LAUTECH Journal of Engineering and Technology 18 (3) 2024: 113-121
10.36108/laujet/4202.81.0321

Development and implementation of smart wheelchair with obstacle avoidance for safe navigation

[1]Pokyse E, [1*]Ohemu M. F., [1]Ajimah E. N., [2]Zubair Z. O. and [3]Raymond J.

[1]*Department of Electrical and Electronics Engineering, Airforce Institute of Technology, Kaduna, Nigeria*
[2]*Department of Physics, Nigerian Defense Academy, Kaduna, Nigeria*
[3]*Department of Telecommunication Engineering, Airforce Institute of Technology, Kaduna, Nigeria*

Article Info

Article history:

Received: June 30, 2024
Revised: August 27, 2024
Accepted: August 28, 2024

Keywords:

Smart wheelchair,
Joystick control,
Ultrasonic sensor,
Motor Driver Module,
Arduino

Corresponding Author:
monfred@afit.edu.ng

ABSTRACT

The primary goal of this work is to develop a dependable and efficient solution for maintaining optimal mobility in wheelchair systems. The aim is to enhance functionality and reduce the physical effort of the user required to move the wheelchair wheels. The proposed system integrates advanced sensing technology, intelligent control algorithms, and robust hardware components to manage the wheelchair, detect obstacles, and eliminate the need for external assistance. This wheelchair employs joystick control and halts when the system senses an obstacle. The system enhances user autonomy by providing ease of control and ensures safety by detecting and avoiding obstacles. Motor speeds are adjusted based on joystick input, and the motor direction (forward, backward, left, right) is determined accordingly. An ultrasonic sensor measures obstacle distance, and if an obstacle is detected (distance <= 20 cm), both motors stop, and a warning buzzer activates for 1 second. If no obstacle is detected, the warning buzzer turns off, and motor speeds are adjusted based on joystick input. The system effectively demonstrated obstacle avoidance by changing direction when a command was issued away from the obstacle. The outcomes of this study contribute valuable insights to the field of wheelchairs, specifically in the realm of obstacle avoidance.

INTRODUCTION

A wheelchair is a chair with wheels designed to assist individuals who have difficulty walking independently (Hartman and Nandikolla, 2019). It is classified as a medical device. The use of wheelchairs has become essential for people with physical disabilities, as navigating without assistance can be challenging. This has led to the development of smart wheelchairs. A smart wheelchair typically consists of either a standard power wheelchair base enhanced with a computer and various sensors or a mobile robot base with an attached seat (Simpson et al., 2004). Previous wheelchair models provided basic locomotion for disabled individuals but did not significantly reduce their dependence on caregivers. Akash et al. (2014) emphasized the goal of making physically impaired individuals more self-reliant.

Advancements in technology greatly benefit people with disabilities, offering increased independence and mobility. The smart wheelchair with obstacle avoidance is a prototype equipped with sensors, actuators, and artificial intelligence (AI) technology. This enables it to navigate its surroundings, avoid obstacles, and respond to user commands via a joystick. The obstacle avoidance feature, utilizing ultrasonic sensors and joystick control, allows the wheelchair to safely navigate even crowded or complex environments.

Historically, various systems have been devised to make wheelchairs more convenient for users. As the demand for assistive technology grew, the manual wheelchair was invented, enhancing personal mobility for disabled individuals. Most manual wheelchairs feature push handles at the top of the backrest, allowing others to assist with propulsion. People with lower limb disabilities often rely on these manual wheelchairs. In user-propelled manual wheelchairs, the disabled user controls and drives the chair. However, using hands for propulsion is less efficient and more straining compared to using legs. Prolonged use of manual wheelchairs can decrease the user's physical capability, making them less advisable for long-term use (Desai et al., 2017).

Electric-powered wheelchairs (EPWs) are propelled by electric motors rather than manual effort, making them ideal for those unable to propel a manual wheelchair. EPWs enable users to move within their homes and communities, maximizing independence without requiring significant physical exertion. They are versatile, and capable of navigating various terrains thanks to different tyre types and wheel positions. The most popular EPW configuration is rear-wheel drive, offering better stability for both indoor and outdoor use. However, individuals with visual impairments, motor skill deficiencies, or lack of strength may find it challenging to use power wheelchairs independently, often resulting in limited mobility (Desai et al., 2017).

Recent developments have extended the capabilities of standard power wheelchairs by incorporating control and navigational intelligence, further enhancing their usability and independence for disabled individuals.

