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Intuitive human-robot interaction using augmented reality: A simulation study on KUKA IIWA robot

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Abstract

The advancement in robotics and automation in manufacturing has resulted in tremendous productivity improvements. However, several tasks still require human intervention due to their unmatched cognitive capabilities, dexterity, proficiency and adaptability. The use of collaborative robots to work in close proximity with humans is one of the steps adapted by the manufacturing sector to increase the flexibility of human-robot interaction. However, the current interfaces (teach pendants, computer consoles) for programming such robots are complicated, unintuitive and unsuitable for spontaneous interactions. To fully utilize the benefits of collaborative robots, a user-friendly interface allowing workers with non-robotics background to intuitively and safely collaborate with such systems is needed. More recently, augmented reality (AR) tools have shown great potential for creating intuitive robot interfaces. Such interfaces allow the users to command and interact with the robots intuitively using natural gestures and speech while maintaining their concentration on the actual task. In this work, we will investigate the application of AR using a head-mounted display (HMD), specifically the Microsoft HoloLens in helping the worker to intuitively perform tasks by interacting with the collaborative robot. We will present a simulation study using the KUKA LBR IIWA robot to perform different tasks. The teleoperation of the robot will be done with an intuitive interface designed uniquely for HoloLens using the Unity software. The user will be provided with manipulation gestures native to the HoloLens, voice commands and overlaid holographic controls to perform the action on the robot. Through this work, we aim to demonstrate the improvements in the collaboration between human workers and robots to perform tasks in shared workspaces. Such outcomes will help the worker to adapt themselves in working together with the robots to perform different industrial operations efficiently.

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1. Introduction

Active human-robot interaction (HRI) is being emphasized in industries for ensuring a smooth transition towards Industry 4.0 paradigms to achieve increased productivity and improved overall production process [11]. The modern industries are facing non-traditional manufacturing challenges such as high product customization, just-in-time production, minimal warehousing, shorter product life cycles, and small batch sizes [1]. Additionally, despite the use of highly technical machines, the development of sophisticated manufacturing processes requires the presence of skilled human workers due to their unmatched cognitive capabilities, dexterity, proficiency and adaptability. To tackle these issues, design changes are being introduced in industrial robots to work and interact alongside skilled human workers and collaborate on completing the tasks [13]. This has led to the development of more flexible and intuitive ways of programming industrial robots that allows the worker to focus on the task rather than on the complexity of the robotic system [8].

Robot programming in general can be done by three ways: Online mode using software, offline programming done by teach pendent/console and programming by demonstration [11]. The position of end-effector of the robot is changed using an operator console by the operator in online programming mode. To do so, the worker saves each position of the end-effector by moving it from one desired point to another. Once the whole task is completed, the saved program is then executed to achieve the final desired output. In offline mode, the end-effector control program is created using the corresponding software (either with or without a simulator) and then uploaded into the robot controller for execution. This helps the worker to check for different possible solutions and optimize the robot motions accordingly.

More recently, a new approach for teaching robots to complete a task without complex lines of code was presented by Friedrich et al. [5], known as ”Programming by Demonstration” (PbD). This approach involves programming robots by manually demonstrating the tasks and making the robots learn from the actions. This helps an operator to program a robot without having any technical knowledge about programming manipulators. The development of design tools in the domain of Augmented Reality (AR) and Virtual Reality (VR) has helped PbD tremendously by allowing the operators to interact without the need for sophisticated special equipment [2]. Milgram and Kishino introduced the concept of Mixed Reality (MR) which is a combination of AR and VR for extending the idea of PbD by allowing the real and digital environment to co-exist and interact in real time [10].MR has a number of advantages in comparison with only AR or VR as it helps in teaching the robot, testing the program safely with a digital twin virtual environment before executing it in the real world.

The overall objective of the present work is to develop an intuitive human-robot interaction system using augmented reality. As a first step, this study presents the software architecture framework designed to achieve the interaction between a human operator and an industrial robot (Kuka IIWA). The difference between this work and the other existing works is that we have proposed the use of Matlab to establish the human-robot interaction whereas other works have used Robot Operating System (ROS) predominantly for the HRI. Through this setup, the operator can successfully interact with the robot in moving the robot to the desired position. The simulation results obtained is presented in this work to demonstrate the successful implementation of the first step.

