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An IoT-Based Smart Wheelchair with EEG Control and Vital Sign Monitoring †

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Abstract: This study introduces an innovative smart wheelchair designed to improve mobility and health monitoring for individuals with disabilities. Overcoming the limitations of traditional wheelchairs, this smart wheelchair integrates a tri-wheel mechanism, enabling smooth navigation across various terrains, including stairs, thus providing greater autonomy and flexibility. The wheelchair is equipped with two smart Internet of Things (IoT)-based subsystems for control and vital sign monitoring. Besides a joystick, the wheelchair features an Electroencephalography (EEG)-based Brain-Computer Interface (BCI) for hands-free control. Utilizing Support Vector Machine (SVM) algorithms has proven effective in classifying EEG signals. This feature is especially beneficial for users with severe physical disabilities, allowing them to navigate more independently. In addition, the smart wheelchair has comprehensive health monitoring capabilities, continuously tracking vital signs such as heart rate, blood oxygen levels (SpO2), and electrocardiogram (ECG) data. The system implements a SVM algorithm to recognize Premature Ventricular Contractions (PVC) from ECG data. These metrics are transmitted to healthcare providers through a secure IoT platform, allowing for real-time monitoring and timely interventions. In the event of an emergency, the system is programmed to automatically send alerts, including the patient's location, to caregivers and authorized relatives. This innovation is a step forward in developing assistive technologies that support independent living and proactive health management in smart cities.

Keywords: smart stair-climbing wheelchair; EEG control; internet of things; vital sign monitoring

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1. Introduction

In an increasingly inclusive society, addressing the mobility needs of individuals with physical disabilities remains a critical challenge. While traditional wheelchairs have been instrumental in improving mobility and independence, their functionality is largely limited [1,2]. These limitations have driven the development of smart wheelchairs, which integrate advanced technologies to transform basic mobility aids into sophisticated assistive devices [3–5] aiming to improve overall quality of life for individuals with disabilities.

Wheelchairs are classified based on several factors that require ongoing research and improvement [6]. These factors include the form or configuration of the wheelchair, the input methods used to control it, which encompass various types of instructions, and the sensors used for monitoring both the condition of the user and navigation. Additionally, the classification takes into account the operating modes and safety features, ensuring that the end-user can drive the wheelchair safely and according to their preferences.

One of the key advancements in smart wheelchairs is the enhancement of navigation and mobility. These improvements include autonomous navigation systems that utilize various sensors, such as LiDAR, ultrasonic, and infrared, to detect and avoid obstacles [7–

9]. This technology facilitates safer and more efficient movement through complex environments. Furthermore, these wheelchairs come with multiple control options, including manual and assisted controls like joysticks [10–12], voice recognition [13,14], eye control [15,16], gesture control [17,18], and Brain-Computer Interface (BCI) [19,20]. With the help of these facilities, users can tailor their interactions to suit their preferences and physical capabilities [21]. For instance, an eye-controlled wheelchair is proposed in [22], wherein a camera is used to track eye orientation and ultrasonic sensors are used to detect obstacles. The system is built on a Raspberry Pi platform that processes visual inputs to control motor functions and navigate the wheelchair. A wheelchair control system that leverages Electroencephalogram (EEG) signals along with a front-facing camera and Inertial Measurement Unit (IMU) sensors to track head/hand movements and estimate steering intentions, was designed by [7]. Several control interfaces have been implemented and tested in [23], including voice commands, smartphone-based controls through a Bluetooth communication channel, and an EEG device for brain signal interpretation.

The integration of IoT technology has taken this evolution a step further, enabling smart wheelchairs to connect with other devices and networks for remote control [24] This integration enhances users' independence and control, facilitating smoother navigation and better adaptation to complex environments, ultimately increasing autonomy and personal empowerment for individuals with mobility challenges. Nevertheless, contributing to health monitoring, many IoT based wheelchairs have been developed with the capability to monitor vital signs such as heart rate, blood pressure, and body temperature, providing valuable health data for users and caregivers. Several studies discussed the development of a smart wheelchair integrated with IoT technology to assist elderly individuals in healthcare monitoring and mobility. The wheelchair design in [25] incorporated pulse rate and oxygen sensors for online heath monitoring using Wi-Fi module, as well as ultrasonic sensors for obstacle detection, and a GPS tracker for real-time positioning. The accelerometer was used to track head motions to control the wheelchair's movements. While in [26], a wheelchair was equipped with sensors to monitor vital bio-indices such as heart rate, blood pressure, temperature and oxygen levels. Data was sent to a cloud-based system, allowing for real-time monitoring and alerts to caregivers or medical professionals in case of irregularities.

