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Eye-gaze Control of a Wheelchair Mounted 6DOF Assistive Robot for Activities of Daily Living

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Abstract

Background: Building control architecture that balances the assistive manipulation systems with the benefits of direct human control is a crucial challenge of human-robot collaboration. It promises to help people with disabilities more efficiently control wheelchair and wheelchair-mounted robot arms to accomplish activities of daily living.

Methods: In this paper, our research objective is to design an eye-tracking assistive robot control system capable of providing targeted engagement and motivating individuals with a disability to use the developed method for self-assistance activities of daily living. The graphical user interface is designed and integrated with the developed control architecture to achieve the goal.

Results: We evaluated the system by conducting a user study. Ten healthy participants performed five trials of three manipulation tasks using the graphical user interface and the developed control framework. The 100% success rate on task performance demonstrates the effectiveness of our system for individuals with motor impairments to control wheelchair and wheelchair-mounted assistive robotic manipulators.

Conclusions: We demonstrated the usability of using this eye-gaze system to control robotic arm mounted on wheelchair in activities of daily living for the people with disabilities. We found high levels of acceptance with higher ratings in evaluation of the system with healthy participants.

***Trial registration:** Not applicable.*

Keywords

Assistive robot, 6DoF, Eye-gaze control, Wheelchair, Motor dysfunction, Wheelchair mounted robot, Activities of daily living.

Backgrounds

Functional impairments of the Upper or Lower Extremities (ULE) are common in the elderly[1]. They are often secondary to conditions such as strokes, spinal cord injury (SCI), amyotrophic lateral sclerosis (ALS), Cerebral Vascular Accident (CVA), trauma, and occupational injuries[2]. Being a powerful tool for object manipulation and communication, the human Upper Extremity (UE) is the most evolved body part, and its functionality largely reflects our workability. Since most of the Activities of Daily Living (ADL) tasks are fully or partially dependent on UE, therefore, the quality of life heavily relies on the proper functioning of UE motion [3]. Loss of UE function significantly limits the independence of the affected person and the performance of everyday tasks. It is challenging for a person to do their daily activities due to physical mobility loss[4]. Impaired body functions can compromise any person's ability to perform any mobility task. Impairments can occur due to traumatic spinal cord injury, cerebral vascular accidents, limb amputations, etc. [5]. In recent decades the number of Individuals with UE disabilities has increased at an alarming rate.

Approximately 5,357,970 people, or 1.7% of the US population, currently live with central nervous system disorders, causing difficulty or inability to move the upper and lower portions of the body[6]. Around 353,000 Americans live with a spinal cord injury, and more than 795,000 US people suffer a cerebral vascular accident each year, resulting in significant deficits in upper and lower limb disabilities

[6]. Among them, it is estimated that about two-thirds of cerebral vascular accident survivors suffer acute arm impairment[6, 7]. Figure 1 shows the current scenario of people with independent living difficulty[8]. Figure 2 shows the percentage of adults with functional disabilities in the USA[8]. Loss of upper limb function significantly limits the independence of the affected person and everyday tasks' performance—a significant challenge for these people to do their daily activities without any external help.

Although a caregiver and assistive devices providing support for specific tasks, very few individuals use disabled adapted facilities [9, 10]; however, such facilities have restricted their mobility. IwULEDs (Individuals with upper/lower extremities dysfunctions) can be able to take care of themselves without significant help from others[11]. Thus, research on Activities of daily living (ADL) and mobility assistance targeting this specific population is an immense need to improve the independence of those individuals and, therefore, to reduce the burden of care for the family.

