An innovative study on a smart wheelchair with the function of health monitoring

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ABSTRACT

Currently, with the development of society and advancements in technology, there is an increasing need for elderly and disabled people to improve their quality of life and self-reliance. Under such context, designing an smart wheelchair with easy operation, comprehensive performance, and health monitoring functions has become a significant focus in the market. In this project, we used the inertial sensor MPU150 for wheelchair motion direction and speed control, designed the wheelchair control system into the form of glasses. We also improved the PPG probe and its analog front end, presenting an innovative method to detect the weak pulse wave signal from the user's head. Furthermore, the vital signs collected by the wheelchair can be shared through the internet for medical staff and family members to check the health conditions of the user in real-time.

Keywords: Health monitoring, smart wheelchair, self-controlled wheelchair system

1. INTRODUCTION

With the increasing prominence of population aging, more elderly people with mobility impairments find it difficult to lead a free and socially active life due to the lack of assistance. Enhancing the convenience in the lives of the elderly and their sense of security has become particularly urgent and critical[1]. Meanwhile, the number of physically disabled individuals in China is rising. By the end of 2023, the total number of disabled people in China reached 85.914 million, with 45% classified as having severe disabilities in categories I and II, and the number of individuals with multiple disabilities reached 9,000[2]. As national medical standards improve and healthcare systems continue to develop, coupled with the rapid growth of online media, there is a growing focus on the quality of life and travel convenience for the elderly and disabled[3].

Smart wheelchairs, which integrate automatic controllers, sensors, and actuators to propel movement, allow users to control the wheelchair via joystick operation and voice recognition. This not only enhances the mobility and quality of life for the elderly and disabled but also serves as an indispensable tool in rehabilitation and eldercare projects[4]. Additionally, smart wheelchairs can be employed in public places such as airports, hospitals, and subways, providing intelligent services to individuals with mobility difficulties. Therefore, the smart wheelchair has a promising market prospect, high research value, and holds a great significance in social development[5].

Over the years, continuous development and exploration has been made in the field of smart wheelchair domestically and internationally. The VAHM project in France developed a smart wheelchair with manual, automatic, and semi-automatic operating modes[6]. This wheelchair can design routes and reach destinations according to the user's needs. Additionally, users can choose between manual and automatic control modes. The WHEELESLEY project at the Massachusetts Institute of Technology developed a smart wheelchair that can be controlled through menu, human-machine interface, and joystick[7]. In the human-machine interface mode, users can utilize a Hawk-Eye system to recognize the user's eye movements for autonomous driving control. In joystick mode, users can issue commands in the usual manner.

Significant progress has also been made in China regarding smart wheelchairs, especially in such institutions as the Chinese Academy of Sciences, Shanghai Jiao Tong University, and Beijing University of Technology[8,9]. Shanghai Jiao Tong University's smart wheelchair adopts intelligent modules, and also has the functions of active navigation and obstacle avoidance[10]. The smart wheelchair developed by Beijing University of Technology employs a fuzzy Bayesian network algorithm for obstacle avoidance. This approach combines neural networks and the fuzzy control system to effectively

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achieves autonomous navigation and obstacle avoidance through four-wheel drive[11,12], significantly enhancing the safety and efficiency of smart wheelchairs.

2. OVERVIEW OF THE SMART WHEELCHAIR

While current wheelchairs are widely used, they often need specialized operation and supervision, causing higher labor costs. The research and implementation of smart wheelchairs are thus highly valued in such context, although research in this field in China started relatively late. Current smart wheelchairs on the China market are usually controlled through joysticks, center of gravity positioning, voice recognition, head gesture recognition, and facial expressions. However, they can hardly be put into widespread application because of their weaknesses, such as complex operation, unstable performance, low level of intelligence, and high costs. On the other hand, electrocardiogram (ECG) signals are an important information reflecting a patient's health status, particularly significant for the prevention and diagnosis of heart diseases. However, current ECG monitors are only used in hospitals, making the development of ECG monitoring tools and techniques the ultimate way to realize continuous and convenient ECG monitoring on patients.

This project aims to design a head-motion controlled smart wheelchair system with stable performance, easy operation, high usability and the function of health monitoring[13]. This system allows users to control the wheelchair's direction by himself while enabling healthcare personnel and family members to constantly monitor the user's body temperature, pulse, ECG, physical location, and other vital signs in real-time. This innovation can lower the labor costs and increase the reliability in monitoring. Additionally, certain diseases in users can be detected early for the timely treatment by analyzing these physiological date and employing data mining and artificial intelligence methods.