On the other hand, several studies have focused on the development of stair-climbing wheelchairs, aiming to enhance mobility for users with disabilities. These wheelchairs incorporate various innovative mechanisms to navigate stairs effectively [27].

This paper presents a significant advancement over previous studies by integrating IoT-based wheelchair that combines multiple control methods with stair-climbing capabilities. This system not only enhances the wheelchair's ability to navigate stairs safely and efficiently but also leverages IoT technology to monitor the user's health in real-time and deliver immediate alarms in the event of an emergency. The wheelchair can be controlled using either a joystick or ECG signals, providing flexible and adaptive control options for users with diverse needs and capabilities. By incorporating these advanced features, the proposed design aims to offer a comprehensive solution for individuals with mobility challenges, ensuring greater independence, improved health management, and personalized control.This paper cover the comprehensive design and implementation of the smart wheelchair, including the mechanical structure, control systems, and vital sign monitoring. Preliminary testing results will also be discussed, demonstrating the efficacy of the design in real-world conditions. Finally, future developments and potential improvements will be outlined.

2. Materials and Methods

This section is divided into three main sub-sections: mechanical design, electronic control systems, and vital signs monitoring. As shown in Figure 1, the smart wheelchair is equipped with two main subsystems: a control system and vital sign monitoring system. Data from various sensors is sent to cloud servers, such as Firebase and Ubidots, which can be accessed via a health monitoring interface on a mobile app or web page.

On the structural design of wheelchairs, the design includes a tri-wheel mechanism that lets the wheelchair move smoothly over various terrain, including up and down stairs.

On the electronics and control systems, the latter consists of two main methods, namely control using brain waves (EEG) and manual control using a joystick.

Various sensors are used to monitor vital signs such as heart rate, blood oxygen levels (SpO2), and ECG. These sensors are connected to an IoT-based microcontroller that allows patient health data to be monitored in real-time by health workers and authorized relatives. This monitoring scheme is designed to provide early warning in emergency situations, ensuring that patients receive timely assistance.

