Augmented Reality-Based Programming of a Robotic Manipulator

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Abstract. This paper proposes a novel Augmented Reality (AR)-based programming system that simplifies the complex task of programming robotic manipulators. Traditional programming methods are often timeconsuming and require specialized knowledge in robot kinematics and programming languages. The proposed system integrates AR technology with the robotic manipulator, allowing operators to visualize and program the robot's movements in real-time, leading to a more efficient and intuitive programming experience. The developed solution is implemented on a 5-DOF robotic manipulator. For AR development, Unity3D game engine is used along with Vuforia AR framework. The proposed system is implemented and tested on two platforms for user convenience: a mobile phone device for increased accessibility and Xreal AR glasses for a more immersive experience. The AR-based system also opens doors for remote robot control, with potential applications ranging from robotassisted surgery to material handling in hazardous environments. This study aims to contribute to the development of innovative approaches for programming robotic manipulators, thereby enhancing their functionality and usability.

Keywords: Augmented Reality, Robotics, AR-based Programming System, Human-Robot Interaction

1 Introduction

The field of robotics has achieved significant advancements with robotic manipulators playing a crucial role in various industrial and commercial applications. Moreover, cobots, or collaborative robots, where robots and humans work together within the same workspace, have gained significant attention in the manufacturing industry due to their potential to improve productivity and flexibility. The benefits of employing cobots across industries such as biomedical, agriculture, food processing, electronics manufacturing, warehousing, automotive,

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metal processing, packaging, and logistics have been widely recognized [1–4]. The foremost consideration for integrating cobots into factory floors is human safety, which

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drives the central idea of human-robot collaboration (HRC). The introduction of cobots has also led to a shift in the dynamics of human-robot interaction (HRI) within industrial environments.

Despite advancements and widespread adoption of robotics, traditional robot programming methods remain complex, time-consuming, and require specialized skills while reprogramming which is frequent in industrial settings [5]. Traditional methods involve either programming the robot's movement using a low-level programming language or having a considerable grasp on the manufacturer-supplied specialized programming environment specific to the robot being used. Additionally, debugging and testing robotic programs require a controlled environment which further increases the cost and complexity of the development process.

This paper presents an Augmented Reality (AR)-based solution designed to simplify and enhance robotic manipulator programming while ensuring safe human interaction. Unlike traditional methods that rely on complex programming languages or physical teach pendants, our solution empowers users to intuitively define robot motions through direct interaction with a virtual robot model overlaid on the physical world. By leveraging AR technology and intuitive gesturebased controls, we offer a significantly more accessible and safer programming method compared to existing techniques. Users can visualize and modify robot trajectories in real-time, accelerating programming cycles and reducing errors.

We tested our developed solution on a 5-DOF robotic manipulator which is manufactured by the Human-Centered Robotics Lab (HCRL) of the University of Engineering and Technology Lahore, Pakistan. In addition to mobile phones or tablets, we tested our solution on Xreal AR glasses. Fig. 1 shows both the robot and the Xreal AR glasses. The results of our study indicate that the proposed AR-based programming framework is highly effective. Through comprehensive testing and evaluation, it has been shown to significantly enhance the efficiency and accuracy of robot programming tasks. These findings underscore the potential of AR to revolutionize robot programming in real-world applications.

2 Literature Review

Various methods have emerged in recent research to simplify robot programming for non-experts. While programming by demonstration (PbD) offers a user-friendly alternative [6] and can learn task structures [7], it can struggle with adaptation and environment-specific details. Additionally, PbD often lacks a code-like representation which limits its applicability and scalability [8,9]. Pan et al. [5] have presented various methods used for programming of industrial robots.

Recent research explores Augmented Reality for robot programming by nonexperts. Aleotti et al. [10] proposed an AR system for task learning from human demonstration. Other studies use hand gestures or virtual object manipulation to teach robots [11–13]. More examples include ABB's GoFa AR offering a user-

(a) (b)

Fig.1: (a) 5-DOF Robot (b) Xreal AR Glasses

friendly interface for managing robots using Microsoft HoloLens 2. ABB has also launched its AR-based application namely ABB RobotStudio [14] for robot visualization in AR.

3 Methodology

The Android applications were created using the Unity3D game development engine. We developed two applications: one for mobile devices or tablets and another for the Xreal AR glasses. The first thing required was the 3D CAD model of the robotic manipulator to be programmed. For our study, we used the 5-DOF robotic manipulator, manufactured by HCR Lab at UET, Lahore. Hence the 3D CAD model and the actual physical robotic manipulator, both were available. This is typically the case in most practical scenarios, as 3D models of target robots are usually available from the manufacturers. The model was then imported into the Unity3D project. A graphical user interface (GUI) was created in Unity3D for users to interact with the robot.

Forward kinematics was implemented to calculate the position and orientation of the robot's end-effector based on its joint angles. This allowed the user to provide joint angles and visualize the corresponding pose of the robotic manipulator in real-time.

As the robotic manipulator was treated as a dynamical body in the Unity3D environment, we utilized its physics engine to handle the movements of dynamically coupled bodies. This allowed us to bypass the need for numerical or analytical solutions of the inverse kinematics of the robotic manipulator, which is indeed a complex task. The user was thus able to move the robot by grasping the end-effector of the virtual robot in the AR environment and moving it to any desired position and orientation. Therefore, our virtual robot can be moved in a hand-guided mode, making it a digital twin of a type-2 cobot according to the ISO 10218-1:2011 standard for robots and robotic devices.