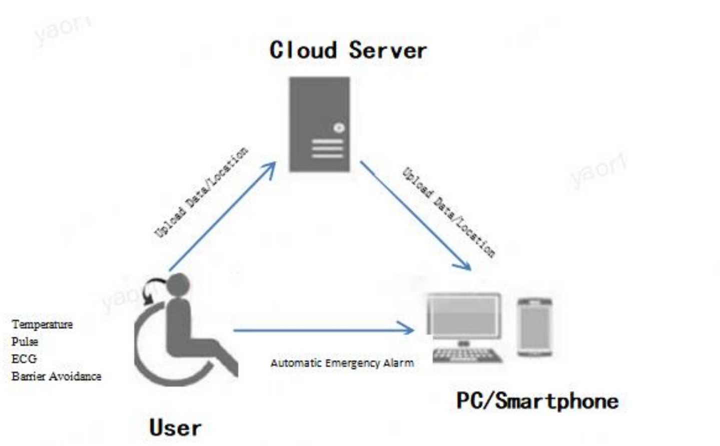

Figure 1. The Working Process of the Smart Wheelchair

2.1 Working principles of the smart wheelchair

The weak pulse wave signals from the head can be detected with the innovative use of photoplethysmography (PPG) waveform recording and the improved PPG probe and its drive circui[14]. The head direction of the user can be tracked synchronously and accurately by the wheelchair under the effective control of the positional PID control algorithm. Through the wireless communication of the NRF51822 Bluetooth System-on-Chip (SoC), the user’s physiological data including pulse waveforms, temperature, heart rate, and electrocardiograms (ECGs) are displayed on an application (APP) and accessed through the network. The built-in MCU of the NRF51822 serves as the main control chip for wheelchair motion control and data exchange.

In this system, the Inertial Measurement Unit (IMU) is used to measure angular velocity and acceleration of objects in three-dimensional space, and the motion status of objects in three-dimensional space can be computed through the complementary inertial navigation system. Angle data is obtained through data fusion algorithms applied to gyroscopes and accelerometers of the MPU9150. The system can monitor the ECG from the user’s head continuously and conveniently through the simplified contact of dry electrodes and the specialized ECG acquisition chip BMD101.

After wearing the wheelchair control system glasses, the user can control the wheelchair's direction in line with his sight by rotating his head horizontally; the user can also increase wheelchair speed by inclining forward with his head, or decelerate and brake by inclining backward. They can start or release the wheelchair control system by moving their head left and right respectively.

Pulse waveforms, temperature, and ECG data collected by the control system are displayed on the APP, with corresponding heart rate updated every five seconds, while temperature is updated every ten seconds.

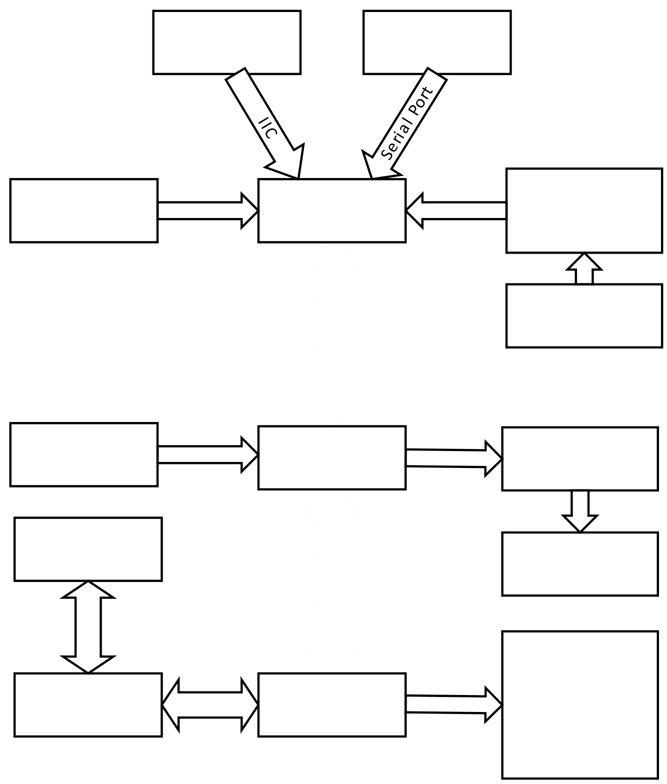

Figure 2. Working principle of the Smart Wheelchair:

2.2 Basic functions of the smart wheelchair

The smart wheelchair can monitor the user's physiological indicators in real-time and transmit this “database” wirelessly to caregivers and family members for monitoring and data analysis by medical personnel. Besides, the user can control the wheelchair's movement in a "direction-to-direction" manner, effectively reducing his manual operation efforts.

