A Remotely Smart Controlled Virtual Telepresence Robotic System

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Abstract: **Advancements in robotics and communication technologies have made it possible to develop systems that allow users to have a virtual presence in a remote location. The proposed remotely smart-controlled virtual telepresence robotic system (RSV-TRS) was designed as an efficient system that is cost-effective and used for remote surveillance. The virtual presence interface enables users to navigate and interact with distant environments in real time. The prototype of the virtual telepresence robot is powered and controlled by the Raspberry Pi 3, and all the final output in the form of real-time data feeds is displayed in virtual reality. The system designed aims to enable users to interact with remote environments in real time through a robotic platform equipped with audio, video, and motion capabilities. The prototype implementation system was designed to remotely control a virtual telepresence robot, which is a fixed wheeled device placed in a remote location with a camera to enable live video streaming to a webpage. It allows the camera to move in the direction of the user's head movements. The RSV-TRS testing results improve remote collaboration effectiveness compared to baseline video conferencing and conventional telepresence robots, particularly in tasks requiring spatial awareness and physical interaction.**

Keywords: **Telepresence, Robotics, Real-time Monitoring, Virtual Reality, and Raspberry Pi, computer vision.**

I.   INTRODUCTION

Remote collaboration and telepresence have become essential tools in education, healthcare, industry, and social interactions. The traditional video conferencing lacks physical embodiment and spatial context. A robot is an electro-mechanical machine with sensors, electronics and guided by chips imbedded in it. A robot is any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a human-like behaviour [1]. A robot is a class of motorized devices that has the capacity to do specific tasks with little or no human contribution, showing speed and precision. Machines that are programmed by a computer to carry out complex tasks automatically are called robots [2]. Robotics is the engineering discipline deals with the design, construction and operation of robots.

Telepresence can be defined as a means that allows a person that is not physically present in a location, to interact with his environment through the use of Tele-robotic [2]. This paper examines the progressions and applications of virtual telepresence robots, which enable remote users to interact with their environments as if they were physically present there. Equipped with video streaming cameras and VR capabilities, users can navigate and control the robot's movements using a mobile device or computer, creating an immersive environment where head movements dictate camera direction [3]. Also, their inception in the late 1990s, virtual telepresence robots have evolved significantly, thanks to advances in robotics, artificial intelligence, and networking technologies. Their adoption spans multiple sectors, including healthcare, education, security, and business, demonstrating their versatility and relevance in today's society. For instance, in telemedicine, doctors can remotely monitor patients and provide consultations, while in education, teachers can conduct classes from afar, allowing students to interact collaboratively regardless of their physical locations [4].

The COVID-19 pandemic accelerated the adoption of these robots, highlighting their potential to transform how we communicate and conduct business [5]. Additionally, virtual telepresence robots can aid industries like real estate, enabling

developers to inspect and market properties without physical travel, thereby reducing transportation-related carbon emissions and contributing to sustainability efforts [2]. Even with the recent development in robotics and its rapid adaptation in several industries, the virtual telepresence robot is limited because the robot currently available in the market is too costly, not interactive and not immersive.

This research will provide a cost-efficient virtual telepresence system that can be used for various applications using virtual reality technology. The proposed system has a great flexibility that would enhances remote communication and collaboration by using Wi-Fi technology to transmit camera (video) data of robot's environment to an android phone inserted in virtual reality headset. This paper will delve into the functionality, historical context, and diverse applications of virtual telepresence robots, showcasing their significant impact across various fields and their potential to reshape remote interaction in an increasingly connected world. This work proposes a Remotely Smart Controlled Virtual Telepresence Robotic System (RSV-TRS) that combines teleoperation, local autonomy, and a virtual avatar layer to enhance presence, reduce operator load, and enable richer multi-modal interaction.