Modern technologies help people with disabilities improve their quality of life and do their daily activities using assistive robots/devices[12-15]. People with motor dysfunctionalities, different neuromuscular diseases, and traumatic injuries face several problems in carrying out daily living activities (ADL), including feeding, toileting, dressing, and bathing[16-20]. Usages of assistive technologies like a powered wheelchair and robotic hand to assist these people are on the rise[4]. Working with assistive technologies and upgrading them for better usage is becoming a newer trend [4] and caught the interest of clinics, research, and industry[21]. Different types of research work are going on to improve assistive technology [22-24]. In particular, assistive robotics appeared as an exciting research topic that can enhance people's quality of life with motor dysfunctionalities. The earlier powered wheelchair was controlled with a joystick [25-27], but people with musculoskeletal disease/injury resulting from stroke, spinal cord injury, trauma, amyotrophic lateral sclerosis, etc. could not use the hand-controlled joystick [28]. That is the reason why eye-gaze control has been explored [21, 29-34]. And researchers are improving the eye-gaze control of an assistive robot to help these impaired people's daily activities. This eye-gaze control of assistive robot

technology aims to help mute, paralyzed, elderly, or confined patients so that they can communicate with assistive robots easily, do their daily living activities, and live independently [31].

Eye-tracking is a powerful means for assistive technologies for people with movement disabilities [30, 32, 35, 36]. An eye-tracking device combined with an assistive robot can increase users' speed of interaction and comfort [32, 37, 38]. Therefore, researchers are interested in developing an eye-gaze system interface for paralyzed or physically disabled people [29].

Figure 1. Current scenario of people with independent living difficulty [39].

This paper developed an eye-gaze control architecture and designed a user-friendly graphical user interface with virtual buttons to control wheelchair and wheelchair-mounted 6DoF robotic arms in cartesian mode. In our control, we added a feature to load the predefined path of the robot's end-effector to perform an activity of daily living repetitively, such as a feeding task. We also solved the inverse kinematics of a 6DoF robotic arm, named xArm [40] to achieve the research goal. This work will allow people with UE dysfunctions to manipulate both a wheelchair and a robotic assistive arm to ease their lives.

This paper is organized as follows: Section II represents the related works in controlling robotic arms with eye gaze control. Section III discusses the preliminaries of xArm and its parameters, wheelchair, and eye gaze tracker. Section IV is dedicated to theoretical analysis of forward kinematics, dynamics, and inverse kinematics of xArm, considered workspace and control architecture. Section V talks about user interface development. Section VI presents the experimental setup. Section VII discusses the experiments, results, and discussion. Section VIII gives the conclusion.

Figure 2. Percentage of adults with functional disabilities[8].

Related Works

Some recent works in assistive technologies and how assistive technologies are used to improve the mobility of individuals with a disability are described [4]. This work consists of diverse technology, including powered wheelchairs, prosthetic limbs, functional electrical stimulation, and wearable exoskeletons. This work tried to improve the existing assistive technology mechanics, improved the physical interface, and focused on sharing the control between the technology and the user who will use the system. Oculomotor behaviors, gaze control, smooth pursuit, saccades, and their interactions with vision are described in [41], emphasizing on past 25 years' literature review on eye movements. From this work, we got the general idea of how prediction, learning, and attention work with sensory signals and how these things contribute to effective eye movement operations. If the head movement was permitted during eye-

tracking, it isn't easy to track the eye movement. A simple eye gaze tracker-based interface controls the wheelchair with free head movement described in [29]. A 3D orientation sensor is used in this eye-gaze estimation system to measure the head position and orientation. In this way, a user can keep a comfortable head pose or change head position while navigating the wheelchair. But the experimental result shows that this system is a little bit slower than other keyboard-based navigation systems.

In [30], an eye-tracking-based telerobotic arm system is proposed for tele-writing and drawing. Eight subjects were selected and trained for the experiment. This system's primary purpose is to use eye-tracking to operate a robotic arm and move the robotic arm with their gaze on a flat vertical screen for writing the word with a pen attached with the arm at the endpoint. Authors in [31] describe using a low-cost gaze tracking hardware (Gazepoint GP3 Eye Tracker) to visually draw some shapes, used as input for robot command. A custom algorithm and MATLAB are used to detect and process the command. A small humanoid robot (NAO) is used for this experiment. The robot works as a personal assistant for impaired people, and people can use an eye gaze tracking system to command the robot. An eye-tracking robotic system for controlling a wheelchair and doing some daily living activities (ADL) using a wheelchair-mounted hand-exoskeleton is explored in [32]. The system is named EMOHEX, which can help people with disabilities moving the wheelchair and also holding an object using the robotic arm. A graphical user interface is developed in [33] to control the powered wheelchair. An eye tracker interacts with the system and helps people with upper limb disabilities do their daily living activities.