Nomenclature

AR	Augmented Reality
CAD	Computer Aided Design
FK	Forward Kinematics
HMD	Head-Mounted Display
HRI	Head-Robot Interaction
IDE	Integrated Development Environment
IK	Inverse Kinematics
KST	KUKA Sunrise Toolbox
MR	Mixed Reality
MRTK	Mixed Reality Toolkit
PbD	Programming by Demonstration

ROS	Robot Operating System
VR	Virtual Reality

2. Existing Literature

AR has been applied to many HRI applications such as training [20], maintenance [3], shared manipulation [12] and so on. Several papers are available on AR-based industrial robot programming system. One of the well-known work was presented by [4] in which they developed a system with virtual robot (a replicate of the real robot) to be used in a real environment to perform and simulate the robot trajectory planning process. Gaschler et al. [7] designed a system to define virtual obstacles, tool positions and robot tasks. HRI using AR on mobile devices was demonstrated by Guhl, Tung and Kruger [9]. They used the concept of 'broker' to facilitate the communication between connected devices.

The impact of AR on robot teaching has been explored by Stadler et al. [17] where they focused on the perceived workload of industrial robot programmers and their task completion time when using a tablet-based AR approach with visualization of task based information for controlling a robot. The observed that this approach resulted in less mental demand and shorter completion time. A majority of the works have demonstrated that MR-based HRI interfaces are more intuitive than only AR-based interface. It is also reported that MR can bridge the gap between simulation and implementation [18]. Wassermann et al. [19] used workspace analysis using a depth camera data and point cloud processing for their industrial programming system.

A video-based AR approach for robot programming was used by Shepherd et al. [15] where they used a block-based Integrated Development Environment (IDE) embedded onto the screen. They tested the proposed setup on a real robot by projecting waypoints showing the current planned path in the AR environment (the current path being generated using the programming with controllers). This video based approach proved to be cumbersome as it was tiring to perform the programming with controllers as well as having to move the real robot with hands. Gadre et al. in their work used MR interface using Microsoft Hololens for creating and editing waypoints which were easy to be grouped, previewed and executed on the real robot [6].

Based on the literature, it is evident that use of MR for programming of robots has immense potential to be used for human-robot interaction. However, there are certain challenges which have to be addressed before implementing this approach satisfactorily.

3. Proposed Framework

Most of the works using MR/AR with industrial robots use ROS for their interface [11]. In this study, we propose the use of Matlab with Unity3D for performing the HRI. Microsoft Hololens has been used as the Head Mounted Device (HMD) for allowing the worker to interact with Unity and the robot. The software architecture proposed is shown in Fig. 1. As seen in Fig. 1, the architecture consists of three major parts: a) the Hololens, b) the framework involving Unity3D and Matlab, and c) the industrial robot (Kuka IIWA in this case). The entire study depends on the communication between these three components to achieve an efficient interaction between the user and the robot.

The Unity software consists of the robot Unified Robotic Description Format (URDF) model which is imported using the URDF importer module. We have used Vuforia for the spatial position of the robot while the Mixed Reality Toolkit (MRTK) is used for the various components and features of the Hololens. The communication between Unity and Matlab is achieved using a TCP server/client protocol. Each individual blocks are installed in the software using the available platforms and then programmed using *C#* to communicate with the model.

For Matlab, the Kuka Sunrise Toolbox developed by [14] is used. This toolbox is used for solving the kinematic equations of the Kuka robot selected for the study. The Inverse Kinematics (IK) and Forward Kinematics (FK) equations are needed for moving the robot (either the joints or the end-effector depending on the user). The Hololens 1 from Microsoft is used for the current work to help the worker communicate with the robot through Unity.