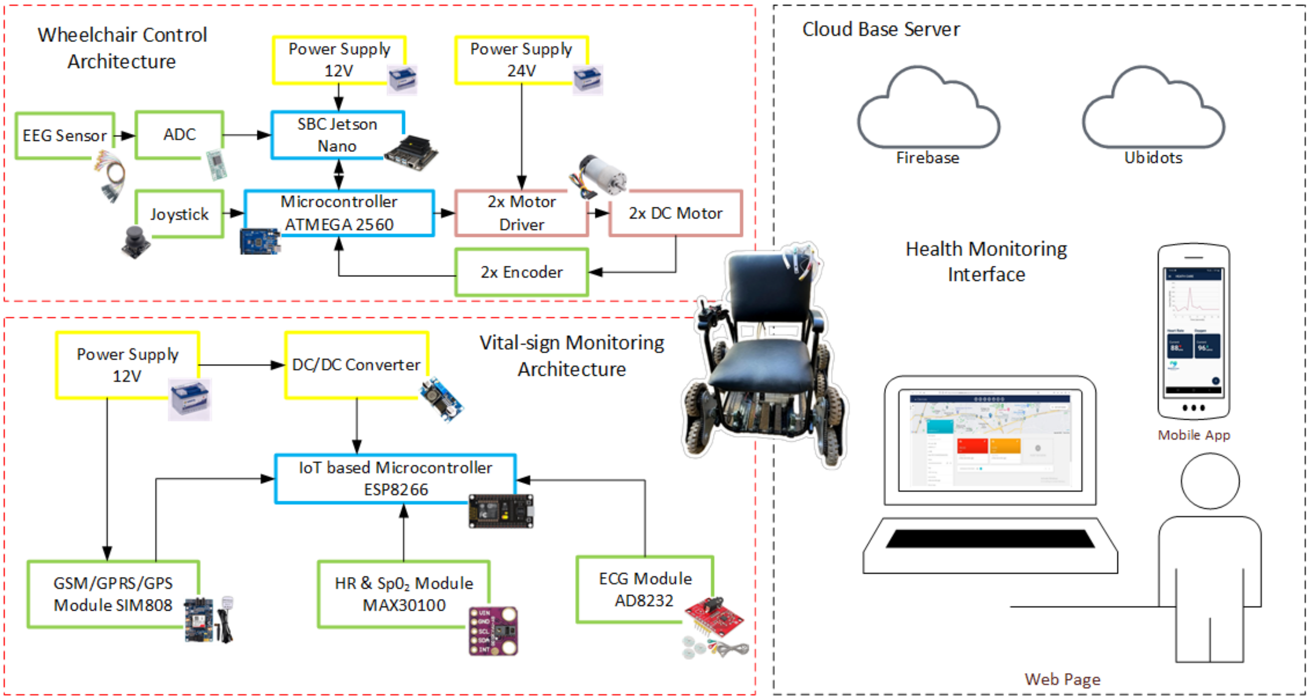


Figure 1. Overall Architectures of Smart Wheelchair System.

2.1. Design and Prototyping

The proposed system comprises a chassis, a stair-climbing mechanism with two motors, and power supplies that are specifically engineered to navigate various types of terrain, including flat surfaces, uneven paths, and stairs. A distinctive feature of this design is its ability to ascend and descend stairs, achieved through the integration of a tri-wheel mechanism, as illustrated in Figure 2a. Dimensions of tri-wheel illustrated in Figure 2c are tailored to standard stair heights (ISO 7176-24:2004).

The stair-climbing mechanism comprises four identical locomotion units, each positioned at a corner and featuring three wheels arranged in a triangular configuration. Each tri-wheel assembly includes four axles: one for each wheel and an additional axle for motor power transmission. All four axles have a diameter of 20 mm, matching the inner diameter of the wheels. These tri-wheels are interconnected by a chain-driven system, which ensures excellent grip and traction on stair surfaces. The tri-wheel frame, a critical component of the mechanism, is constructed from 5 mm galvanized steel for strength and durability. The structural integrity of all components has been analyzed using Finite Element Analysis (FEA) to ensure durability and safety under operational conditions. Furthermore, physical testing has been conducted to validate these analyses.

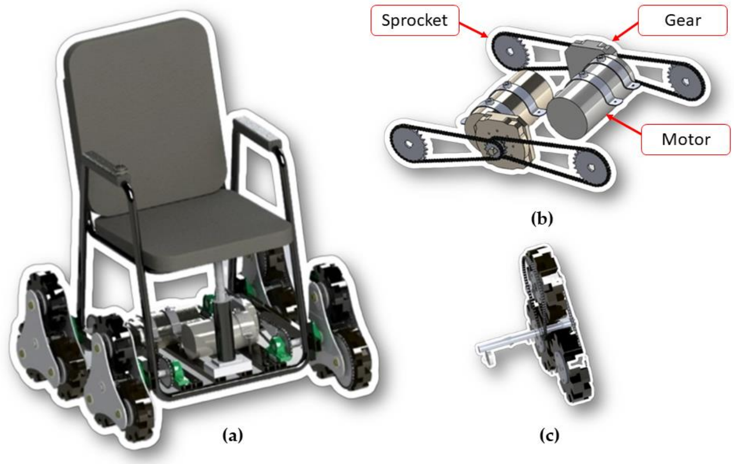


Figure 2. 3D CAD model of the Smart Wheelchair. (**a**) Wheelchair. (**b**) Transmission mechanism. (**c**) Tri-wheel mechanism.

The power and strength of the motors have been carefully calculated to support a maximum load capacity of 100 kg including the weight of the end-user. This load capacity ensures that the wheelchair can perform four essential functions: traversing flat surfaces, ascending stairs, descending stairs, and executing turns. The primary support structure for the chassis is the motor housings, using tool steel rods. Two brushed DC motors (24 V, 25 A) are mounted horizontally in the inner-middle area of the chassis, one for each side of the chair. For power transmission, a chain sprocket mechanism is employed. The larger sprocket is attached to the central axle of the tri-wheel, while the smaller sprocket is connected to the motor shaft. The torque applied to the smaller sprocket is amplified on the larger sprocket by a gear ratio of 7. The detailed design is illustrated in Figure 2b.

