NextGen Wheelchair: A semi-autonomous solution for disabled people using Head Motion and Digital Twin Technology

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***Abstract*—Mobility assistance is essential for physically challenged people such as accident survivors, and patients with spinal cord injury (SCI) or heart diseases. Quadriplegic survivors are more dependent on the assistance of their caregivers even for basic minimal movements. These people may benefit from a wheelchair which can help them accomplish specific everyday tasks independently through the minimal movement of their heads as the functionality of their heads remains stable. The aim of this article is to develop a wheelchair that can be driven by the patients independently as well as by caregivers who experience physical strain while taking care of the patients. The construction of a head motion-controlled wheelchair has been made possible by the use of image processing and machine learning. Besides the remote monitoring and controlling of the wheelchair by the caregivers has been possible by using digital twin technology. A prototype of the system has been developed and it is found to be cost-effective, efficient, and more dynamic than other existing systems.**

***Keywords*—** quadriplegic, SCI, head-motion, digital twin, image processing, remote monitoring.

I. Introduction

One of the difficulties that stroke or spinal cord injury (SCI) survivors encounter is mobility. These people may benefit from a wheelchair to help them accomplish specific everyday tasks independently. The demand for wheelchairs among elderly people and individuals with paralysis has surged recently. A push wheelchair, however, does not offer comfort or maneuverability for physically challenged people. Electric-powered wheelchairs (EPWs) were developed to preserve users' physical energy and give them greater maneuverability. Though this approach came out in handy for most paralyzed individuals, it could not make it this far for those who cannot even use their hands, ultimately making them dependent on a human assistant. To address several mobility issues, extensive research has lately been done on intelligent wheelchair technology.

Besides casualties and injuries caused by road accidents are not unfamiliar scenes in Bangladesh. Many survivors of these incidents are often left with no choice but to embrace immobility. Besides people can be victims of the curse of immobility due to various other physical complications like heart disease, limb damage, etc. As a result, quadriplegic survivors are dependent on the help of their caregivers or relatives even for basic minimal movements. Almost 10% of the total population of Bangladesh (16 Million) has suffering or has suffered at some point in life from paralysis due to some disorders like strokes, spinal cord injuries, autoimmune diseases like multiple sclerosis, brain injuries, etc. These people specially quadriplegic and SCI survivors may benefit from a wheelchair which can help them accomplish certain everyday tasks independently through the minimal movement of their heads as the functionality of their heads remains stable. The aim of this project is to develop a wheelchair that could be driven by the patients independently as well as by caregivers who experience physical strain while taking care of the patients.

The intended audience for our project includes individuals with physical disabilities who are unable to walk or talk and rely on wheelchairs for mobility, as well as their families and caregivers. We also aim to reach healthcare professionals such as doctors, nurses, and physical therapists who work with individuals with physical disabilities, as well as researchers and engineers in the field of assistive technology.

Additionally, our project may be of interest to funding organizations, non-profit organizations, and government agencies that focus on improving the lives of individuals with physical disabilities. We aim to raise awareness about the importance of mobility and independence for individuals with physical disabilities and promote greater inclusiveness and accessibility in our society.

Our project may also be of interest to the wider public, as it highlights the potential of technology to address real-world problems and improve the quality of life for individuals with physical disabilities. We hope to inspire others to pursue innovative solutions in the field of assistive technology and create a more inclusive and accessible world.