During the last three decades, several prototypes of smart wheelchairs have been developed. Although there has been an improvement in the design of smart wheelchairs, most of the designs are not implemented due to the cost, the complexity of manufacturing, or because they are still under development. Minguez et al. (2005) proposed a smart wheelchair that is controlled by voice commands. This wheelchair has two direct current motors which drive the rear wheels. The wheelchair has a computer screen to check the commands and it also has a microphone to give the inputs. The system avoids collisions with objects and it can arrive at its destination through narrowed spaces. The limitations are the wheelchair follows commands of any voice, and additionally, it is not able to perceive the environment.

Satoh and Sakaue (2007) developed the Omnidirectional Stereo Vision Smart Wheelchair that detects both the potential hazards in a moving environment and the postures and gestures of a user by equipping an electric wheelchair with the stereo omnidirectional system (SOS). To use the multi-camera system SOS on an electric wheelchair, an image synthesizing method of high speed and high quality was developed, and a method for recovering SOS attitude changes by using attitude sensors. The system has a storage of different user positions through which the system can respond without confusion to know the specific situation of the patient and the electronic system can act directly. The limitation of the proposal is the high cost of the equipment because a video system of high video quality is necessary for the processing of the user’s situation and, therefore, it also has a complex control system.

Nishimori et al. (2007) developed a voice-controlled wheelchair to help disabled people. The main goal of the project was to avoid the muscle force required to operate a traditional manual wheelchair. A laptop was used to execute the main commands. The limitation is that it does not consider obstacle avoidance. Purwanto et al. (2009) developed an electric wheelchair controlled by gaze direction and eye blinking, where a camera is set up in front of the user to capture image information. It can be controlled only with the eyes and the face without lifting a single finger, which is of great benefit for people who have become quadriplegic. However, the limitation lies in the operation, especially since it can be very difficult to take care of each expression that the user makes with his/her face.

Gomez and Medel (2009) proposed a prototype of an intelligent wheelchair controlled through easy gestural instructions. The robotic prototype hardware was designed with a PIC16F877A microcontroller as a control device, and some sensors like analogue presence sensors, analog light sensors, and a digital webcam sensor. Gestures were determined by the position of the eyebrows, eyes, and mouth.

Tomari et al. (2012) proposed a semi-autonomous control wheelchair system with a multi-input interface to aid the mobility of people with severe motor impairment. The system is implemented on an electric wheelchair and it is equipped with a switch and four types of sensors (a standard webcam, a RGBD Camera-Kinect, a laser range finder and an Inertial Measurement Unit sensor IMU). The wheelchair has two control modes: the manual mode and the semi-autonomous mode. The user can change the modes freely by manual switch operation (incorporating a safety map, the wheelchair can avoid collision in both modes). The system allows users with severe motor impairment to operate a wheelchair when they are in a tight space (passing a doorway) or when avoiding obstacles. Also, it provides independence, because the critical and dangerous situation is effectively overcome, but at the same time the user is still feeling that he/she is driving the wheelchair.

Android & Gutiérrez (2012) proposed a mechanism to move a wheelchair using a mobile device, as they highlighted the inability to recreate a physical environment for all people in wheelchairs. This work aimed to develop a control system to apply the same to a wheelchair, which was aimed at promoting the quality of life of people who use this device. The control system responds utilizing a mobile device, using a touch screen. The system can apply to any non-intelligent wheelchair, however, it does not consider the point that many people using this type of electronic chair can feel equally uncomfortable and the batteries it uses are not rechargeable.

Cifuentes et al. (2016) developed a system that can turn a traditional electric wheelchair into a smart wheelchair. This system consists of the design and implementation of a microcontroller that can process different types of environmental signals that produce automatic movement outputs so that the wheelchair moves in a specific path. The authors claimed that the device is easy to adapt to any manual chair to make it electric. The system can change from 4 to 2 support wheels which allows it to overcome obstacles more easily using fuzzy-logic controllers. One advantage is that it obtained efficient results when checking the user's vital signs in 95% of the cases. A weakness of the work is that the number of bits used to design the processing card was not enough to achieve its overall goal.

Rashmi et al. (2021) developed an electric wheelchair for smart navigation and health monitoring systems. The system contains a Raspberry Pi that has its operating system, thereby reducing the circuiting on the person's body. Bluetooth application-controlled robot is used for the effective movement of a wheelchair in any direction. Various sensor modules are used for acquiring data like heart pulse rate, and body temperature. The wheelchair can be converted into a wheelchair. The limitations of the proposed system are cost versus accuracy and does not consider obstacle avoidance.