This wheelchair system can monitor the ECG from user’s head continuously and conveniently through the simplified contact of dry electrode and the specialized ECG acquisition chip BMD101. The weak pulse wave signals from the head can be detected through the innovative use of photoplethysmography (PPG) waveform recording and the improved PPG probe and its drive circuit. The head direction of the user can be tracked synchronously and accurately by the wheelchair system under the effective control of the positional PID control algorithm. Under the wireless communication via the NRF51822 Bluetooth System-on-Chip (SoC), the user’s physiological data including pulse waves, temperature, heart rate, and electrocardiograms (ECGs) are displayed on an application (APP) and accessed through the network. The built-in MCU of the NRF51822 serves as the main control chip for wheelchair motion control and data exchange.

2.3 Innovations of the smart wheelchair

Display of users’ vital signs on smartphones through network for their family members and physicians to check.

Innovative realization of continuous and convenient monitoring of ECG from the head, with reduced psychological burden on users through the simplified contact of dry electrodes measurement.

Stable extraction of weak pulse wave signals from the head by improving the PPG probe and its hardware signal processing circuit and employing software and hardware to process pulse signals.

The improvement in appearances and stability by transforming the wheelchair control system into glasses form. This system features compact size, simple structure, and stable operation, ensuring the stability of wheelchair control.

User-friendly control performance and high practicality by directing the wheelchair parallel to the user's line of sight using sensitive and stable direction and speed control system MPU9150. It can get rid of the complexity and ineffectiveness of current smart wheelchairs that use control rods, eye image processing, center of gravity positioning, voice recognition, and facial expression recognition.

The realization of aligning the wheelchair with the user's line of sight and freely controlling the wheelchair's direction and speed only by slightly adjusting user’s head. The innovative "direction-to-direction" control method totally outshines the current mechanical control of “four directions” movements.

Urgent call by pressing the emergency button to dial the emergency numbers in the smartphone.

2.4 Testing of the smart wheelchair

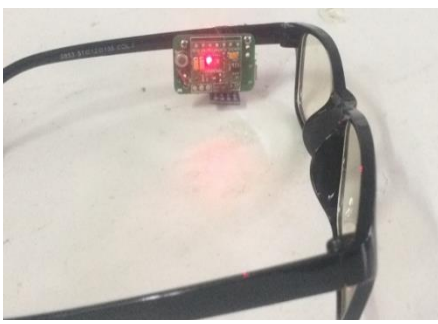

Figure 3. Part of the Control System

Figure 4. Actual Image of the Smart Wheelchair

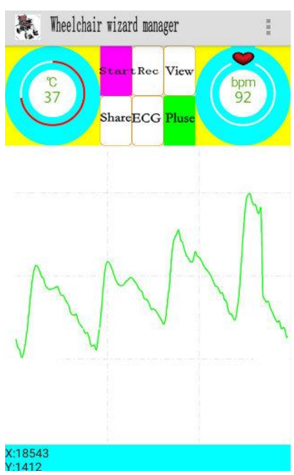

Figure 5. Pulse Detection Results

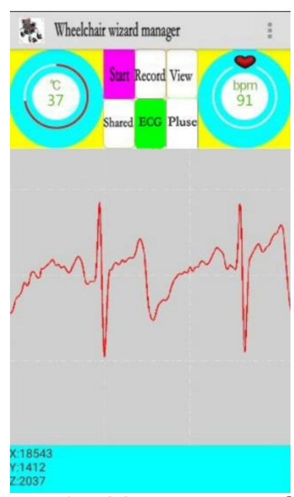

Figure 6. ECG Detection Results

2.4.1 Head nod recognition test. Test Method: Fifty volunteers, consisting of an equal number of males and females with varying heights, were recruited from the university. Volunteers wore the eyeglass control system, seated on chairs, and nodded their heads. Whether nodding movements were correctly recognized can be determined by observing the activation condition of the system.

Table 1. Head Nod Recognition Test (Partial Data)

Nod	Activation of the System	Success Rate
30	30	100%
30	29	97%
30	28	94%
30	30	100%
30	30	100%
30	29	97%
30	30	100%
30	29	94%
30	28	94%
30	30	100%
30	30	100%
30	30	100%

Results Analysis: After a comprehensive comparison of data from 50 trials, it was found that the success rate of head motion recognition reached 98%, indicating the high recognition accuracy of the system and a low rate of misjudgment.

2.4.2 Heart Rate and Temperature Test. Fifty students in the test were divided into two groups. Both groups of students remained calm before the test. After the exercising of Group B, Group A students still maintained calm. Then both groups wore the glasses and their heart rate and temperature were recorded on the mobile phone in real-time.

