Robot vision and virtual reality integration to help paralyzed patients mobility

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ABSTRACT

This study aims to develop a device that can assist the mobility of paralyzed patients, enabling them to communicate with family and caregivers by integrating robot vision and virtual reality (VR). The method used to connect audio and visual data communication between robot vision and VR is by utilizing the robot operating system (ROS2) middleware communication node through topics over a wireless network. In this research, paralyzed individuals can maneuver based on the movement direction of robot vision, which is remotely controlled via a joystick through Bluetooth communication. The input devices used in this system include a camera, microphone, joystick, and ultrasonic sensors. The processing part uses a Raspberry Pi as the data processing center, and the output includes a DC motor, servo motor, speaker, 5-inch monitor, and headset. The results indicate that the integration of robot vision and VR can assist paralyzed individuals in communicating with family or caregivers at distances of up to 10 meters. This is due to the maximum joystick control range for moving the robot via Bluetooth communication being 10 meters. Furthermore, this study shows that the use of robot vision and VR can improve paralyzed patients' motivation, supporting the medical field in patient care.

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1. INTRODUCTION

Paralysis is a condition that results in an inability to perform activities, leading to limitations in mobility and communication with family members or the community [1]. Paralysis is a daunting illness because it can prevent individuals from engaging in activities, thereby causing mental distress. This can occur due to congenital paralysis, accidents, strokes, brain injuries, nerve injuries, polio, and other causes [2]. One activity that individuals with paralysis cannot perform is moving their legs to walk, which makes it difficult for them to request assistance. This can lead to stress, emotional pressure, and even mental and psychological disorders [3]. This research focuses on the challenges experienced by paralyzed individuals who struggle to communicate and move due to physical limitations. The situation is worsened by the lack of continuous support from family or caregivers, especially when they are occupied elsewhere. To address these issues, the study aims to create a healthcare device using robot vision and virtual reality (VR) to support patient communication and mobility.

Various researchers have explored the development of assistive technologies to support individuals with paralysis in daily tasks. Lokitha *et al.* [4] designed a smart voice assistance system tailored for individuals with speech impairments and paralysis [4]. Their system translates voice commands into text using speech recognition algorithms, then forwards the message to caregivers via Twilio's messaging service. The implementation relies on machine learning techniques such as support vector machines and Convolutional Neural Networks to process and classify speech inputs. Jayavel *et al.* [5] proposed a hand assistive device with suction cup (HADS) technology designed for post-stroke rehabilitation. In their research, they developed a functional rehabilitation device that integrates flexion-extension mechanisms with suction cup features to support post-stroke patients in enhancing their grip strength during daily grasping tasks. In a separate study, Triwiyanto *et al.* [6] developed a hand exoskeleton system for individuals with paralysis, incorporating voice pattern recognition as the control method. The system utilized voice commands to regulate the mechanical movements of the exoskeleton, enabling stroke patients to operate it effectively.

Hasan developed a cost-effective, wearable rehabilitation device aimed at assisting individuals with partial hand paralysis in performing repetitive exercises essential for recovery after strokes or injuries [7]. The system features a smartphone-based graphical user interface that helps guide and encourage patients to conduct rehabilitation exercises independently. In another study, Khan *et al.* [8] proposed a brain-controlled wheelchair system for patients with paralysis. This system utilizes electroencephalogram (EEG) signals, captured via an electrode cap placed on the user's scalp, to interpret brain activity. The signals are processed by an Arduino microcontroller, which converts them into commands to control the wheelchair's movement. Similarly, Kanna *et al.* [9] introduced an intelligent assistive module based on internet of things (IoT) technologies. The module is designed to interpret sign language by detecting hand gestures using sensors embedded in specialized gloves. These gestures are translated into text and displayed through a mobile IoT application. Additionally, Manjula *et al.* [10] developed an electronic assistant (E-Assistant) to support paralyzed individuals. This system integrates IoT technologies to offer a user-friendly and low-cost platform that monitors essential health parameters and facilitates communication, thereby improving the overall quality of life for users with severe mobility impairments.