The prototype was designed for quick manufacturing using in-house facilities such as CNC laser cutting, grinding, arc welding, turning, drilling, bending, cutting, and 3D printing. This research culminated in the development of the first working prototype, depicted in Figure 3. The prototype embodies all the theoretical design principles and has been subjected to preliminary testing to assess its performance in real-world conditions. These tests include evaluations of the wheelchair's stability, maneuverability, and ability to navigate stairs and other obstacles, thereby providing proof of concept for the innovative design.

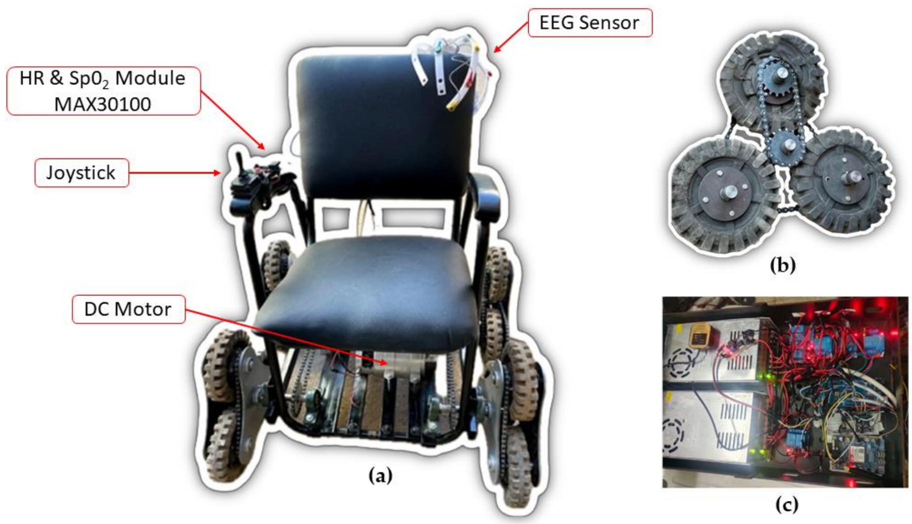


Figure 3. Prototype of the Smart Wheelchair. (**a**) The actual prototype. (**b**) Tri-wheel configuration. (**c**) Electronics for control system.

2.2. Control System

The wheelchair is designed to be controlled using two distinct methods: brain wave control and joystick control, as illustrated in Figure 4. The implementation of dual control methods is intended to minimize the risk of faults occurring in either system, which is particularly important given the wheelchair's intended use by individuals with disabilities.

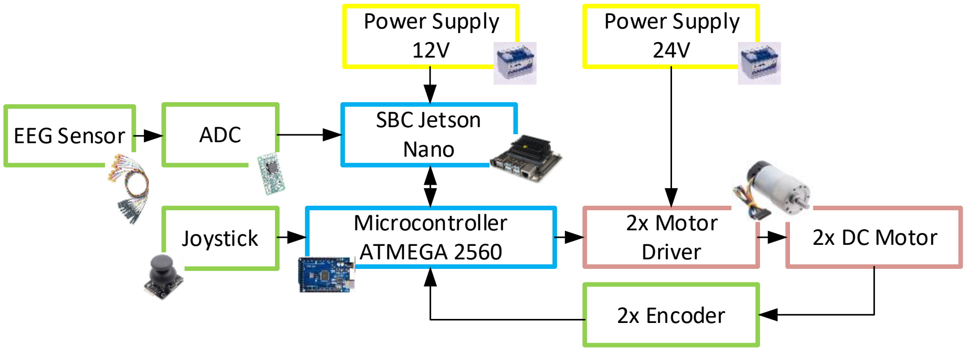


Figure 4. Control System Architecture for the Smart Wheelchair.

The EEG-based BCI utilizing motor-imagery (MI) paradigms are applied to wheelchair apparatus control. This technological approach eliminates the need for conventional manual steering, allowing users to navigate to specific locations using only brain signals. In this BCI system, the EEG module captures brain signals associated with limb movements to navigate the wheelchair in five directions: forward, backward, right, left, and stop. The feature extraction method focuses on Mu waves (8–12 Hz) and Beta waves (13–30 Hz) frequency bands, which are linked to cortical areas directly connected to the brain's motor output channels. The act of moving or getting ready to move generally leads to a reduction in Mu and Beta rhythms, particularly on the opposite side of the body from the activity [28]. The captured signals are then classified using a Support Vector Machine (SVM), a robust classification method that constructs a hyperplane in a multidimensional space to optimally separate different classes [20]. The classification output is transmitted to a Jetson Nano, which processes the results and converts them into commands for the electric wheelchair.