Table 2. Heart Rate and Temperature Test Results (Partial Data)

Monitoring system of this smart wheelchair（Bpm）	Other heart rate monitors (Bpm)	Samsung smartphone heart rate modules (Bpm)	Monitoring system of this smart wheelchair（℃）	Other temperature monitors（℃）
63	63	64	36.2	36.2
58	60	59	36.5	36.3
71	70	70	36.0	36.1
71	70	70	36.0	36.1
86	87	78	37.2	36.9
94	94	96	36.9	37.0
92	94	91	36.5	36.7
88	87	87	37.3	37.2
80	79	79	37.5	37.4

Monitoring system of this smart wheelchair (Bpm)	Other heart rate monitors (Bpm)	Samsung smartphone heart rate modules (Bpm)	Monitoring system of this smart wheelchair（℃）	Other temperature monitors（℃）
65	63	65	36.8	36.6
68	68	69	37.4	37.5
72	75	76	36.9	37.0
70	73	75	36.8	36.9

Results Analysis: After a comprehensive data comparison, it was found that the testing deviation of this system in heart rate was within ±1.5 bpm, which indicated a higher accuracy than other heart rate monitors on the market and Samsung smartphone heart rate modules. The system also demonstrated excellent temperature recognition efficiency from the minimal difference between the two sets of data .

2.4.3 Direction Control Test. Fifty volunteers in the test wore the glasses control system and rotated their head. Then the deviation between the wheelchair direction and the actual direction of participants' head was measured to determine the accuracy of the wheelchair direction control system.

Table 3. Direction Control Test Results (Partial Data)

Participates	Head rotation angle	Wheelchair rotation angle	Angle deviation
A1	10°	10°	0°
A2	12°	11°	1°
A3	8°	8°	0°
A4	15°	14°	1°
A5	20°	18°	2°
A6	15°	14°	1°
B1	14°	15°	1°
B2	3°	3°	0°
B1	14°	15°	1°
B2	3°	3°	0°
B3	6°	7°	1°
B4	23°	22°	1°
B5	15°	15°	0°
B6	13°	12°	1°

Results Analysis: After a comprehensive data comparison, it was found that the wheelchairs' rotation angle corresponded closely with the that of users' head rotation, indicating the excellent control efficiency of the wheelchair system.

In summary, the system features clear pulse waveforms and accurate heart rate calculations and temperature testing. Meanwhile, the wheelchair also has the advantages of stable control and a comprehensive range of functions.

3. ADVANTAGES OF THE SMART WHEELCHAIR

3.1 Easy operation

Current smart wheelchairs are cumbersome and less efficient in control performance as they generally use ordinary control rods and signal acquisition methods such as eye image processing, center of gravity positioning, voice recognition, electroencephalography (EEG), and facial expressions. However, in our this project, the user only needs to move his head slightly to control the direction and speed of this smart wheelchair. The innovative "direction-to-direction" control method totally outshines the current mechanical control of "four directions" movements. Moreover, users can activate emergency measures through specific head movements and dial emergency numbers in the smartphone to call for urgent care.

3.2 Physiological monitoring

Unlike the normal smart wheelchairs, which only have the function of temperature tests, this smart wheelchair integrates more functions like electrocardiography (ECG), heart rate tests, and pulse tests. The user's psychological burden can be significantly reduced by simplifying the dry electrodes contact for measurements, while rapidly testing his physiological data.

3.3 Wireless transmission

This smart wheelchair can transmit the user's physiological data to a designated app via wireless Bluetooth, which is then forwarded to medical personnel. Medical professionals are able to monitor, predict, and manage the user's heart rate, blood pressure, location, and other relevant information on their smartphones, greatly reducing the workload of medical staff and ensuring one-to-many health care management. At the same time, the data is also shared with the user's family members through the internet, truly relieving their minds.

4. CONCLUSION AND OUTLOOK

After our vigorous trials and testings, this project successfully performs such main functions as physiological monitoring, intelligent control, and internet embedding on smart wheelchairs. Our smart wheelchair in this project is highly targeted, with stable and reliable functionality, exquisite appearance and structure design, high practicality, and low cost, making it highly competitive in the market.

Next, we will integrate mobile phone receiver terminals with the internet, sharing monitoring results with caregivers and community medical institutions to conduct remote medical monitoring and big data monitoring and predicting in real-time. Additionally, we plan to set smartphones as another object controlled by the smart wheelchair system. This not only solves the smartphone operation problems of elderly people with hands weakness but also pioneers more smartphone operation methods. With the smartphone embedded in the system, the wheelchair's movement status and positioning can be tracked by the phone's GPS navigation system. Combined with the physiological parameters obtained by the system, the wheelchair can achieve other functions like preset route activities, automatic routes tracking in lost condition, and automatic referral for physiological abnormalities, presenting promising prospects for research and development and promotion of this product. Furthermore, we will collaborate with medical departments to transmit preliminary disease diagnosis based on raw physiological signals such as electrocardiography into the smartphone app terminal, providing preliminary medical treatment solutions on-site.

Moreover, we will further upgrade the technical capabilities of this smart wheelchair. In the future, we will add more modules such as voice-controlled direction modules, one-touch contact with family modules, and smart bracelet modules to the current monitoring wheelchairs, developing them into intelligent home devices instead of wheelchair derivatives only.

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