Khan *et al.* [11] introduced an assistive robotic exoskeleton aimed at enabling independent mobility for individuals with paralysis. Their system was engineered to mimic natural leg movements by providing physical support to the user. In a related effort, Salih and Aboud [12] developed a smart ankle-foot exoskeleton using 3D printing technology to support lower limb rehabilitation. Their device was designed to restore functionality in daily activities (ADLs) by enabling three degrees of movement-abduction/adduction, inversion/eversion, and plantarflexion/dorsiflexion. Zhu *et al.* [13] further contributed to lower limb rehabilitation research by creating an exoskeleton system with motion control. Their design utilized closed-loop position control and trajectory planning at each joint, enabling precise movements tailored for paralyzed patients. Sørensen *et al.* [14] conducted a review of humanoid robotic technologies developed to support individuals with physical impairments in carrying out daily tasks. The study highlighted various robotic systems used to assist those with limited mobility. Additionally, Catalan *et al.* [15] developed a modular mobile robotic platform for individuals with varying degrees of disability. This platform features an upper limb exoskeleton mounted on a robotized wheelchair and is designed with modular components, allowing customization based on each user's physical needs and preferences.

Based on previous research findings, it can be observed that no studies have yet integrated robot vision and VR technologies to assist paralyzed individuals in both mobility and communication with family members or caregivers. Most existing studies focus solely on robotic systems that support movement for paralyzed patients. Therefore, the novelty of this study lies in the development of a device that enables both mobility and communication for paralyzed individuals by leveraging the integration of robot vision and VR technologies through a wireless network. In this research, the robot vision and VR components communicate and exchange audio/visual data using the robot operating system 2 (ROS2) middleware over a wireless connection. The robot vision system is capable of autonomous navigation based on commands sent via a Bluetooth-controlled joystick operated remotely. We expect that the implementation of this integrated robot vision and VR system will support paralyzed patients in communicating effectively and enhance their mobility, allowing them to experience outdoor environments virtually without leaving their beds, thus contributing positively to their mental health.

This paper includes four chapters that systematically present the research. Chapter 1 outlines the background, objectives, recent advancements, and the study's novelty. Chapter 2 describes the methods used to design, develop, and evaluate the integrated robot vision and virtual reality system. Chapter 3 presents and discusses the experimental results. Chapter 4 concludes the paper by summarizing key findings and emphasizing their significance and potential applications.

2. METHOD

In this study, the function of robot vision is to assist in the mobility of paralyzed patients, while VR serves as the medium for interaction between the paralyzed patient and their family members or caregivers through robot vision. Figure 1 illustrates the system architecture block diagram, and Table 1 presents the details of the hardware and software components used to develop the vision and VR robot, along with their respective functions.

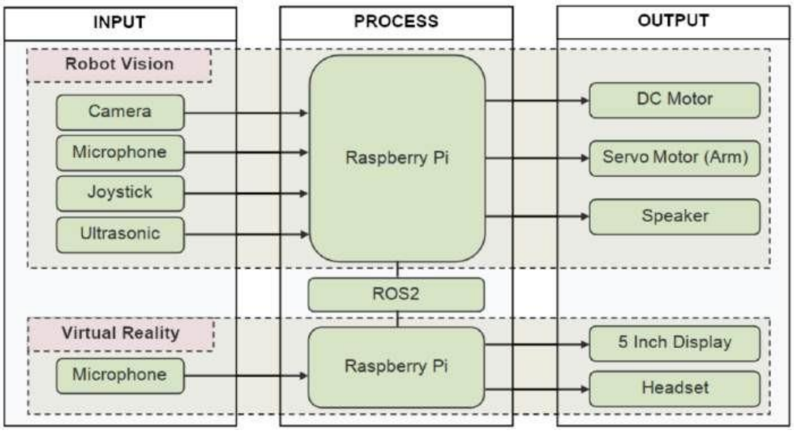

Figure 1. The systems architecture

Table 1. Types and functions of hardware and software in the robot vision and VR systems