The Jetson Nano is selected due to its support for the development of artificial intelligence (AI) and machine learning (ML) [29], which are necessary for processing these brain data. Utilizing a laptop is refrained due to its excessive dimensions, which rendered it impractical for integration into a smart wheelchair. Hence, the selection of the Jetson Nano was based on its small dimensions and its aptitude for AI/ML deployment.

For joystick control, we will use a simple joystick to facilitate the user in operating the wheelchair. This control method provides an intuitive interface for the user to control the direction and speed of the wheelchair.

By providing both brainwave control and joystick, this smart wheelchair can meet the needs of a variety of users. This dual control approach not only improves the usability of the wheelchair but also significantly contributes to the safety and independence of its users.

2.3. Vital Sign Monitoring System

The smart wheelchair is designed to monitor the patient's condition and location in real time. The IoT architecture of this smart wheelchair, as shown in Figure 5, includes sensors to monitor heart rate, SpO_2, ECG, and patient location. The IoT-based microcontroller ESP8266 is employed for data acquisition from several key modules: the SIM808 (GSM/GPRS/GPS) for location tracking and communication, the MAX30100 (HR and SpO2) for heart rate and blood oxygen monitoring, and the AD8232 (ECG) for electrocardiogram readings. The system is powered by a 12 V power supply, regulated through a DC/DC converter for stable operation.

Data from these vital signs sensors is then sent to cloud-based platforms such as Ubidots and Firebase, which can be accessed by authorized health workers and by the patient's relatives.

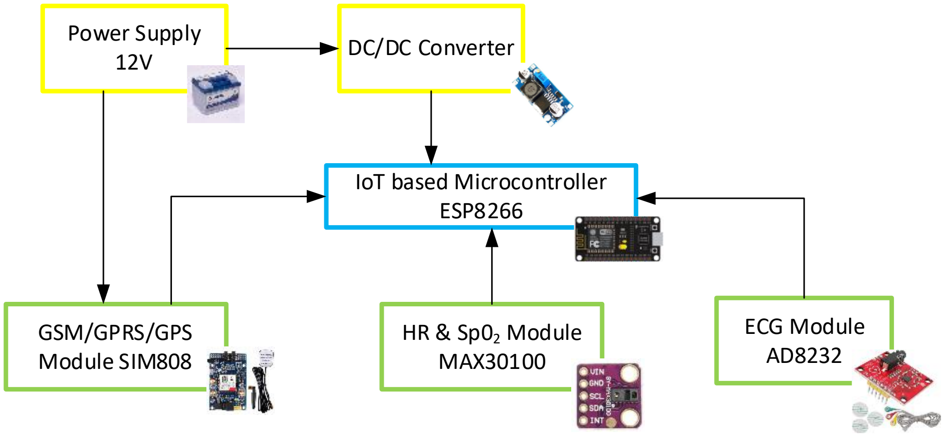


Figure 5. Architecture of the IoT-Based Smart Wheelchair System.

To obtain heart rate and oxygen saturation conditions, we have used the MAX30100 module that communicates with the microcontroller using the I2C protocol. For real-time heart condition monitoring, we have used the AD8232 ECG module. This signal is analog and will be directly read by the Analog to Digital Converter (ADC) on the microcontroller. To determine the position of the smart wheelchair, we use the SIM808 module. This module communicates using the UART protocol. It is also used to send health data and the position from the microcontroller to the cloud server.

In this study, a Premature Ventricular Contractions (PVC) recognition system based on a ML approach utilizing the MIT-BIH Arrhythmia Database [30], is proposed. Recognizing PVC is crucial for early detection and management of underlying heart conditions such as arrhythmias and cardiomyopathy. It aids in monitoring heart health, risk stratification, and symptom management, ensuring timely medical intervention and appropriate treatment [31]. A comparative study has been done to determine the most suitable ML model for this application. However, the detailed findings of this study will be presented in future work.