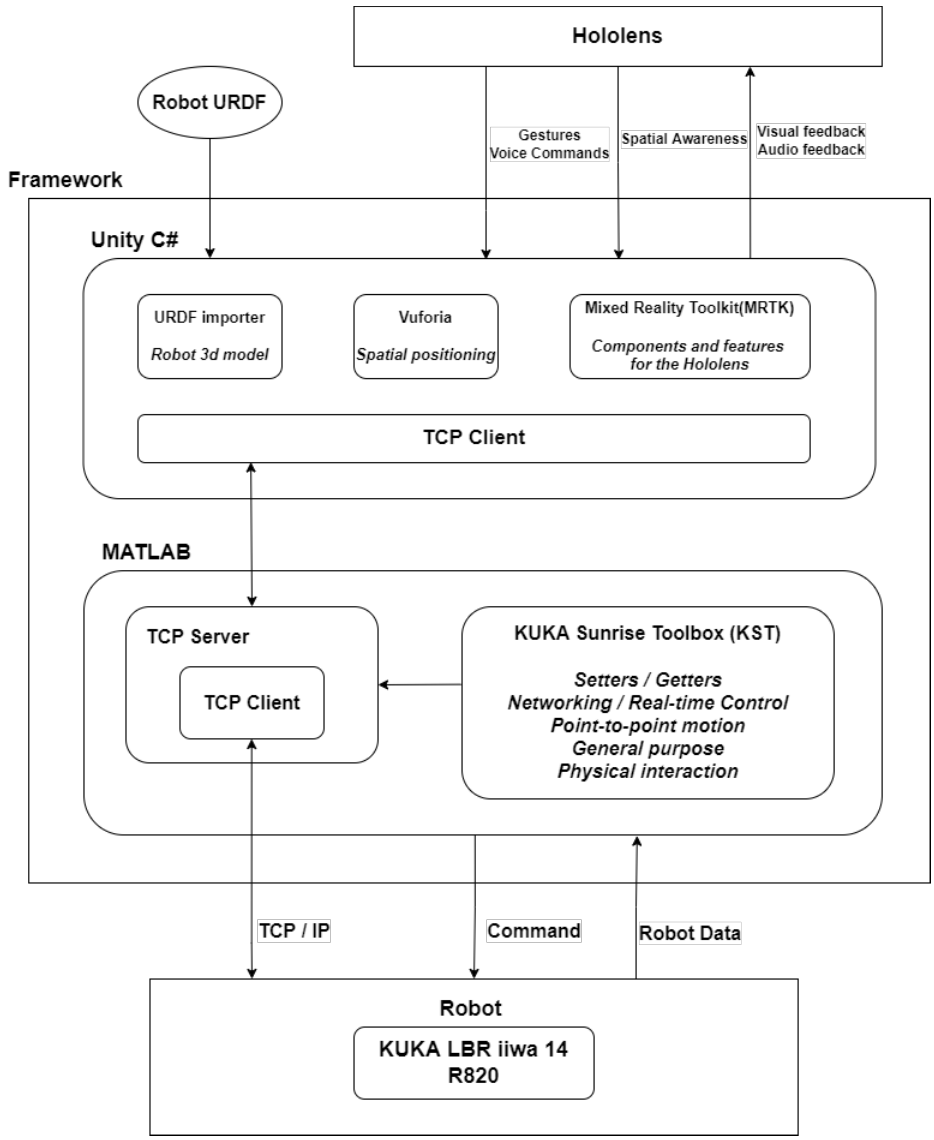


Fig. 1: Software architecture for the proposed human-robot-interaction

4. Work Flow

The work flow followed for the study is explained in this section. The work consists of various steps as shown in Fig. 2. The first part consists of steps where the user or the operator will either use gesture or voice command to move the 3D model seen in the Hololens. The user has the freedom to chose between moving the joints of the robot or moving the end-effector in the cartesian co-ordinate system. The movement desired by the user can be seen visually with the robot URDF model placed using the Unity software. The visual feedback will help the user to then decide if the movement is desirable following which it will be sent to Matlab to calculate either the joint angles or the pose of the end-effector (depending on whether it is forward kinematics or inverse kinematics). The KST toolbox in Matlab then calculates the desired variables and then sends the command to the robot. At this stage, only the simulation results are available and the robot variables are calculated successfully as the robot model is moved in the simulation space. The view in Hololens and Unity is shown in Fig. 3. The video of the movement can be seen in the uploaded video [16].