Devices	Hardware and software systems	Types	Function
Robot vision	Camera	Logitech	Video streaming
	Microphone	Logitech	Audio input
	Joystick wireless	Play station 2	Robot control
	Ultrasonic sensor	HC-SR04	Obstacle detection
	Raspberry Pi 4	Processor: ARM v8 1.8GHz RAM: 4 GB	Robot data process
	DC motor	Omni wheel	Robot navigation
	Servo motor	MG995	Camera moving
	Speaker	Logitech	Sound output
	Middleware	ROS2	Data communication
	Operating system	Linux Ubuntu 22.04 LTS	OS for Raspberry Pi
Virtual reality	Microphone	Logitech	Audio input
	Raspberry Pi 4	Processor: ARM v8 1.8GHz RAM: 4 GB	Robot data process
	Headset	Logitech	Sound output
	Display	LCD HDMI TFT touchscreen 5 Inch	VR display
	Middleware	ROS2	Data communication
	Operating system	Linux Ubuntu 22.04 LTS	OS for Raspberry Pi

As shown in Figure 1 and detailed in Table 1, the system architecture proposed in this study is structured into three main components: input, processing, and output. The robot vision input module consists of a camera for capturing live video, a microphone for audio acquisition, an ultrasonic sensor for obstacle detection, and a joystick for manual navigation control. In the VR system, a microphone is used to record the patient’s voice during interactions with caregivers or family. In this study, the camera function captures visual data for the computing system [16], the microphone provides audio input [17], the ultrasonic sensor identifies surrounding objects [18], and the joystick facilitates movement control [19]. At the core of the processing unit, a Raspberry Pi functions as the main computing platform for both robot vision and VR components. This microcomputer operates like a standard PC [20], handling data from all input devices and managing outputs such as the DC motors for movement, servo motors for arm control, and speaker for audio playback. In the VR section, it also processes incoming visual and audio streams and directs them to the monitor and speaker. To enable real-time data communication between robot vision and VR, ROS2 middleware is used. This framework supports wireless inter-node communication and provides various libraries and tools for robotic hardware integration [21].

In the output module of the robot vision system, several actuators and devices are utilized, including a DC motor responsible for the robot's movement control, a servo motor used to adjust the camera's position, and a speaker that enables the paralyzed individual to communicate audibly with caregivers or family. On the

VR side, a 5-inch monitor is implemented to display visual data received from the robot vision system, while a headset delivers audio signals during interactions initiated by caregivers or family members. The DC motor enables navigation functions [22], the servo motor responds to pulse-width modulation (PWM) signals to reposition the robot components [23], and the speaker and headset operate as audio output interfaces [24]. the monitor serves as a visual interface in the VR environment [25]. For system operation, the software is based on the linux ubuntu operating system, which is installed on the Raspberry Pi units managing both robot vision and VR. ROS2 middleware facilitates wireless communication between both systems by transmitting visual and audio data through a publisher-subscriber model using the DDS protocol [26]. Figure 2 shows the flowchart of the systems carried out in testing the integrated robot vision and VR system.