3. Results and Discussion

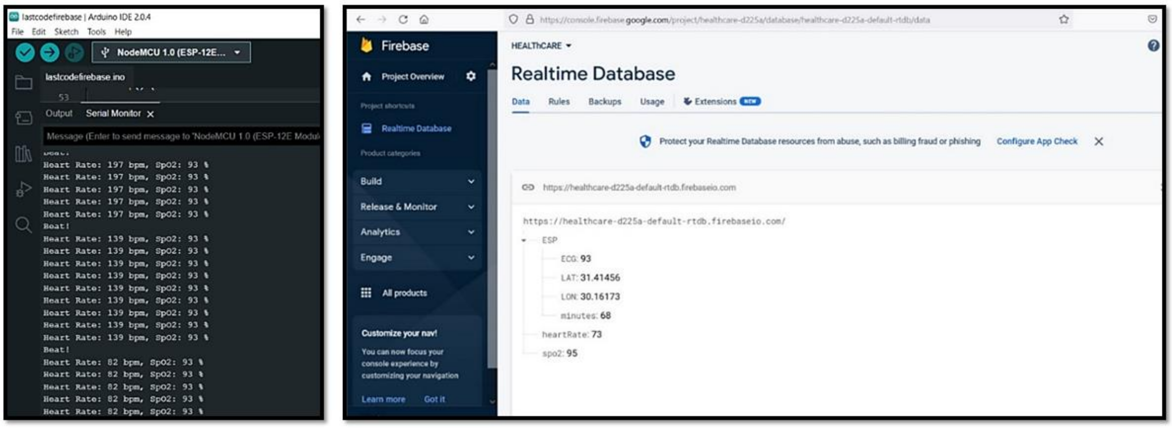
The signals collected on cloud-based platforms, as shown in Figure 6 can be displayed on the web page or mobile app that we have developed. As shown in Figure 7, the web page displays the wheelchair user's position as well as vital signs such as heart rate and oxygen saturation. This information can be accessed at any time by authorized healthcare personnel.

Additionally, a mobile application has been developed and integrated with a Firebase server, as shown in Figure 8. This application can be accessed by wheelchair users to monitor their health conditions. It also provides access to doctors, caregivers, and family members, facilitating comprehensive health management and support.

Monitoring the patient's vital signs is very important, especially in emergency situations. In an emergency, the system we have developed will automatically send messages via SMS and/or email to authorized health workers and relatives, providing information about the patient's condition and location, as shown in Figure 9. This facilitates the process of being picked up by an ambulance or relatives, ensuring that the patient receives fast and appropriate assistance.

This innovation is very important considering the high risks faced by patients using wheelchairs. Despite their higher health risks, they often still need to leave their homes for unavoidable reasons, such as medical appointments, social gatherings, or everyday needs. With this advanced health monitoring and emergency notification system, patient safety and independence can be significantly improved.

Furthermore, the use of a cloud-based platform for data storage and access ensures that patient health information is stored securely and can be accessed by the healthcare or relatives. This not only improves response times in emergencies, but also allows for continuous monitoring and timely medical intervention.



(a) **(b)**

Figure 6. Real-Time Data Transmission. (**a**) The data output from the sensors, including heart rate and SpO2 levels, as transmitted to Firebase in real time. (**b**) The real-time database in Firebase, including ECG, heart rate, SpO2, and the patient’s location (latitude and longitude).