II. LITERATURE REVIEW

Research on telepresence robots' spans hardware platforms, human-robot interaction, autonomous navigation, and virtual reality (VR) integration. Robotics has seen advancements in artificial intelligence, machine learning, and autonomous systems, leading to more sophisticated and adaptable robots in fields like self-driving cars and personal assistants [6]. Robotics continues to evolve, with the potential to transform industries, enhance daily life, and address complex challenges across the globe. These robots help human beings to perform tasks that are hazardous with more efficiency and accuracy [7]. Telepresence robots have been used to help young students who suffer from chronic illness to attend school to gain a sense of normalcy and presence, especially in instructor and student to student interaction [4]. The use of telepresence robots for hospitalized children has also helped facilitate students' academic progress [8]. Telepresence robots have been tested as a resource for distance learning education, allowing remote teachers to interact with students in two geographical locations. Telepresence robots can be used by international students to attend lectures in a different location while remaining in his home country.

In a research and development of artificial intelligence (AI) coupled with industrial robots and control methods. Robotic systems with AI capabilities are crucial for industrial operations that require flexibility and competitiveness. The study examines current advancements in learning approaches, including computer vision, deep reinforcement learning, and imitation learning, and tackles gaps, problems, restrictions, and unsolved concerns in manufacturing. Because production has to improve performance, flexibility, safety, and cost-effectiveness, traditional control systems are no longer viable. AI-based technologies facilitate intelligent industrial robot control, enabling robots to comprehend intricate manufacturing procedures and adjust to dynamic surroundings. To fully explore and harness this technology's potential, more study is needed to solve concerns like sample inefficiency and knowledge generalization [9].

Naseer *et al.*, [10] classified the robot utilizations in healthcare in different categories, including receptionist, nurse, ambulance, telemedicine, serving, cleaning, spraying/disinfestation, surgical, radiologist, rehabilitation, food, and outdoor delivery robots. Information and Communications Technologies (ICT), including the Internet of Things (IOT) were linked to the robot application to improve the performance. A semi-automatic oropharyngeal swab telepresence robot was used to take swabs test with the patients to test if the patient had the disease [20]. A remote camera is attached on the swab robot, which helps the medical staff to perform the sampling with a clear vision but without close contact with the patient. The results of the collections are satisfying, whose sampling success rate is 95 % percent [8].

Tang, *et al.*, [11], designed a Virtual Reality robot with 3D vision which showed how a raspberry pi is used to transmit video data using Wi-Fi and uses a Node MCU microcontroller to control the robot's movement. It allowed for two-way collaboration in real-time between people who aren't in the same location or physical space. The combination of the Raspberry Pi and the Node MCU enhances the overall operation of the robot by improving its speed and functionality. In this paper, the robot used a Raspberry Pi cam v1.3, a 5MP, which has poor-quality video. Nitesh, *et al.*, [3],designed a Wi-Fi based wheeled robot that is not limited by distance. A Node MCU ESP32 microcontroller is used to control the movement of the robot within the remote location. This paper uses IoT concepts to control the operation of the robot using the Blynk app which is connected via Wi-Fi. The implementation of IoT concepts makes it possible to control the robot from anywhere in the world. The robot does not have a camera attached to it so it does not give a sense of presence within the virtual location [12].

Charteris, *et al*., [13], designed the virtual telepresence robot uses a camera with 180-degree pan-tilt head mechanism and a web server to remotely control from a different location. The web interface is built on a flask Micro-web server application, which used to control the robot in local-host. Ngrok is used for tunneling local host web server to the internet, through which the user can control the robot over the internet. The web server sends a wireless command which is received by Raspberry pi thus actuating robot and camera directions. The MJPEG streamer application is used for streaming video that gets MJPEG data and sends it through a HTTP session. In this paper, the camera is manually controlled and does not use an accelerometer and magnetometer sensor to determine the position of the user's head movement.

