**A Report on Robotic Arm Control via VR Glasses**

**Name : Gu**

**GUID: 2614344**

**Supervisor: Dr.Guodong Zhao**

**August 10, 2023**

***Abstract***

*This report presents an in-depth analysis of a pioneering project that harnesses the power of Virtual Reality (VR) glasses to control a robotic arm. The project is anchored in the Unity platform, which is utilized to create a real-time physics simulation that accurately reflects the robotic arm's movements within a virtual environment, and all settings are built in VR glasses. Fundamental to the project's operation is the implementation of each single joint of robotic arm model being controlled by VR glasses, and Transmission Control Protocol (TCP) connections, which ensures smooth and continuous communication between the VR interface and the Robot Operating System (ROS) platform. One of the project's features is its dual approach to Inverse Kinematics (IK) – utilizing both Unity's native IK and the ROS moveit! IK – which transforms desired end effector positions and orientations into the necessary joint parameters, thus enabling precise control of the robotic arm. The project explores potential enhancements, including the introduction of machine learning techniques for enhanced IK precision and the establishment of TCP connections on a cloud server, thereby greatly broadening the system's scalability and operational flexibility.*

1. **Introduction**
   1. **Background**

In the era of rapid technological advancement, the intersection of robotics and virtual reality (VR) has emerged as a fertile ground for innovative applications. Combining the immersive experience of VR with the physical capabilities of robotic systems offers a unique opportunity to enhance human-machine interaction. The use of VR in robotics is not a new concept. Previous studies have explored the use of VR for teleoperation of robots [1], and the use of VR interfaces for controlling robotic arms has been a particular focus of research [2].

However, this project elevates these existing efforts by capitalizing on the robust capabilities of the Unity platform to deliver real-time physics simulations. This approach facilitates a more immersive and responsive control interface, augmenting the user's experience and control precision in VR glasses. A crucial aspect of this project is the use of TCP connections to forge a reliable communication pathway between the VR interface and the Robot Operating System (ROS) platform that governs the robotic arm. This application of TCP is rooted in prior research that underscores the critical role of dependable communication protocols for VR-guided robotic systems [3].

* 1. **Objectives**

This project's primary objective is to design and implement a system that allows a user to control a robotic arm using VR glasses. To achieve this, the project has several specific goals.

A pivotal goal is to establish an immersive and intuitive control interface for a user to control each joint of a robotic arm using VR glasses and VR controllers. To achieve this, The VR headset provides an immersive visual platform, while the VR controllers allow for direct, intuitive control over the robotic arm's individual joints. These tools aim to mirror the user's hand movements in the robotic arm's actions, fostering a powerful and intuitive connection between the user and the machine. This interface is essential for transmitting control signals to the robotic arm, ensuring precise and robust control over its movements.

One of the key goals is to to establish a reliable TCP connection between the VR interface and the Robot Operating System (ROS) platform. This connection is crucial for transmitting the control signals from the VR controllers to the robotic arm, and therefore for the robust control of the robotic arm's movements.

Another key objective is to implement two separate inverse kinematics (IK) systems — Unity's built-in IK and ROS's moveit! IK. IK is a fundamental aspect of robotic control, enabling the accurate positioning of a robot's end effector based on specified positions and orientations [4]. By using two IK systems, the project aims to provide a robust and flexible approach to this critical aspect of robot control.

Furthermore, the project seeks to enhance the system by incorporating machine learning techniques to optimize IK calculations [5], and considering a transition towards cloud-based operations for increased scalability and flexibility [6].

1. **Literature review**

The design and implementation of a system for controlling a robotic arm using VR glasses and controllers, as proposed in this project, stands on the foundation of extensive research in robotics, virtual reality, communication protocols, inverse kinematics, machine learning, and cloud robotics.

* 1. **Virtual Reality in Robotics**

The utilization of virtual reality in advancing human-robot interaction has been a significant focus in academic studies. These studies underscore the immersive nature of VR as a platform for creating more intuitive control systems. The ability of VR to mimic human movement, as elucidated by Burdea and Coiffet [7], is a critical feature that this project harnesses. By doing so, the project bridges the gap between user hand movements and the robotic arm's actions, thereby creating a more natural and responsive control interface.

* 1. **Communication Protocols in Robotics**

Robust and reliable communication protocols are essential in the field of robotics, especially when dealing with real-time control systems. TCP connections, in particular, play a critical role in ensuring stable control of robotic systems. Drawing from the insights provided by Tanenbaum and Wetherall [8], this project establishes a reliable TCP connection between the VR interface and the Robot Operating System (ROS) platform. This setup enables efficient transmission of control signals, ensuring the smooth operation of the robotic arm in response to user inputs.

* 1. **Inverse Kinematics in Robotic Control**

Inverse kinematics (IK) is a core component of robotic control, facilitating the precise positioning of a robot's end effector based on specified positions and orientations. Craig's comprehensive exploration of this subject [9] provides valuable insights that this project incorporates. By implementing two IK systems — Unity's built-in IK and ROS's moveit! IK — the project ensures the robotic arm can accurately and flexibly mirror the user's movements.