The primary audience for a head motion-controlled wheelchair system is people with impairments who have limited or no use of their hands or arms, including individuals who have spinal cord injuries, muscular dystrophy, cerebral palsy, or multiple sclerosis. These individuals have mobility issues that make it difficult for them to move around independently. Our project intends to provide disabled people to maneuver freely which is important to make them independent. A head motion-controlled wheelchair offers an alternative method of operating their mobility equipment. This system will enable people with impairments to access and navigate their environments more freely, enhancing their overall quality of life. It will enable this by detecting and interpreting head motions. Another target group for a Head Motion Controlled Wheelchair system is caregivers who assist individuals with physical disabilities operate their mobility aids. A head motion-controlled wheelchair system may reduce the physical strain on carers and increase the safety of wheelchair operations. These caregivers frequently experience physical strain and damage from prolonged use of manual control systems. The NextGen wheelchair is a head motion-controlled wheelchair that will be controlled through the movements of the head obtained by a USB camera. After that, interaction will be made with a raspberry pi module to translate the head motions into commands which will drive the wheelchair. The system is expected to take intelligent decisions like halting when it will see any obstacle as well while moving. As an alternative, a voice control system will also be added. Additionally, an emergency alarm will be activated in order to ensure the user's safety. Although the system's initial cost is anticipated to be slightly higher, it can be offset by the benefits it will provide in the long run.

This proposed project has the potential to greatly improve the quality of life for those who are physically challenged and unable to move without assistance, as well as make it easier for the their caregivers to look after them.

II. Literature Review

Hassani et al.(2015) developed an interface for disabled people to control the standard electric wheelchair with head gestures [1]. They developed the system based on the principle of acceleration and rotation rate of the patient's head which was detected using an accelerometer and gyroscope sensors embedded with MPU6050. Overall performance was evaluated in an indoor environment with a healthy object. However, the system was limited to the X and Y axis of the user's head angles, which limits the movement of the wheelchair in some defined directions. Future work can be implemented on driving the wheelchair on diagonal regions and the Z - axis, which can make the system more reliable and efficient. *Patil et al.(2020)* designed a system that was operated with the help of a tilt of the head movements [2]. The system was designed and developed using tilt sensors and wireless modules and can bear a capacity of up to 100 kg and be implemented practically. One of the main objectives of implementing a low-budget system with a better accuracy rate was achieved through this project. A semi-autonomous head-motion controlled wheelchair is proposed for quadriplegic patients by *Kader et al.(2019)*. A 3-axis accelerometer sensor was used to detect the head movement and two DC motors were used to navigate the wheelchair [3]. Two sonar sensors were used to detect the obstacles in the front and back directions of the wheelchair. An SMS system was integrated with the system through a GSM modem with location information to inform the family member about any collision or accident. However, a machine-learning-based approach can be implemented in the future to detect the head motion for controlling the wheelchair more precisely and ensuring a better accuracy rate. Also, the authors have suggested working on IoT based health monitoring system to continuously monitor the physical condition of the patient. *Bakouri et al.(2022)* developed and implemented a voice control algorithm to control a smart robotic wheelchair (SRW) using the neural network technique [4]. Network In Network (NIN) and Long Short Term Memory (LSTM) structures were integrated into the system with a built-in voice recognition algorithm. A Wi-Fi hotspot was used to connect the hardware and software parts of the system with a configured mobile application. Five voice commands were employed with the Raspberry Pi and DC motors in the system to navigate the wheelchair. The system was implemented in both indoor and outdoor environments which resulted in an accuracy rate of 98.2% for the proposed five voice commands - left, right, yes, no, and stop. Though, the authors have suggested enhancing the system with GPS technology which can allow the users to design their routes for future work. Besides, adding safety measurements like integrating ultrasonic sensors, integrating more voice commands with the system, and controlling the wheelchair with brain signals can be a great addition. So, future research is needed to implement these proposals which can make the system multi-operational, more accurate, and reliable. Artificial neural networks were trained through the user's voice commands based on neural networks and a backpropagation algorithm by *Karande et al.(2022)*. The proposed prototype was trained using five voice commands - Forward, Backward, Left, Right, and Stop [5]. The commands were written on target hardware wirelessly by using a Bluetooth module for the motion of the DC motors. The overall prototype was designed on MATLAB R2020a and Arduino UNO. To make the system more efficient and less costly, the authors suggest future work like deploying the whole MATLAB code directly to the target hardware. *Karim et al.(2022)*, constructed the wheelchair using a microcontroller and other electronic devices to control the motors and process the voice commands [6]. The system was designed in such a way that it remains cost-effective and can be commercialized for needy users. *Rulik et al.(2022)* designed a multimodal control method for robotic self-assistance that can assist patients with disabilities in performing self-tasks daily [7]. Two interchangeable operating modes- chin and finger joystick control frameworks were developed to control the movements of the assistive robot. The system was tested by performing some daily activities such as picking up and placing items which resulted in a completion time of less than 1 minute for each task. The absolute position accuracy was spotted at approximately 5 mm. However, to pick up heavy objects, the system needs high torque and the performance of the system becomes low also. So, the authors should work on this area to make the system more efficient. *Kulkarni et al.(2022)* developed a "signal-controlled wheelchair" that can be controlled with a small motion of the hand [8]. The proposed system was implemented with Arduino grounded predispositions which is similar to the Arduino NANO and UNO microprocessors. The system was developed to address the challenges of using joysticks to control a wheelchair. The authors proposed a mixed optic indicator to detect the retina to move the wheelchair for future research. Besides, GSM technology can also be used to transmit messages in an emergency.