Madhumitha, *et al.,* [14], designed an IoT-based Military Surveillance Robot by using Blynk Application. The Military Surveillance Robot uses a Node MCU ESP8266 and Blynk app to remotely control the robot. Blynk App is used to control the movement of the robot and display the output parameters. The robot uses IR Sensor that detect the obstacles in the surroundings and generated output can be seen as message in Blynk app. Motor Driver is used to run the geared motor to move the rover in any direction. IP camera is used for continuous surveillance and can be recorded in the mobile phone using internet. A mobile phone is used in this paper as a camera, limiting its rotation around the robot's location. Chirapornchai *et al*., [15], designed a gesture-controlled spi-bot virtual telepresence robot. The quadruped telepresence robot relies on an NRF transceiver, Arduino Nano, Raspberry Pi3, and a Triple axis analog accelerometer to control the robot using gestures. The degree of tilt of the mobile phone is transmitted over the Bluetooth module to the Raspberry Pi. The robot is limited to a range of connectivity of 15m to 20m and cannot connect over long distances.

III.   DESCRIPTION OF THE COMPONENT DESIGN SPECIFICATIONS

A. Implementation of AR and VR using 5G in conventional industry applications

Huma *et al.* [1] developed a virtual reality robot featuring 3D vision, leveraging a Raspberry Pi for video transmission via Wi-Fi and a Node MCU microcontroller for movement control. This setup enabled real-time, two-way collaboration among users in different locations. While the combination improved the robot's operational speed and functionality, the Raspberry Pi camera used (v1.3, 5MP) provided poor video quality. Similarly, Boppudi *et al.* [16] presented a virtual telepresence robot equipped with a pick-and-place hand gripper. In this design, the Raspberry Pi also manages the camera and robotic movements, transmitting video through a web interface. However, this approach proved inefficient, as controlling the robot using buttons on a webpage became challenging when users wore a virtual reality headset, complicating navigation and interaction.

B. Telepresence Robot with Hand Gripper

Boppudi *et al.,* [16] developed a telepresence robot featuring a hand gripper, remotely controlled via a web interface with live video. The Raspberry Pi governs the camera and robotic functions. While the web-based control allows for interactivity, users find it challenging to manage the robot effectively while wearing a virtual reality headset.

C. Wi-Fi Controlled Wheeled Robot

A wheeled robot controlled using a Node MCU ESP32 and the Blynk app, enabling operation from virtually any location. However, a significant drawback is the absence of a camera, limiting the robot's capacity to provide a sense of presence [17].

D. Telepresence Surveillance Robot

The virtual telepresence surveillance robot employs a Raspberry Pi to transmit HD video footage over Wi-Fi and utilizes Bluetooth for movement control via Arduino. While it can deliver high-quality live video, its operation is restricted by the limited range of the Bluetooth connection, preventing long-distance functionality [18].

E. Virtual Telepresence Robot

This study features a virtual telepresence robot equipped with a 180-degree pan-tilt camera and a web server for remote operation [19]. Users can access the robot's controls online; however, it requires manual camera adjustments and lacks accelerometer and magnetometer sensors for head movement detection, which could enhance user experience.

F. Virtual Reality Robot with 3D Vision

This study presents a virtual telepresence robot utilizing a Raspberry Pi to manage the camera and a Node MCU microcontroller for robot movement [6], [20]. The integration of the Node MCU enhances response time, making the robot more efficient. However, it is limited by the use of a Raspberry Pi camera v1.3, which produces poor-quality video.