The work in [34] describes an intelligent user interface designed with an eye-tracking system named Display/Eye Tracker device Set (DETS). The system is based on the VHF+ algorithm. Using this system, a wheelchair user can select a destination on a local map space, and after that, the wheelchair automatically started to go to that destination point. The objective of this work [21] is to use low-cost equipment and design a system where an assistive robotic arm can be used with the help of eye-tracking. The research aimed so that individuals can afford the system and use the system to control the robotic arm for reaching and grasping an object successfully.

Methods

Description of Materials

Robotic Arm

For this experiment xArm 6 from UFactory is used [40]. The xArm 6 is a versatile, 6 degree of freedom (DoF) robotic arm utilizing high-performance harmonic reducers and brushless motors to achieve a payload capacity of 5kg and repeat position accuracy of $\pm 0.1\text{mm}$. It has RS-485 [42] communication mode, Modbus RTU protocol [43]. It has the position, speed, and force control for programmable gripping parameters with motor current, gripper position, video, and grip detection as feedback. Figure 3 shows the joint coordinate definition of xArm 6.

Figure 3. Joint coordinate definition.

Power Wheelchair

Permobil M3 Corpus power wheelchair [44] comes with a carefully engineered suspension to help maintain better positioning, feel more secure, and reduce driving fatigue. M3 Corpus power wheelchair provides improved drive performance and a more consistent driving experience for all users. M3 Corpus

offers 12" of seat elevation and 20° Active Reach Technology that gives additional comfort experience and maintains full suspension at any elevation, seating position or driving speed. Permobil M3 is incredibly reliable at low speeds, in tight areas, or using various alternative drive controls. A hardware interface module that converts the wheelchair electrical interface signals, available through an DB-9 connector in the chair electrical control module, to USB interface signals. An overview of Permobil M3 corpus is shown in Figure 4.

Figure 4. Overview of Permobil M3 corpus.

Eye-Tracker

For eye-tracking control, PCEye5 from Tobii (See Figure 5) [45] is used. The PCEye5 is a Tobii EyeChip™ with a fully embedded processing clip-on eye tracker that lets one access and control computer using only one's eyes. Looking at the computer screen and select commands by dwelling, zooming, and clicking a switch. Alternatively, fully control the mouse cursor directly with eye movements. The eye tracker can be moved between different computers and the PCEye5 is operated mainly by the user by using their eyes, and it's workspace is calibrated against each user's eye movements. The PCEye5 is attached to

its Magnetic Mounting Plate and to a computer device using mountings. It is designed to work optimally when it is parallel to the user's eyes at a distance from about 50 — 95 cm (20 to 37 inches. Tobii Dynavox eye trackers allow easy calibration for both advanced and novice eye-tracking users. Once the PCEye is calibrated to user's eyes, it allows to hit even the smallest targets on the screen with almost pixel precision because of the zoom functionality of Computer Control software.

Figure 5. PCEye5 eye tracker.

Theoretical Analysis

Dynamics of Robotics Arm

This section presents the mathematical formulation of direct kinematics, which calculates the end-effector's position given the actuators' joint angles. To this end, we consider the Denavit-Hartenberg (DH) parameters for xArm-6 as presented in Table 1.

Table 1 Denavit-Hartenberg parameters for XARM-6

i	a_i	α_i	d_i	θ_i
1	0	0	L_1	θ_1
2	0	$-\pi/2$	0	$\theta_2 + {}^0\theta_2$
3	L_2	0	0	$\theta_3 + {}^0\theta_3$
4	L_3	$-\pi$	L_4	θ_4
5	0	$\pi/2$	0	θ_5
6	L_5	$-\pi/2$	L_6	θ_6

Here, a_i is the lengths of the common normal, α_i is the angle about common normal, d_i is the offset along previous z axis, and θ_i represents the joint angles. Note that the terms L_i represents the length of the i link, and ${}^0\theta_i$ represents the offset of the θ_i angle. The values of those variables are presented in Table 2.