* 1. **Machine Learning and Cloud Robotics**

Machine learning and cloud-based operations are two emerging trends in robotics research that offer exciting possibilities for this project. Goodfellow et al. [10] have highlighted the power of machine learning in robotics, particularly in optimizing control algorithms. This project takes note of such potential and plans to incorporate machine learning techniques in future iterations to improve the system's responsiveness and precision.

Similarly, the concept of cloud robotics, as discussed by Kehoe et al. [11], offers improved scalability and operational flexibility. By transitioning towards this model, the project aims to allow for simultaneous control of multiple robotic arms, opening up new avenues for applications in industries such as manufacturing and logistics.

In conclusion, this project integrates and expands upon diverse fields of study, intending to make a significant contribution to the ongoing evolution of human-robot interaction.

1. **Methodology**

Building on the foundation established in the literature review, the primary objective of this project was to design and implement a system that could control a robotic arm using VR glasses and controllers. This project was propelled by the insights gleaned from the fields of virtual reality, robotics, communication protocols, inverse kinematics, machine learning, and cloud robotics.

* 1. **VR System Setup**

The project commenced with the setup of the VR system using a high-quality VR headset and controllers, selected for their ability to provide an immersive experience and accurately track the user's movements [7]. The VR system was calibrated to ensure that the movements of the controllers accurately corresponded with the intended movements of the robotic arm. This calibration was a crucial step in creating an intuitive interface for the users.

* 1. **Establishing a TCP Connection with ROS**

After the VR setup, a reliable TCP connection was established between the VR interface and the ROS platform. This involved setting up a server on the ROS side and a client on the VR side, as nuanced by Tanenbaum and Wetherall [8]. The server was configured to listen for incoming connections and receive control signals from the VR system. These signals were then translated into commands for the robotic arm, ensuring a seamless control flow from the user to the arm.

* 1. **Implementation of Inverse Kinematics Systems**

The next phase involved the implementation of two inverse kinematics (IK) systems - Unity's built-in IK and ROS's moveit! IK. The IK systems were integral to the precise positioning of the robotic arm, based on the positions and orientations specified by the VR controllers [9]. These systems were meticulously calibrated to ensure the robotic arm could accurately mirror the user's movements.

* 1. **Machine Learning and Cloud Robotics**

Looking towards future enhancements, the project also explored the integration of machine learning techniques to optimize the control algorithms [10]. Similarly, the potential of cloud robotics was considered to improve scalability and operational flexibility, aligning with the insights provided by Kehoe et al. [11].

1. **Results**

The project went through rigorous testing and validation stages. Users performed a series of tasks using the VR controllers, and the corresponding movements of the robotic arm were evaluated. The system demonstrated excellent responsiveness and precision, mirroring the user's movements effectively. The successful replication of user hand movements in the robotic arm's actions signified the project's success.

However, the project wasn't without its challenges. One notable issue was the minimal latency between the user's movements and the response of the robotic arm. Although the latency was within acceptable limits, future iterations of the project will aim to reduce this latency further.

The project successfully replicated and advanced the functionality of existing systems, demonstrating the potential of VR in creating a more intuitive and responsive control system for robotics. The integration of machine learning and cloud robotics, as future enhancements, could lead to further improvements in responsiveness, precision, and scalability.

1. **Conclusion and future work**
   1. **Conclusion**

This project successfully achieved the goal of creating an intuitive system for controlling a robotic arm using VR glasses and controllers. By implementing a reliable TCP connection with the ROS platform and leveraging the principles of inverse kinematics, the project demonstrated the potential of VR in driving advancements in human-robot interaction. Although the system exhibited minimal latency, the overall performance was satisfactory with excellent responsiveness and precision.

The findings of this project underscore the effectiveness of integrating VR technology with robotic systems. The project not only replicated the functionality of existing systems but also offered new insights into potential improvements in responsiveness, precision, and scalability. The exploration of machine learning and cloud robotics further highlighted the potential of this technology in future advancements.

* 1. **Future work**

Given additional time, there are several avenues for further development and refinement of this project:

Latency Optimization: The primary focus would be to reduce the latency in the system. This could involve optimizing the communication protocol or upgrading to a more powerful computing platform. Research into real-time operating systems or dedicated hardware could also be beneficial.

Integration of Machine Learning: Machine learning techniques could be employed to optimize the control algorithms, making the robotic arm more responsive and precise. This could involve the development of predictive models that anticipate the user's movements, thereby reducing latency.

Cloud Robotics: Exploring the integration of cloud robotics would allow for improved scalability and operational flexibility. It could also facilitate the sharing of learned behaviors among multiple robotic systems, thereby improving overall performance.

Haptic Feedback: Implementing haptic feedback in the VR controllers could create a more immersive experience for the user. This would allow the user to feel the movements of the robotic arm, adding a layer of realism and potentially improving the precision of the system.

User Testing and Iteration: Extensive user testing across a wider demographic could provide valuable insights for further refinement of the system. Gathering user feedback would help identify any unforeseen issues and provide direction for future enhancements.

In conclusion, while the project has achieved significant milestones, there is an exciting scope for further development. The integration of VR and robotics holds great promise for the future, and there are many avenues for exploration and improvement.

1. **References**

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1. **Appendix**