivity [7], [10], with [7] concluding that AR is a powerful tool for the visualisation of robot operations and safe areas. Different kinds of virtual safety barrier have been considered, including 2D fields [6], safety curtains [3] and user-configurable barriers (including around the user) [4], along with more general work on how to provide feedback for users [9]. However, the issues of safety zone size in relation to a robot arm and how to display the safety zones remain unresolved. Our paper considers these issues.

The initial experiments we report on use a virtual robot arm. This creates a safe testing environment, allowing quicker, safe feedback on parameter variation, e.g. safety zone size. The system makes use of Robot Operating System (ROS-Industrial) and HoloLens 2 so the work could easily transfer to using a real robot arm (when COVID restrictions allow).

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## II. The System

The system brings together Unity, ROS-Industrial and HoloLens 2. Whilst earlier AR studies made use of HoloLens 1 (e.g.[3], [6]), HoloLens 2 is lighter and more ergonomic that the HoloLens 1, has an increased field of view (FOV) and is now used widely in industry. The Unity real-time engine on Windows 10 is used as the development environment and to deploy HoloLens apps. ROS-Industrial on Linux (Ubuntu 18.04 in our system) is used to control the robot arm. ROS-Sharp [2] is used as the basis for communication between Unity and ROS. A similar ROS-Sharp-based approach is used to communicate between ROS and HoloLens, with the HoloLens used for AR display and user interaction.

The general idea behind our approach to AR is to align a virtual robot arm with a real robot arm using a QR code and some initial user interaction. HoloLens 2 is able to detect QR codes and establish a coordinate system for the QR code object's real-world location. Thereafter ROS commands can be used to keep the real robot arm and the virtual robot arm in sync, with the virtual robot arm being made invisible (a phantom model), but facilitating the addition and HoloLens display of AR information in relation to the real robot arm. The initial tests are done as a simulation, for safety purposes, but the same processes could be used for a real robot arm once the virtual and real robot arms are aligned.

## III. Safety Zone Experiments

For the initial experiments, the system is used to control a virtual UR10 robot arm whilst using AR to overlay a safety zone around the robot arm. The kinematic calculations for the trajectory of the robot arm were performed using the ROS MoveIt library. The safety zones are used in detecting proximity violations so that the user is warned and the movement of the robot arm is stopped. The questions to be considered are how large the safety zones should be and how to display them.

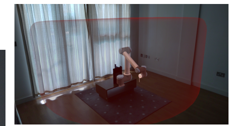
The first consideration is safety zone size. However, there is some uncertainty in the published safety standards about size [1]. Four approaches were considered. Safety Zone 1 is a large static safety zone that includes a range of possible points that the robot arm can reach (figures 1a, 1b and 1c show cuboid, cylinder and sphere versions, respectively). Safety Zone 2 is again static and encloses only the volume required for a specific task (figure 1d). Safety Zone 3 is a dynamic volume that grows and shrinks as the robot arm moves (figure 1e). Safety Zone 4 wraps the robot arm in a number of closer-fitting shapes that move with the robot arm (figure 1f).

Safety Zone 1 (cuboid version) is similar to a standard safety cage, keeping the user away from the robot arm for a range of possible tasks. Overall, Safety Zone 1 is the safest approach of the four, but may not produce the most effective HRC. The cuboid version includes dead space that the robot arm never reaches and is perhaps too general depending on how often each of the range of tasks it includes is done. The amount of dead space can be reduced by changing the shape of the safety zone to a cylinder or sphere, as shown in figures 1b and 1c. Safety Zone 2 shrinks the safety zone covering only the zone required for the specific task. This would be equivalent to a physical cage that could be reconfigured, possibly saving on factory floor space. Safety Zones 3 and 4 provide the opportunity to work more closely with the robot arm, but are potentially less safe that the other two static safety zones. A range of factors means that a dynamic safety margin must be considered in each case. The speed of the user and the robot arm become more important. For example, ISO 13855 [8] recommends that if the speed of the operator or user is 2000mm/s and the robot arm speed is 1600mm/s, the safety distance should be greater than 500mm. However, humans are unpredictable, different users may feel safer with larger safety zones than calculated, and robot sensors have latencies that must also be considered. These issues complicate the calculation of safety margins.

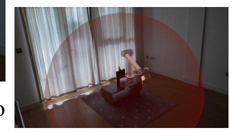
The second aspect is how to display the safety zones. This is currently user configurable. Figures 1f and 1g show highlighted edges and enhanced edges, respectively. It is also possible to change the colour used to display the safety zone. Other work [3], [6] does not have this level of user configuration. Red was chosen as the safety zone colour as it is a warning signal in many countries and edge highlighting makes the volumetric space of the safety zone clearer. However, user testing is still required to determine the best way to visualise the safety zones.

The warning message that is displayed when a safety zone is breached by the user. This causes the virtual robot arm to immediately stop moving.

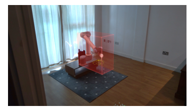
(a) Large static safety zone (cube) to cover a range of robot movements



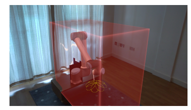
(b) Cylinder version of figure 1a



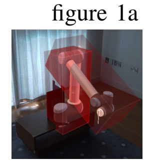
(c) Sphere version of figure 1a



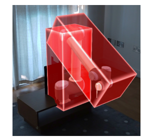
(d) Task-specific static safety zone with edge highlighting



(e) Dynamic safety zone resizing as the robot arm moves



(f) Moving sectional safety zones with edge highlighting



(g) Enhanced edge highlighting for figure 1f

Fig. 1: Safety zone visualisations

## IV. Conclusions

We have presented a system that uses Microsoft HoloLens 2 to display AR information in relation to a robot arm. For safety reasons, initial experiments have used a virtual robot arm instead of a real robot arm. Different safety zones are visualised around the robot arm in a range of visualisation styles and a warning is given if the safety zone is violated by the user. The use of safety zones is still an active research challenge [5]. The next steps in our work are to conduct user tests on how best to display safety information and to test the system with a real robot arm. The target system for these experiments will be a spot welding system which currently uses a combination of cage and sensors to separate a user and the robot arm and the spot welding machinery.

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