Table 2 Dimensional parameters of XARM-6

L_1	L_2	L_3	L_4	L_5	L_6	${}^0\theta_2$	${}^0\theta_3$
267 mm	289.49 mm	77.5 mm	342.5 mm	76 mm	97 mm	-1.3849 rad	1.3849 rad

Additionally, the terms a_i, α_i, d_i , and θ_i follow the DH convention as presented in [46]. This convention considers the following homogeneous transformation matrix:

$${}^{i-1}T_i = \begin{bmatrix} \cos \theta_i & -\sin \theta_i & 0 & a_i \\ \cos \alpha_i \sin \theta_i & \cos \alpha_i \cos \theta_i & -\sin \alpha_i & -d_i \sin \alpha_i \\ \sin \alpha_i \sin \theta_i & \sin \alpha_i \cos \theta_i & \cos \alpha_i & d_i \cos \alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Where ${}^{i-1}T_i$ represents the transformation between coordinate frame i relative to coordinate frame $i - 1$, according to Figure 1. Ultimately, the position and orientation are obtained by applying equation (1). We calculated the end-effector homogeneous transformation matrix as follows:

$${}^0T_6 = {}^0T_1 {}^1T_2 {}^2T_3 {}^3T_4 {}^4T_5 {}^5T_6 \quad (2)$$

Roll, Pitch, and Yaw sequentially rotate around the XYZ of the selected coordinate system. The following describes the roll, pitch, and yaw orientation representation of frame {B} relative to frame {A}: For example, the coordinate system of frame {B} and a known reference coordinate system {A} are first superposed. First rotate {B} around $\widehat{X}_A$ by γ , then around $\widehat{Y}_A$ by β , and finally around $\widehat{Z}_A$ by α . Each rotation is around a fixed axis of the reference coordinate system {A}. This method is called the XYZ fixed angle coordinate system, and sometimes they are defined as the roll angle, pitch angle, and yaw angle which is shown in Figure 6. The equivalent rotation matrix is represented through equation (3).

$${}^A_B R_{XYZ}(\gamma, \beta, \alpha) = R_Z(\alpha)R_Y(\beta)R_X(\gamma) \quad (3)$$

Figure 6. Roll, Pitch, and Yaw angle.

Inverse Kinematics

Inverse Kinematics was performed using the gradient descent method (See Algorithm 1) [47]. For this method, the cost function is the Euclidean distance between the current end-effector position and the target end-effector position. The learning rate used in each iteration is adaptive and is a function of the cost function value. In this way, gradient descent will take bigger steps when the cost function is large and smaller steps when the cost function is small.

Algorithm 1: Gradient Descent Method

```

while  $J(q,p) > threshold$  do:
    gradient =  $\partial J_{\theta,p} / \partial q_1 \dots \partial J_{\theta,p} / \partial q_n$ 
    for  $j = 0 \dots 5$ :
         $\theta_j = \theta_j - \alpha \partial J_{\theta,p} / \partial q_j$ 
    end for
end while

```

Where, q is the current joint angles, p is the target position, $J(q, p)$ is the cost function defined as the distance between end-effector position and target position, and α is the learning rate.

Workspace consideration

To fulfill the activities of daily living, we considered three required workspaces. Considered workspaces are shown in Figure 7. Each workspace has a preferred orientation of the end-effector due to its location and the activities to perform. For example, the workspace C is near to the individual. Within this workspace, the robot must perform activities associated with holding or maneuvering objects. Hence,

the preferred orientation is aligned with the positive y-axis. Likewise, workspace A has the preferred direction is the negative z-axis, owing to the activities that imply pick objects from the ground. Finally, workspace B is far from the wheelchair. Hence, its main direction is the positive x-axis.