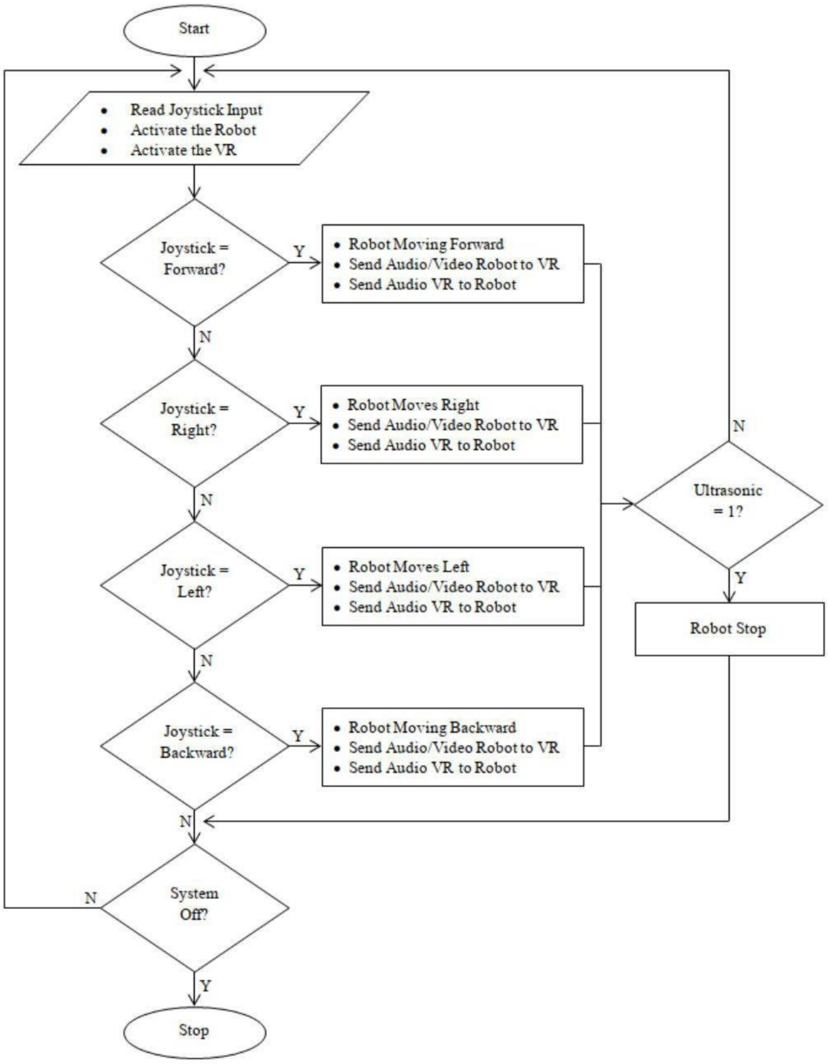

Figure 2. The system flowchart

Based on the flowchart shown in Figure 2, it can be observed that the initial step in implementing the research is to activate the robot vision and VR devices. Following this, the robot waits for commands from the joystick to move forward, turn right, turn left, or move backward. In this research implementation, when the patient presses the forward button on the joystick, the robot moves forward and simultaneously transmits audio and video data to the VR system via a wireless network. The VR system then displays the visual feed from the robot on a monitor and plays the corresponding audio through a headset. If the user presses the right, left, or backward buttons, the robot responds according to the joystick commands and continues transmitting the audio/video data between the robot vision and VR modules. Additionally, if the ultrasonic sensor detects an obstacle around the robot, the robot will automatically stop to avoid a collision. In this study, if the device is turned off, all components of the developed system will cease operation.

3. RESULTS AND DISCUSSION

In this research, a healthcare system was developed to support individuals with paralysis in achieving mobility and enabling communication with caregivers or family members. The system integrates robot vision and VR technologies, allowing users to control robot movement through a joystick, which communicates with the robot vision unit via Bluetooth. A camera on the robot captures live video and audio from a microphone, which is then transmitted wirelessly to the VR system. The VR displays the visual feed on a 5-inch monitor and plays audio through a headset. Additionally, a speaker on the robot plays the user's voice sent from the VR headset using ROS2-based inter-node communication. Figure 3 presents the system implementation and robot vision parts.

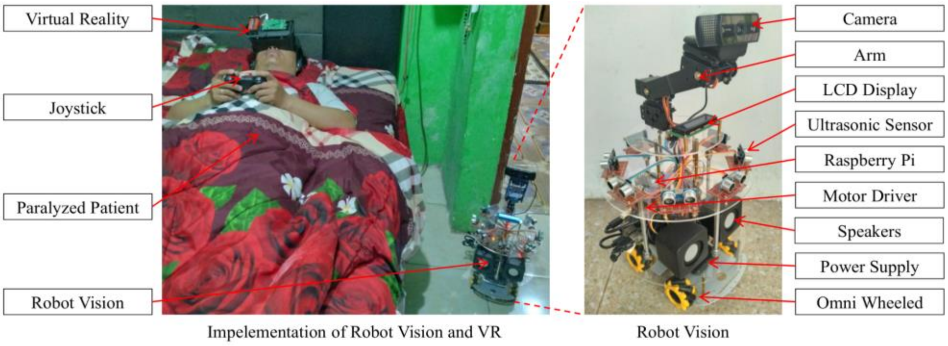

Figure 3. Implementation results of robot vision and VR, and the part of robot vision