As a goal of developing a wheelchair with control methods of head motion, voice, and wireless control that is specially tailored to quadriplegic as well as other disabled patients, is a good starting approach. This system is proposed to develop of a wheelchair that can be controlled via the head motion of the user, as well as with voice and joystick modules as two other alternatives. A web interface is also developed for continuous monitoring of the system as well as controlling the system through that web interface. Besides, the caregivers can control the system from a far distance which can reduce the physical strain that they experience while being with the patients.

III. Concept Design and Architecture

This proposed NextGen Wheelchair is suggesting a semi-autonomous wheelchair with multiple control modules for physically challenged people. The wheelchair can also be controlled remotely by the caregiver of the patient.

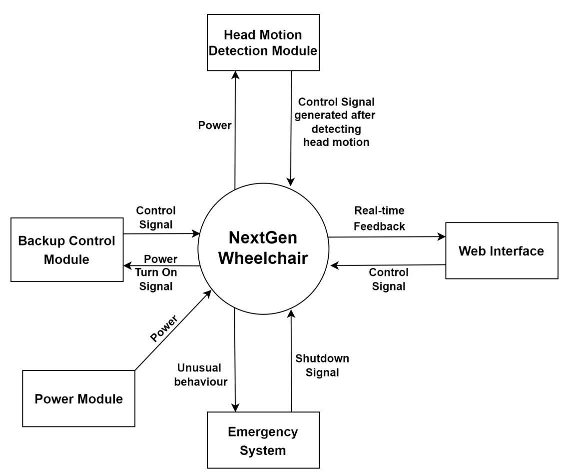

Fig. 1: Context diagram

The system is divided into multiple modules and subsystems- head motion detection module, backup control module, web interface, power module and emergency system. (see Figure 1)

The web interface, power module and emergency systems all operates parallelly with either of head motion detection or backup control module. Here the backup control module contains the voice and joystick control.

The overview of the proposed system's architecture is presented in Figure 2) that represents the links and flow of information between different physical and logical components in the system.

The system can be controlled manually (with a joystick), vocally, or by moving the head. Any of these three control techniques can be