Figure 7. Considered workspace for daily living activities.

Control Architecture

Control architecture for the eye-gaze control system is depicted in Figure 8. The joints' torque commands and the cartesian commands are the output of the xArm controller. However, the torque commands are converted to motor currents and finally to reference voltage as voltage value is the drive command for the motor drivers. The controller updates the torque commands every 4 ms and is executed in xArm controller. Furthermore, to realize the real-time control of the system, and also to ensure the right control torque commands were sent to the joints as well as the reference voltage commands for the drivers, we have also added a PI controller to minimize the differences between desired and measured currents. The current signals measured from the current monitor output of motor drivers are sampled at 0.1 ms, and are then filtered with a 2nd order filter with a damping factor $\zeta=0.90$ and natural frequency $\omega_0=3000$ rad/s prior

to being sent to the PI controller. This control architecture includes combination of three types of control loops: a position loop, a speed loop, and a current loop (See Figure 8).

The primary goal of the current loop is to control torque, which influences speed, and therefore, position. The current loop is nested inside the speed loop, making current the innermost loop, with the speed loop in the middle, and the position loop being the outermost loop. Current loop here is PI controllers, with both proportional and integral gains. Current control parameters are set for tuning the current control loop.

On the other hand, the speed loop compares the commanded speed to the actual speed via an encoder and issues commands to increase or decrease the motor's speed accordingly. The speed loop is also a PI controller, with proportional gain and integral gain to determine the correction command. The amount of proportional gain is directly proportional to the amount of the error, while the integral gain increases over time and is used to "push" the motor to zero error at the end of the move. The position loop determines the following error, which is the deviation between the actual and commanded positions, and issues speed commands to reduce or eliminate the following error. In this cascaded system, the position loop used only a proportional gain.

Figure 8. Control architecture of the system.

Graphical User Interface Development

User Interface is built with virtual buttons with python using PyQt5 and integrated with multithreading, allowing sending the commands from virtual buttons to the controller simultaneously. For better eye tracking, we used Tobii PCEye 5 hardware with their integrated software system. We used it with the latest Microsoft Surface Pro 7, mounted with wheelchair-using mounting brackets. We are using computer control software for tracking eye movement and operate the computer. For better performance, we have to calibrate it first. Then we use the gaze control cursor for the left mouse button click, which works both in dual time and continuous mode.

At first, we started using our system with a user interface, where we faced some issues. The issues are too many buttons, small button size for triggering with eye gaze control, and the interface's complexity. After that, we updated our graphical user interface, which is much simpler and easier to understand for everyone. We have created a graphical user interface for interacting with the wheelchair and xArm. In addition, we have added a tabbed view for selecting the xArm and wheelchair mode. Figure 9 shows the updated graphical user interface to control the robotic arm. This was needed for simple button representation and ease of usage.

The xArm tab is divided into three different modes of operation. For operating the xArm we have added some buttons for the functionalities of Cartesian mode, Gripper movement, Pretrained ADLs, and Joint maneuvering. In cartesian mode, the buttons control the arm in XYZ axis and open and close the gripper. For more effective and efficient control, we added buttons for maneuvering the joints individually. For repetitive ADL tasks, we added buttons to load and run predefined trajectories. Using the return button, the end-effector can move between two specific target positions following the same trajectory.

Figure 9. Graphical user interface for robotic arm control.

Again, for moving the wheelchair, we have added virtual buttons. In wheelchair tab of the interface four buttons are placed which is triggered through left mouse click and this click is done through eye gaze dwell time. If the mouse cursor is on the button after the dwell time wheelchair will go in that specific direction and the wheelchair will stop if the cursor moves out from the button. Figure 10 shows the user interface for controlling the wheelchair using eye gaze control.

Figure 10. Graphical user interface for controlling the wheelchair.