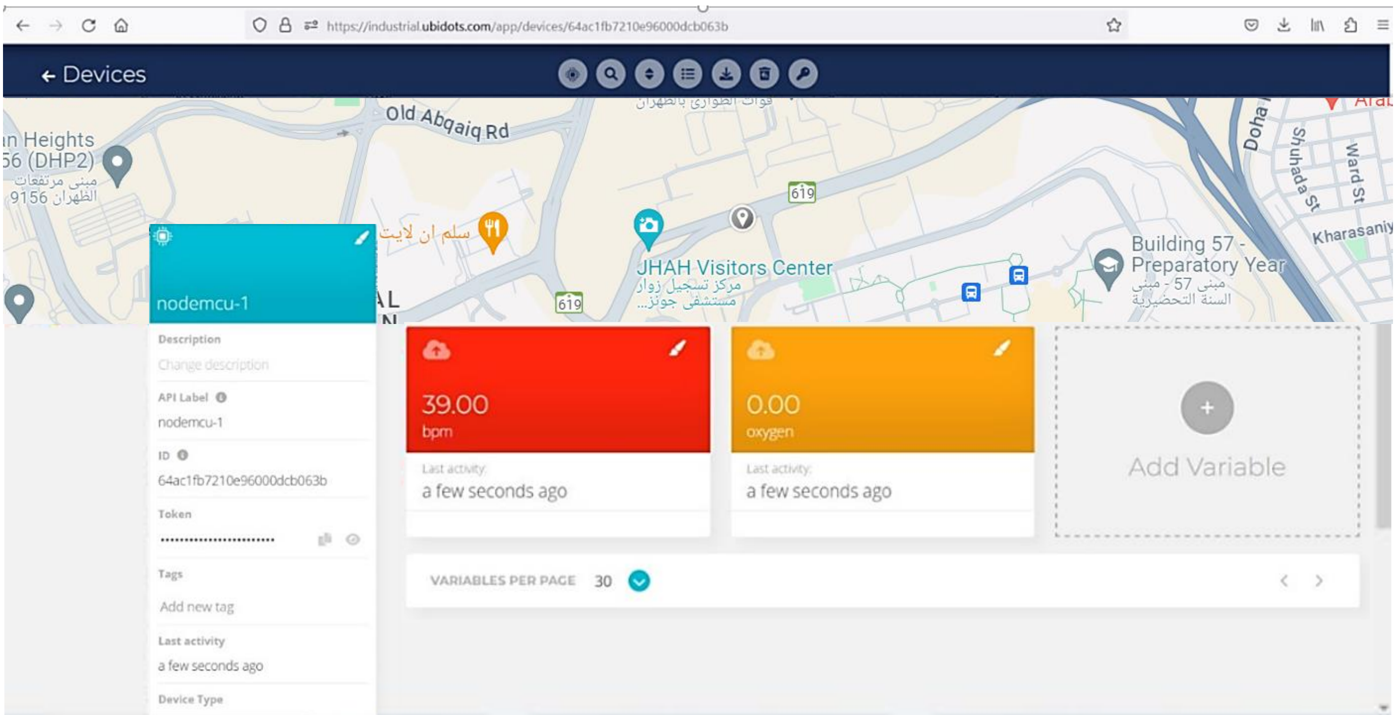
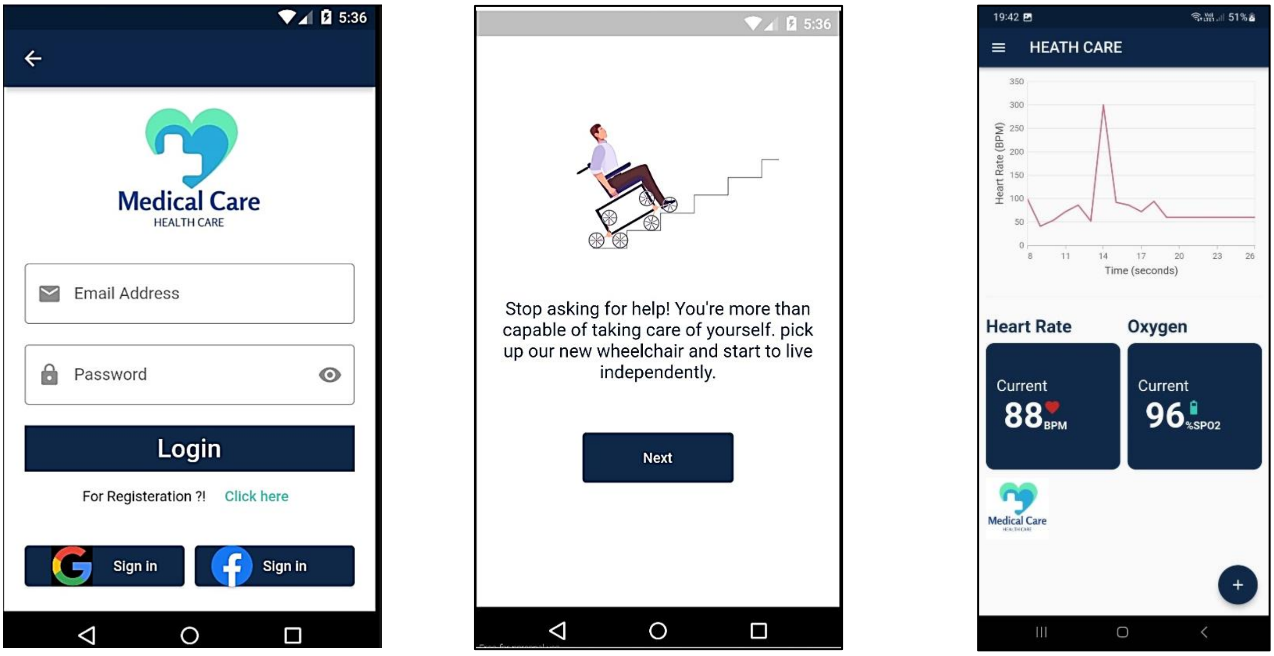
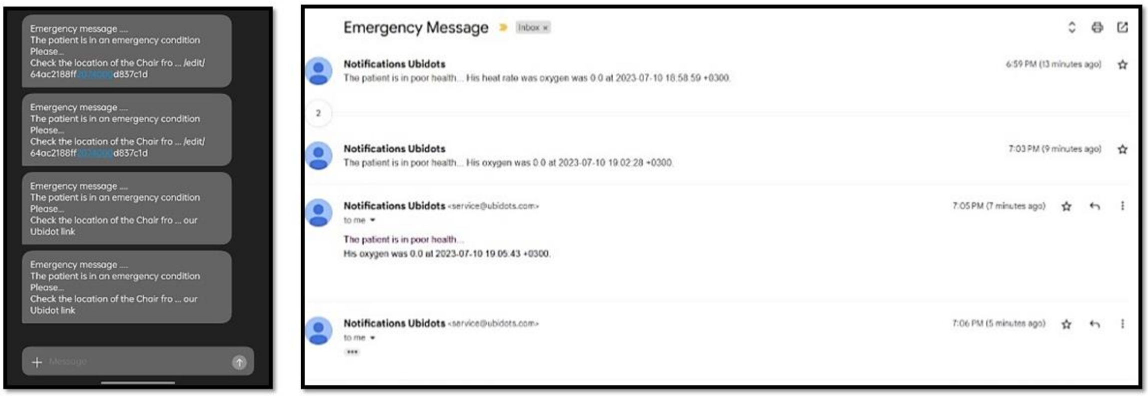