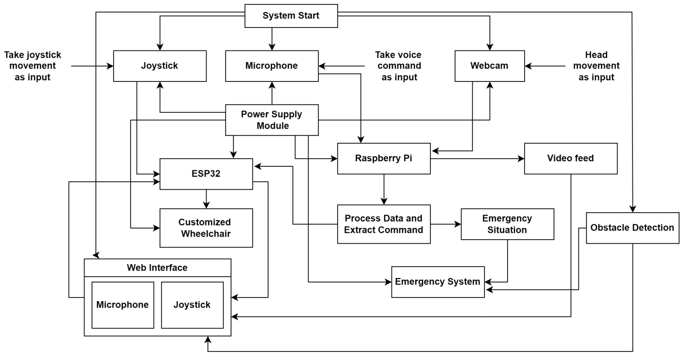

Fig. 2: System architecture

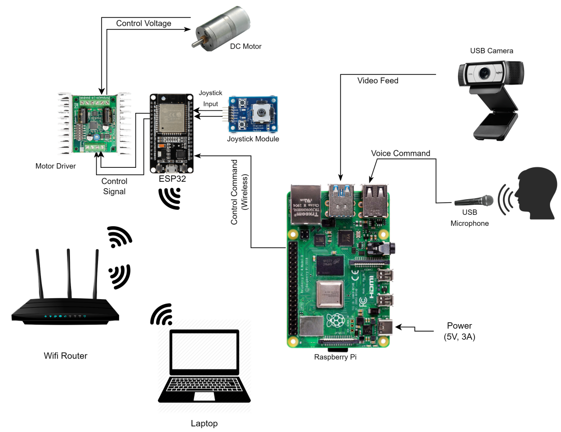

Fig. 3: Circuit diagram of system workflow

used by the patient to operate the system. Additionally, a caretaker can operate the system vocally and manually. Using a web interface, he can control the system. In the event that the patient chooses manual control, the joystick data will be delivered straight to the esp32. If voice or head motion is chosen, the processor (in our case, a Raspberry Pi) will first receive voice input from a microphone or video feed from a webcam, process the data, and then extract the user's intended commands before sending them to the esp32. The esp32 will receive the caretaker's webpage command directly. The wheelchair will then be ordered to proceed in the direction chosen by the patient from this esp32. A buzzing alarm will sound if an emergency arises at any time, alerting the caregiver. In order for the safety of the patient, some control commands might also be blocked at the same time. The wheelchair would automatically detect any obstacles in its path and sound the buzzer to let the user and caregiver know there was an obstacle in the path of the wheelchair. To provide proper voltage and current delivery to all the components, a power supply module has been incorporated.

IV. Methodology

A. Overview

Our project consists of a prototype car, instead of a real wheelchair. Its movement is primarily determined by the movement of the patient's head, observed through a camera. Two backup control modules — voice command and joystick control — are also added to the system to achieve greater control versatility.

B. System Design

Our system incorporates various control methods and features, primarily relying on the patient's head movement. Moreover, voice command and joystick control are also added as backup control systems. Additionally, the system intelligently handles the situation when obstacles are present around it. To produce a seamless and coordinated system, the various elements of the wheelchair system — including head movement detection, voice command control, manual joystick control, and obstacle detection — are combined. In order to ensure that control commands are correctly processed and carried out, as well as that obstacle information is reliably identified and responded to, communication protocols and software interfaces permit seamless interaction between various components.

C. Head Movement Detection

Head movement is detected by the camera feeds obtained from a USB webcam. A javascript library named face-api.js is used for analyzing the camera feed and detecting the orientation of the patient's head. For face detection, this javascript library uses models like SSD Mobilenet, Tiny Face Detector, MTCNN, 68 Point Face Landmark Model, Face Expression Recognition Model etc.

D. Backup Control System

The backup control system is made up of two components: voice command and joystick control. The joystick here used is a generic one, providing the basic functionality of moving it 360 degrees around. In the voice command mode, it will take basic voice commands like "move left", "move back", "stop" and act accordingly.

E. Obstacle Detection

The principle of obstacle detection is to measure the distance between the reference and any object. This process can be done by an ultrasonic sonar sensor module. This module fires an ultrasound and receives the reflection of that sound. Then, by measuring the duration between the time of firing and the time of receiving, we can find out the distance between the prototype and the obstacle. If the distance is less than 20 cm, the prototype stops moving towards that direction.