Figure 3 demonstrates that the robot vision system developed in this research comprises several integrated components. The system includes a robotic arm that serves as a camera actuator, enabling paralyzed users to adjust the camera's position and observe the environment around the robot. The camera functions as a visual input device, capturing real-time video streams continuously for processing by the system. A motor driver controls the DC motors, adjusting their speed and direction based on commands from the control module to support the robot's navigation. The system also features an LCD screen that displays text messages to facilitate basic interaction with the user. An Arduino Mega is used to control the servo motors of the robotic arm, receiving serial commands from the Raspberry Pi. An ultrasonic sensor is employed to detect obstacles by analyzing reflected ultrasonic waves. The Raspberry Pi acts as the system's microcomputer, handling data processing tasks. A speaker is included to output the patient's voice, transmitted from the VR headset for communication. For movement, the robot uses four omni-wheels, allowing 360-degree mobility. Power to the entire system is supplied by a dedicated power unit, ensuring stable voltage and current distribution to all hardware components. Furthermore, Figure 4 shows the joystick, virtual reality earphone, and VR equipment used in this study.

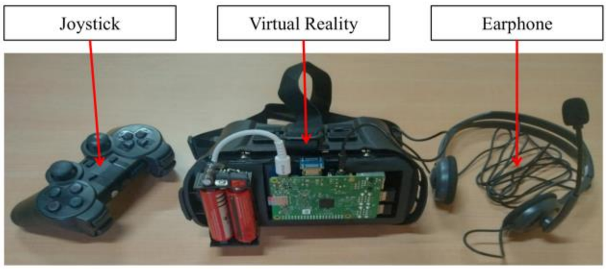

Figure 4. Joystick, virtual reality, and earphone

Based on the information shown in Figure 4, the joystick operates as the primary control interface for robot navigation and communicates with the robot vision system's Raspberry Pi via Bluetooth. It features directional buttons, allowing paralyzed users to easily command the robot to move forward, turn left or right, and move backward. To enhance safety, the system is equipped with an ultrasonic sensor that automatically stops the robot when obstacles are detected nearby, reducing collision risk and protecting the device. The VR unit functions as a visual interface, displaying environmental data around the robot through real-time video transmitted from the robot vision camera. Additionally, the headset receives audio from the robot, while its built-in microphone allows the user to send voice input back to the system, enabling communication with family or caregivers. Figure 5 illustrates the completed VR device, showing both inside and outside details.

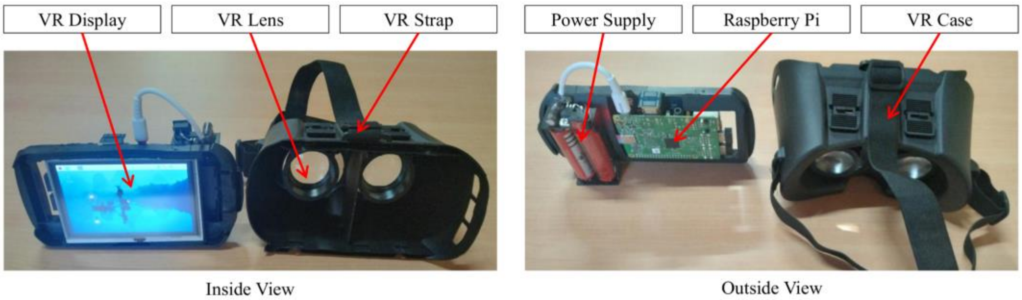

Figure 5. Inside and outside view of VR results

Figure 5 depicts the inside and outside view of the VR device developed in this study. The VR features a 5-inch display monitor that presents visual data transmitted wirelessly from the robot vision camera via ROS2 node communication. The device is designed with a head strap to secure it to the patient’s head, along with convex lenses on each side to magnify the display, enhancing the user’s visual experience. A focus adjustment mechanism is included in the lens housing for improved clarity. Externally, the VR is powered by a 7.2V, 9,900 mAh Ni-MH AA battery. A 7805-voltage regulator IC is used to convert the battery's 7.2V DC to 5V DC, which powers the Raspberry Pi. The front of the VR contains an HDMI interface for connecting the Raspberry Pi to the display, and the Raspberry Pi 4 Model B, equipped with a 1.8 GHz processor and 8 GB of RAM, serves as the system’s computational core. The device also has two additional convex lenses and a casing that integrates all components. Furthermore, Table 2 presents the results of the remote-control test of the robot from the joystick to the robot vision using Bluetooth communication, while Table 3 shows the results of the test on the patient's success in controlling the robot's movement remotely.