IV. METHODOLOGY

The Virtual Telepresence Robot consists of both hardware and software components that work together to provide full functionality and operability. Fig. 1 shows the block diagram of the Virtual Telepresence robot. The core system components include a Raspberry Pi, NodeMCU ESP32, servo motors, motor driver IC, geared motors, and a smartphone interface for control via WiFi.
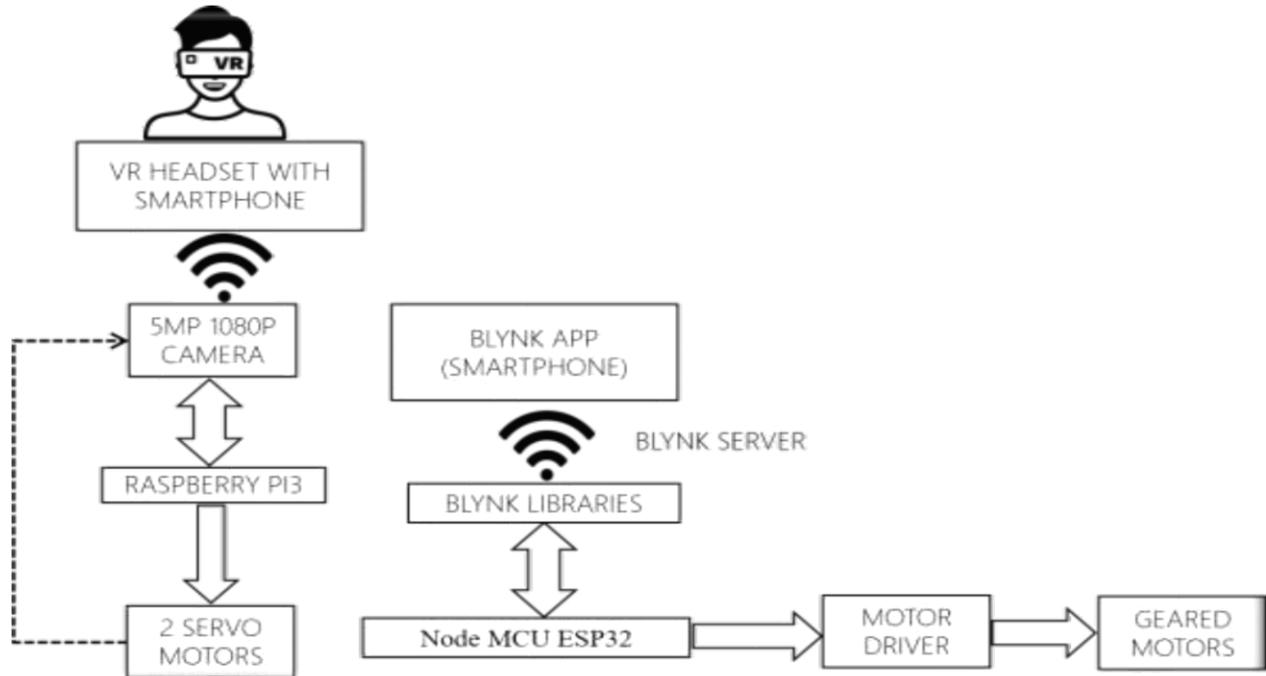

Fig. 1: The block diagram of virtual telepresence robot

A. System Architecture and Hardware Components

The architecture and hardware components of the system consists of

   i.   Raspberry Pi (Model 3B+ or newer)

  ii.   NodeMCU ESP32 microcontroller

 iii.   RPi Camera Module

 iv.   Servo motors for camera movement

  v.   Motor driver IC

 vi.   Geared DC motors

 vii.   SD Card (for Raspberry Pi OS)

viii.   Blynk app (installed on smartphone)

 ix.   Power supply for Raspberry Pi and motors

  x.   Putty software for SSH communication

The Virtual Telepresence Robot operates through the coordination of hardware and software components. The Raspberry Pi receives control commands via WiFi from a smartphone and translates them into motor movements. It also directs the servo motors to adjust the camera angle. For navigation, the NodeMCU ESP32 receives inputs from the smartphone to control the robot's motion using geared motors connected via the motor driver IC. Commands are transmitted from the smartphone using the Blynk app, which acts as a remote-control interface. Users can direct the robot's movement and adjust the camera orientation in real-time, facilitating virtual telepresence.