V. Testing and Evaluation

To measure the accuracy and find out how reliable the system is, an evaluation study was performed within an academic environment through using the agile process. A test case was generated for each primary functionality of the system and the users were told to conduct the test cases five times. As our system was implemented on a prototype car, the tasks were evaluated among the academic students. For each task, five people were invited to be the test subjects. Before the evaluation, a brief discussion about the system was given to the participants to explain the objective of the study and provide an overview of the proposed system. During the evaluation, the participants were given the opportunity to interact with the system from their respective points of view for a period of approximately 4 – 5 minutes. They were encouraged to explore the system's features and functionalities and provide feedback on their usability and effectiveness. After the initial interaction, the participants were assigned a set of tasks to perform using the system. These tasks were designed to assess the system's performance in specific scenarios and evaluate its ability to meet user requirements. Throughout the evaluation process, the participants were encouraged to ask questions and provide their opinions on the system's usability. The researchers observed and recorded relevant data, such as the number of attempts taken to complete tasks and the time required for task completion. At the end of the evaluation, the participants were asked to provide opinions on the system's usability and effectiveness. Basically, the system was evaluated by explaining the participants to try out how much time the system takes to operate on required directions and to take intelligent decisions. They were also invited to share any suggestions they had for improving the system. A recorded summary is shown in TableI.

Task	**Module**	**Result**	**Number of Attempts (M±SD) (sec)**	**Task Completion Time (M±SD) (sec)**	**Number of Times Asking For Help (M±SD) (sec)**
Log in	Software	100%	1±0	12.64±8.02	0±0
System control with head motion	Software	83%	1.25±0.43	20.56±2.75	0.2±0
System control with voice speech	Software	77%	2.6±0.44	17.71±4.28	0±0
System control with manual joystick	Software/ Hardware	100%	1±0	10.01±1.94	0±0
Obstacle detection	Hardware	100%	1±0	0.17±0.02	0±0
Emergency Stop	Hardware	100%	1±0	0.33±0.07	0±0
Speed Control	Hardware	71%	1.4±0.55	2.25±0.55	0±0

TABLE I: Data analysis of prototype system performance

From the data table, we can see that participants struggled to perform the designated tasks by using head motion with the highest mean completion time. Besides, participants needed to ask for help to operate the system with the main feature of the system according to the observing researchers. Besides, participants needed more time in implementing the voice modules and speed control than expected. Except for the Login system and emergency stop, participants were struggling to do the required tasks. A good number of participants were confused about using the system efficiently as the system was completely new to them. They had the opportunity to use the system for a few minutes, followed by the performance of a set of tasks. The outcomes and findings of the system provided us with some innovative feedback to develop the system more efficiently in the future. Besides, the lack of accuracy and reliability of the system made us motivated to research the system in the future and make it much more error–free and user–friendly to the users.

VI. Discussion and Conclusion

This system uses head motion as the primary method of wheelchair control and uses a joystick and voice command as secondary control methods. The caregiver can also remotely control the wheelchair through the web interface. In the first instance, this system ensures user safety using a semi-autonomous halt system. Additionally, it notifies in case of emergency situations. Multiple research works were conducted to build a head-motion controlled electric-controlled wheelchair [9] and remote heal-care monitoring systems [10]. But none of the works were embedding both head-motion-controlled wheelchairs and remote monitoring and control systems.

The use of a semi-autonomous halt system also makes our system stand out from other existing systems. Besides the use of multiple backup control modules and emergency systems makes this system more reliable and safe.

Despite having multiple features this system doesn't cover shortcomings like the patient and the caregiver must be under the same WiFi network which restricts the usage of the system from a broad perspective. Furthermore, in low light conditions, the low accuracy of eye gestures to halt the wheelchair makes this system less effective. The system can be extended to more effective and precise operations and voice assistance by the proper use of digital twin technology, remote health monitoring, and mapping technology.

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