Setting of the Study

Figure 11 shows the components and connections of the robotic-assisted power wheelchair with the control architecture. The green section is composed of the Permobil M3 corpus power wheelchair with its electronics that use the R-net control system that manages the inputs and output to control and share the variables of the wheelchair. Using R-net[48], the Input-Output Module (IOM), purple box, takes the joystick values. Through a D-Sub 9 Pin, it sends logical values (0 or 1) for each direction sent by the input device in the chair, or in our case, it receives logical values from an external computer to move the wheelchair. The robotic assistive arm consists of its drivers, motors, actuators, and sensors, and this is a self-contained device over a designed data. Power cable gets the control signals and shares status data (position, speed, acceleration, torque, current consumption, etc.) to an external computer.

Figure 11. Block diagram of the experimental setup

The white box shows the user application layer. This can be run in any common Operatives System (OS) like Linux, macOS, and Windows. The programs in this layer are based on Python programming language and a Software Development Kit (SDK) that came with the robotic assistive arm. From this layer, the control signals to move the arm and the power wheelchair are sent. It also can read the variables of the whole system to do an appropriate control. The program in this layer was designed to be used with an Eye Gaze Tracker to allow patients with restricted mobility to access all the old and new system functionalities.

Integrated system with eye tracker, developed circuitry, and a software system that seamlessly allows users to control wheelchair and assistive robotic arms. The blue box represents the control computer. It handles the communications of the whole system, reading and sending data to the power wheelchair with its General-Purpose Input Output (GPIO), sending and receiving data from the application layer over ethernet communication, and manipulating the robotic arm over a closed-loop control. This box gets the main power supply from the Alternative Current (AC) connection and regulates it to a 24V supply and logic

for its references. It also has an emergency stop button in case of an undesired situation. The flowchart in Figure 12 shows that the user needs to calibrate the eye tracker in computer control software.

Figure 12. Flowchart of the experiment.

Results

The study conducted in this paper was approved by UWM IRB (21.310.UWM). After getting the IRB approved, for validating the developed system, we recruited healthy subjects to do the activities of daily living. Socio-demographic profiles of the participants are presented in Table 3.

Table 3 Description of the Profiles of Participants (N=10)

Characteristics	Value
Age (years) (Mean±Standard Deviation) (n=10)	27.8±2.95
Gender	
Male	9
Female	1
Civil status	
Single	7
Married	3
Health Status	
Healthy	10
Person with disability	0

The xArm is mounted with the side rail of the Permobil power wheelchair. Figure 13 shows the experimental setup with the robot mounted on the wheelchair. We made accounts for each participant in our system and calibrated the eye tracker using the computer control software to use the developed graphical user interface to control the wheelchair and robotic arm performing activities of daily living. As a safety measure, we constrained the robot workspace to avoid contact between the robot and the participants.

Figure 13. A user is sitting in a wheelchair and using the system.

As activities of daily living, we selected picking objects from the upper shelf, pick an object from a table, picking an object from the ground. We recorded the data for both manual operations of the robotic arm and pre-recorded trajectories of these activities of daily living. Cartesian mode is used for the manual operation of the robotic arm. Still, for predefined ADL trajectories, the pickle file is loaded and executed through the graphical user interface to complete the task. Figure 14 shows the example of these ADL tasks performed using eye gaze control. The object on the shelf was five feet from the ground, and the object on the table was two and a half feet from the ground. Figure 15 shows the end-effector trajectories while

performing an ADL picking object from an upper shelf in manual cartesian mode operation and previously saved path. From both trajectories, it can be concluded that manual cartesian manipulation is traveling some extra distance than the predefined ADL path. The joint angles, torques, and speed of each joint are represented in Figure 16. Each joint begins to move at the initial angle for this specific task and stops at the final angle. From the initial position of the end effector to the final position, most of the load was imposed on joint two and joint three. We can also observe the speed fluctuations over the course due to the switching frequencies of the control.

Figure 14. Activities of daily living experiment with a healthy subject. From the left, getting something from the upper shelf, picking objects from the table, and picking things from the ground

Figure 15. Trajectories of picking an object from a shelf using cartesian mode as well as following a predefined path.