B. Working Principle

The proposed system working principle were outline as follows:

i. Installation and Configuration

The Raspberry Pi software was installed on an SD card using the Raspberry Pi Imager tool, which involved formatting the SD card, loading the Raspberry Pi OS (32-bit), and configuring network and SSH settings for headless operation.

Steps followed include:

a) Downloading and installing Raspberry Pi Imager and Putty software.

b) Configuring the Raspberry Pi OS for SSH access.

c) Writing the OS image to the SD card and booting the Raspberry Pi.

ii. Communication Protocol

The system uses WiFi as the primary communication protocol between the smartphone and the Raspberry Pi, as well as the NodeMCU ESP32. The Blynk app was set up as the control interface for both navigation and camera adjustment.

iii. Motor Control

The robot's movement is controlled by commands sent from the NodeMCU ESP32 to the motor driver IC, which drives the DC geared motors. The Raspberry Pi controls the camera's orientation using servo motors that respond to input from the Blynk app.

iv. System Integration

Integration of all components, including the camera, motors, and controllers, was done by ensuring proper communication through the WiFi network, facilitating remote control of the telepresence robot.

v. Algorithm

The steps to set up the system, including software installation, are as follows:

1. Download the Raspberry Pi Imager software and install it on a computer.

2. Download and install Putty for SSH access.

3. Use Raspberry Pi Imager to format the SD card and install the Raspberry Pi OS.

4. Enable SSH and configure network settings through the Raspberry Pi Imager.

5. Insert the SD card into the Raspberry Pi, boot it up, and access it via SSH using Putty.

6. Update the Raspberry Pi using the commands:

- `sudo apt-get update`

- `sudo apt-get upgrade`

7. Shut down the Raspberry Pi and connect the camera module.

8. Reconnect through Putty and continue with further software setup, including installing the Apache web server and additional components required for remote operation.

V. TESTING AND RESULTS DISCUSSION

The virtual telepresence robot is developed using a Raspberry Pi microcontroller as the central controller, managing video streaming, camera movement (tilt and pan), and video storage. The ESP32 board is employed to control the robot's movement, while a Wi-Fi module serves as the communication protocol between the Raspberry Pi, ESP32, and a mobile phone. The Raspberry Pi runs on Raspbian OS, with a custom program that streams video data over Wi-Fi for remote access. The system integrates head-based control of the camera's tilt and pan, and the ESP32 board communicates with the robot via the Blynk IoT app and interface as shown in Fig. 2 for remote mobility control. Once fully configured, the robot's functionality was successfully tested.

Fig. 2: Control of the Robot using Blynk app

The camera module of the virtual telepresence robot was tested to ensure its functionality, including recording videos at 1080p resolution with MPEG encoding and transmitting video over the internet. Testing involved powering the Raspberry Pi using a power bank, connecting it to a Wi-Fi network, and using the camera's interface to record and capture static images. The complete system design it shown in fig. 3a and 3b. Video streaming latency was assessed to confirm smooth, delay-free transmission. The camera is equipped with motion detection to automatically start and stop video recording. Additionally, a scheduling feature was tested, enabling automatic video recording at specified times. Pre-recorded videos and captured images can then be accessed and downloaded remotely through the system's webpage interface.

a   b

Fig 3: The complete design setup

VI.   CONCLUSION

The virtual telepresence robot, designed using a Raspberry Pi, ESP32, ultrasonic sensors, an RPi camera, and a robot chassis, and controlled via the Blynk mobile app, provides an efficient solution for remote communication and interaction. It allows users to observe environments and interact without physical presence, proving beneficial for elderly care, virtual attendance for physically disabled students, and reducing the need for business travel. The robot can be controlled over long distances through Wi-Fi or mobile networks and monitors its environment using a camera. It features autonomous movement, can detect motion to start recording, and operates based on schedules, offering a cost-effective solution for various real-world applications.

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