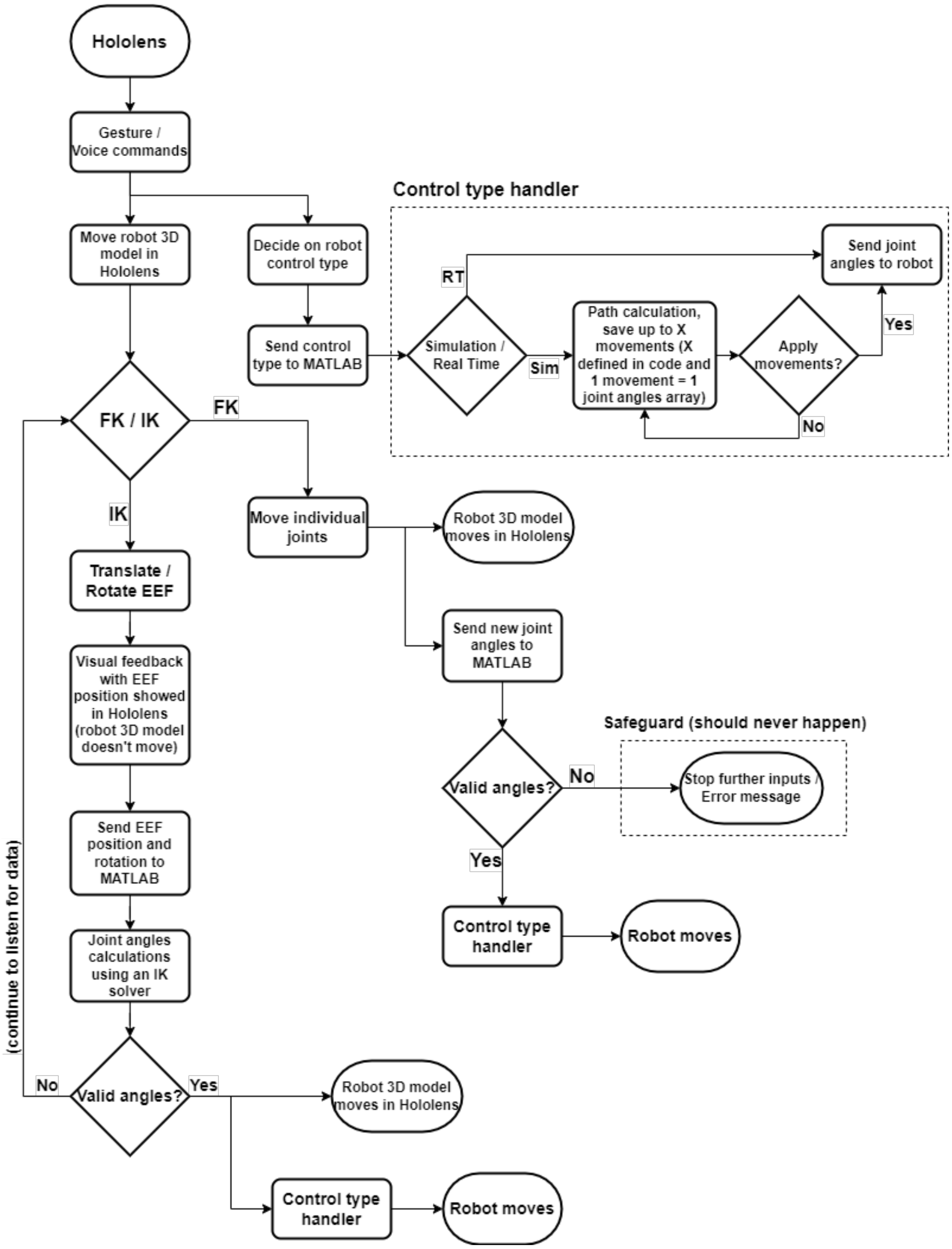
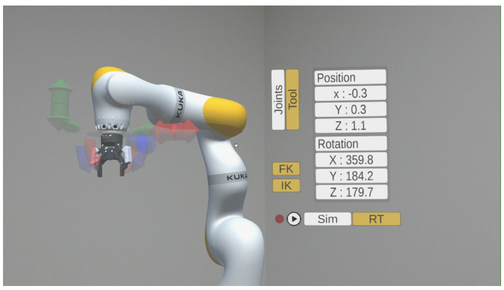
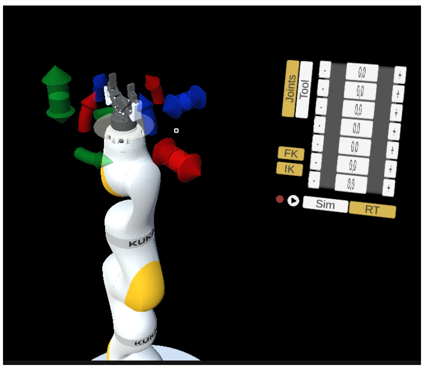


Fig. 2: Flowchart of the proposed study



(a) Robot model in Hololens



(b) Robot model in Unity

Fig. 3: View of the robot model in Hololens (left) and Unity (right)

5. Conclusion and Future Work

This work presented the initial results of the human-robot interaction system designed using a head mounted display (Microsoft Hololens) and the collaborative industrial robot from Kuka (Kuka IIWA) using Matlab. The software architecture and the work flow used in the study works successfully in moving the robot model according to the requirement of the worker in the simulation environment. Future work will focus on extending the results obtained in simulation to the real robot and moving the robot for pick and place operations. Once the real world movement will be done, tests will be conducted to perform pick and place operation in an environment with obstacles.

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