Figure 16. Joint angles, torques, and speed observation while picking an object from a shelf

Figure 17. Completion time analysis of activities of daily living.

This study yields ten samples from 10 participants from 3 types of tasks. Figure 17 shows the distribution of completion time as a box plot. For picking an object from a shelf, the minimum time required is 53 seconds, the maximum time required is 71 seconds, and the median for this task is 56 seconds. Also, for picking an object from a table, the minimum time required is 46 seconds, the maximum time required is 74 seconds, and the median for this task is 54 seconds. Similarly, for picking an object from the ground, the minimum time required is 50 seconds, the maximum time required is 80 seconds, and the median for this task is 63 seconds. Before performing all these tasks, participants practiced for around 15 minutes. After completing all the tasks, we got positive responses from the participants, and they perform all tasks with ease. Table 4 shows the overall experience of 10 healthy participants.

Table 4 Overall experience using assistive robot

Item	Question	Avg. Score (0-5) (N = 10)
1	How do you rate Assistive Robot (overall satisfaction)	4.65
2	How do you rate the comfort of using Assistive Robot?	4.72
3	How do you rate the ease of maneuverability of Assistive Robot?	4.58
4	How did Assistive Robot assist you with Activities of Daily Living (ADL)?	4.88

Discussion

This proposed method is for individuals with higher upper extremity motor dysfunctions to do activities of daily living with a wheelchair-mounted robotic arm. Because of the higher degree of the upper extremity, they cannot control the wheelchair or the robotic arm with other standard input devices such as finger or chin-controlled joystick. The developed control system and the interface are validated through the experiments with the healthy participants. Our experiments involved different essential activities of

daily living and controlling the wheelchair with the same interface, which is also necessary for the mobility independence of people with disabilities. From the overall experience results obtained from the participants indicate a promising solution for the individuals who are struggling with or unable to do their primary day-to-day tasks for their motor dysfunctions.

Participants gave positive feedback about the eye-gaze interface for its user-friendly design. For the large virtual buttons, they could controlled it with ease. The tabbed view feature in the interface allowed us to add bigger buttons for controlling both the wheelchair and the robotic arm. To make this control system more efficient and user-friendly in the next phase, we will add object detection features. Object detection and recognition features of computer vision will aid the user in manipulating objects involved with activities of daily living more easily.

Conclusion

The objective of this work was to develop a control architecture to assist people with disabilities using an eye gaze interface to control a wheelchair and wheelchair-mounted robot arms for their daily living activities. To accomplish this task, we first develop a graphical user interface based on wheelchair and robotic arm control commands to control manually in cartesian mode and follow the predefined trajectory of specific ADLs. Then, we solved the inverse kinematic of the robotic arm using the gradient descent algorithm. Finally, we evaluated the control system involving the eye gaze tracker in a human-robot collaboration with ten healthy participants. We constrained the robot workspace for safety measures. This project conforms to how eye gaze helps to manipulate assistive robotics. Our future direction for this project will be improving the robotic control architecture to reduce task completion time. Moreover, we will evaluate our developed system further with people with upper mobility impairments.

Authors Contribution

MSHS: conceptualization, methodology, software development, formal analysis, investigation, data collection, manuscript preparation, visualization. MIIZ: methodology, software development, data collection. IR: methodology, Software development, embedded system. JS: methodology, software

development. MHR: methodology, investigation, supervision, project administration, funding acquisition, writing—review and editing. SIA: resources, writing—review and editing, supervision, funding acquisition. IW: data analysis, funding acquisition, writing—review and editing. KS: data analysis, writing—review and editing. BB: control method analysis, writing—review and editing. All authors read and approved the final manuscript.

Declarations

Ethics approval and consent to participate

The study conducted in this manuscript was approved by UWM IRB (21.310.UWM) and participants gave their consent to participate.

Consent for publications

We got the consent of the participants' as per the protocol of UWM IRB (21.310.UWM).

Availability of data and material

The datasets generated during and/or analyzed during the current study are not publicly available due to the conditions of the funding source but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Disclaimer

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