Figure 7. Real-time Health Monitoring Interface on Ubidots Platform.



(**a**) (**b**) (**c**)

Figure 8. Mobile Application Interface for Smart Wheelchairs. (**a**) The "Medical Care" app login screen. (**b**) Application introduction. (**c**) Health monitoring interface.



(**a**) (**b**)

Figure 9. Emergency Alert Notifications from the Smart Wheelchair System. (**a**) Real-time SMS alerts. (**b**) Email notifications.

4. Conclusions

This study introduces a novel IoT-based smart wheelchair that aims to improve the mobility and health monitoring of those with impairments. The smart wheelchair integrates a tri-wheel mechanism, enabling it to navigate various terrains. The wheelchair is equipped with two smart IoT-based subsystems for control and vital sign monitoring.

The dual control system, comprising EEG-based brainwave control and joystick control, guarantees dependability and user-friendliness, accommodating individuals with varying degrees of mobility. The EEG-based control utilizes SVM algorithm, which have proven effective in classifying EEG signals.

By integrating modern sensors with IoT technology the system continuously monitors vital signs like heart rate, SpO_2, and ECG. The system implements SVM algorithm to recognize PVC from the ECG data. These health metrics are sent to cloud-based platforms such as Ubidots and Firebase, allowing healthcare providers and family members to access them in real-time through a mobile app or web page. The technology is designed to autonomously dispatch emergency notifications through SMS and email, guaranteeing swift intervention in urgent circumstances.

The development of this intelligent wheelchair prototype showcases notable progress in assistive technology. The initial testing demonstrates encouraging outcomes in terms of stability, maneuverability, and the capacity to traverse stairs and other obstacles. Future developments will concentrate on conducting thorough examinations of the brain wave control system, enhancing the prototype to a greater degree, further integration of the learning network for detecting PVC into the single board computer, and incorporating sophisticated artificial intelligence algorithms to enable predictive health monitoring.

The advanced wheelchair's extensive health monitoring and strong emergency response capabilities signify a significant advancement in promoting self-sufficiency and proactive healthcare administration for those with impairments. This innovation enhances the users' quality of life and guarantees their safety and well-being, making it a vital addition to the field of smart cities and assistive technologies.

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