Vuforia, an AR framework, was integrated into the Unity3D project to provide AR capabilities. The model targeting solution of Vuforia was used and trained for the 3D model of the robot to track the physical robot accurately and overlay the virtual robot onto it. The Xreal SDK was integrated into the Unity3D project to provide support for the Xreal AR glasses which are used to view the AR content and interact with it in real-time.

Hand tracking was implemented using the Xreal SDK. This allowed the user to control the robot using hand gestures, providing a more intuitive and natural way to interact with the robot. We used the “pinch” gesture to interact with the robot and GUI buttons. One instance of right hand detection with a “pinch” gesture is shown in Fig. 2.

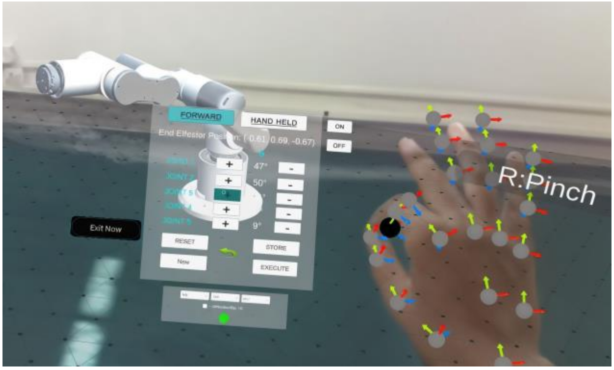

Fig.2: An instance demonstrating our system: a virtual robot augmented on the ground, GUI interface, hand tracking, and ’pinch’ gesture interaction.

A primary challenge was the integration of disparate software tools, including SolidWorks for 3D modeling, Unity3D for application development, Vuforia for augmented reality capabilities, and the Xreal AR Glasses SDK.

4 Results and Conclusion

The mobile phone application enabled users to control the robot via a graphical user interface (GUI) on their mobile devices. When the physical robot is viewed from the mobile phone camera, it is detected by the application using the Vuforia AR framework, and the 3D model is superimposed onto it as shown in Fig. 3(a). Users can then set different joint angles and the augmented robot executes the motion while the physical robot stays at the home location. One such instance is shown in Fig. 3(b). The set path is then transferred to the physical robot for execution.

(a) (b)

Fig.3: (a) 3D Model superimposed onto the robot; (b) Setting trajectory with the virtual robot while the physical robot stays at home position.

The Xreal AR glasses application provided a more immersive AR experience, leveraging hand gesture commands for robot control. The Xreal AR glasses first scan the surroundings, detect the ground plane, and localize itself in the realworld environment. Users can then place the virtual robot on the real-world ground plane. The application allows path planning in both the joint space, using forward kinematics, and the workspace, leveraging the hand-guiding method in the AR environment and offering advanced motion planning capabilities. The process is depicted in Fig. 4.

This study presents an innovative approach to simplifying and enhancing the programming of robotic manipulators using AR technology. The developed ARbased programming system offers intuitive interfaces for real-time robot control, streamlining the programming process and enhancing user experience.

5 Future Work

Future iterations will focus on enhancing communication between Xreal AR glasses and physical robots by real-time mirroring of virtual robot movements by the physical robot, ensuring accuracy through dynamic and kinematic profile comparison. Moreover, optimization of path planning using machine learning algorithms can be incorporated for improved performance and usability. In the future, the system could be enhanced by adding a remote operation mode, which would allow the operator to program the robot remotely over the internet in a virtual environment. This would be particularly useful in situations where

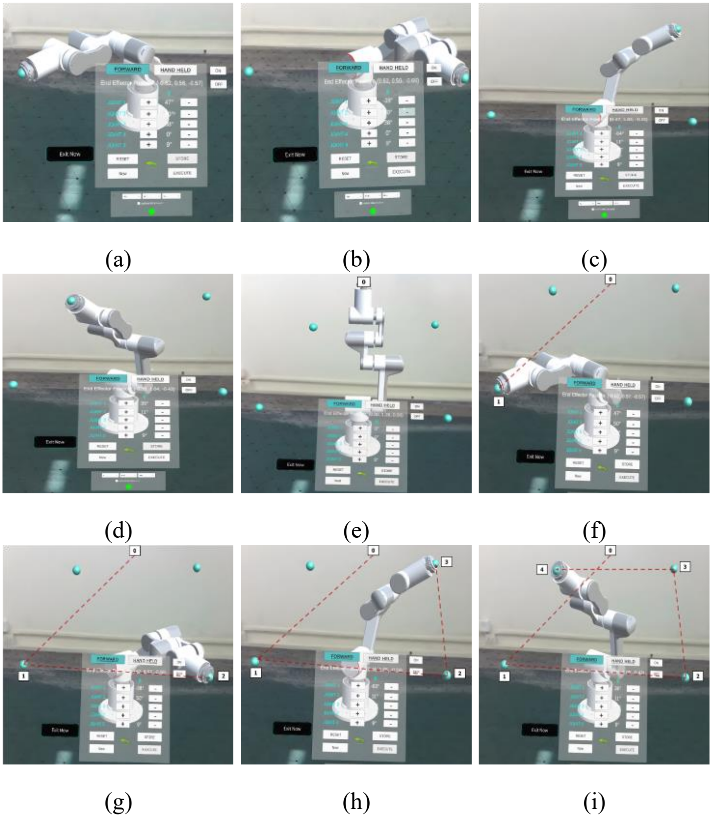

Fig.4: Robot Path Planning Demonstration. (a-d) Setting the four waypoints; (e) Robot at home position; (f-i) Robot following the set trajectory.

the operator cannot be physically present at the robot's location, such as in hazardous environments or during a pandemic.

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