Table 2. Results of remote robot control and audio/visual data communication tests

Tests	Distance of joystick and robot vision (meters)	Remote robot control	Audio/visual data communication
1	1	Succeed	Succeed
2	2	Succeed	Succeed
3	4	Succeed	Succeed
4	6	Succeed	Succeed
5	8	Succeed	Succeed
6	10	Succeed	Succeed
7	12	Failed	Succeed
8	14	Failed	Succeed
9	16	Failed	Succeed
10	20	Failed	Succeed

Table 3. Test of the successfully operation of the robot vision

Patients	Number of test	Results
Patient 1	< 5	Failed
	5 ~ 10	Failed
	11 ~ 20	Succeed
	21 ~ 30	Succeed
Patient 2	< 5	Failed
	5 ~ 10	Succeed
	11 ~ 20	Succeed
	21 ~ 30	Succeed
Patient 3	< 5	Failed
	5 ~ 10	Failed
	11 ~ 20	Succeed
	21 ~ 30	Succeed

Based on the data presented in Table 2, it can be observed that patients with paralysis are able to control the navigation of the robot vision system using a joystick at distances up to a maximum of 10 meters. Control is lost when the distance exceeds 10 meters, which is due to the typical maximum range limitation of Bluetooth communication, generally up to 10 meters. Furthermore, the analysis of data communication between the robot vision system and the VR device shows that audio and video data can be successfully transmitted. This is because the communication protocol used for audio/video transmission between the robot vision and VR systems is based on wireless networking, which typically supports transmission distances of up to 300 meters. Additionally, as shown in the experimental results in Table 3, the average number of attempts required for patients to effectively learn how to operate the robot vision device using the joystick ranges from 11 to 30 training sessions. Furthermore, based on the analysis and experimental results, it can be concluded that the integrated robot vision and VR system is capable of assisting individuals with paralysis in achieving remote mobility and communication with family members and caregivers using a joystick interface. This approach provides greater flexibility and efficiency compared to previous studies that employed smart voice assistants [4], robotic hands [5], [7], wheelchairs [8], [15], and exoskeleton systems [6], [11]-[13]. This indicates that the research conducted presents an innovative novelty in assisting individuals with paralysis to communicate and mobilize with their families or caregivers. However, the study still has several limitations, including the restricted control range of the robot as well as patient comfort when operating the vision-based robot and using VR technology. These limitations will be continuously addressed and improved upon to advance future research.

This study develops a healthcare device designed to assist individuals with paralysis in communicating with their families or caregivers through the integration of robot vision and virtual reality VR technologies. This research is important to pursue further, as it has the potential to support the mental health of individuals with physical disabilities. In future work, the researchers plan to enhance the integration of the robot vision and VR system by incorporating artificial intelligence and IoT technologies. This development aims to support the advancement of Society 5.0 by enabling smarter, more connected assistive mobility solutions for people with physical disabilities.

4. CONCLUSION

This study has implemented the integration of robot vision and VR to assist individuals with paralysis in communicating and mobilizing remotely with their families or caregivers using a joystick-based control system. The results of this research indicate that paralyzed individuals are able to establish communication with their families or caregivers at a maximum distance of up to 10 meters. This limitation is due to the control communication between the joystick and the robot vision system being managed via Bluetooth connection. Furthermore, the findings show that paralyzed individuals were able to operate and control the robot's movements after an average of 11 to 30 training trials. This variation in training duration is attributed to differences in users' familiarity and understanding of operating the remotely controlled Robot Vision system. For future research, it is recommended to enhance the integration of robot vision and VR with the IoT, and to develop brain-based control of the robot vision system using EEG technology.

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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