Al Rakib et al. (2021) developed a smart wheelchair with voice control for physically challenged people. The phone app serves as the system's input. It can take voice commands from the user and ignore other sounds. The mobile app will be positioned according to the user's preference the output is in the form of speech signals, which are sent to the voice recognition software, which serves as a bridge between the Bluetooth module and the Arduino. The output from the speech recognition software is then received by the Arduino, which converts it to binary code. The suggested system has several drawbacks as well, such as the fact that it requires an additional supply to operate the model and that the module only recognizes the inserted voice and button. It does not consider obstacle avoidance.

Shashidhar *et al.* (2023) developed a smart electric wheelchair for disabled and paralyzed persons using attention values on Arduino. The system operates on the theory of brain-computer interface (BCI) and was created based on their blinking capacity (BCI). This 2-wheel drive control, which works well with the BCI, can accept two-gear engines, each of which can control the left and right wheels. The beginning and ending of left, right, backward, and forward wheelchair movements are accomplished with the aid of the number of eye blink values. The wheelchair movement is entirely dependent on attention values. In this project a microcontroller is developed to translate the electroencephalography (EEG) signal into mental commands and transmit the controlling signal wirelessly to the wheelchair. The limitations are the work presented has not yet been put into practice, control functions need some form of muscular movement, the wheelchair may be manoeuvred by using a person's cognitive abilities and it does not consider obstacle avoidance.

METHODOLOGY

The setup employs economical hardware, utilizing minimal resources both from the sensors and hardware components. Figure 1 illustrates the schematic of the setup, including an Arduino, L298 motor driver module, two DC gear motors, a joystick, and an HC-SR04 Ultrasonic sensor. An electronic wheelchair that can be controlled by a joystick is the technology that has been developed. The ultrasonic sensor HC-SR04, which is attached to the Arduino in this setup, is used to detect obstacles. According to specifications, the control of the wheelchair is via a joystick. The wheelchair goes forward and any direction due to command received from the joystick depending on the obstacle threshold value; if it is more than 20 cm, it keeps moving forward but when is it less than 20 cm, it stops and awaits further command from the joystick.

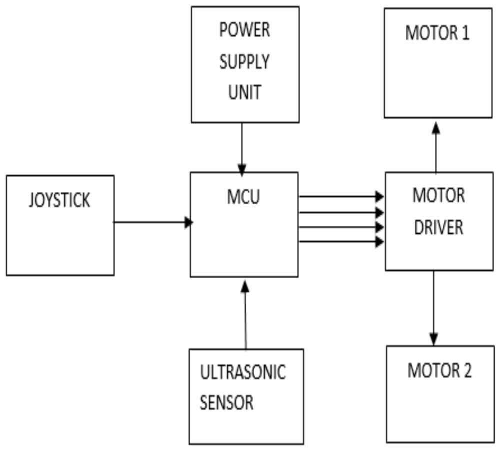

Figure 1: Block diagram of the Smart wheelchair.

The system initializes by configuring pins (`enA`, `in1`, `in2`, `enB`, `in3`, `in4`, `trigPin`, `echoPin`, `buzzerPin`) and setting initial motor speeds (`motorSpeedA` and `motorSpeedB`) to 0. The X and Y values from the joystick are continuously read to determine user input. The Y-axis controls forward, backward, or stopping, while the X-axis controls left or right movement.

Motor speeds are adjusted based on joystick input, and the direction of motors (forward, backward, left, right) is set accordingly. Low-speed checking prevents buzzing at minimal speeds. The ultrasonic sensor is used to measure obstacle distance. A pulse is sent, and the duration of the pulse is measured to calculate distance. If an obstacle is detected (distance <= 20 cm), both motors are stopped, and the warning buzzer is activated for 1 second. If no obstacle is detected, the warning buzzer is turned off, and motor speeds are adjusted based on joystick input. The system continuously loops through these operations, maintaining continuous monitoring, motor control, and obstacle detection.

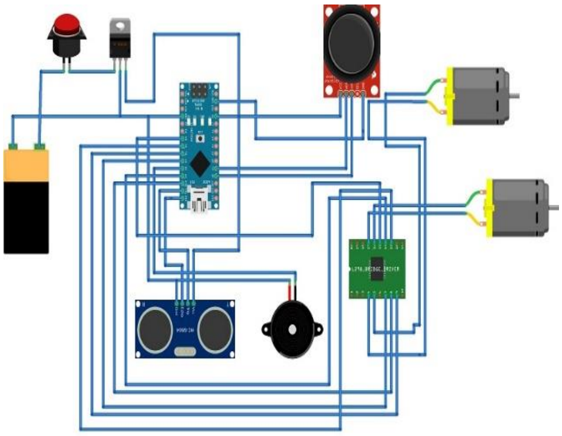

Figure 2: Circuit diagram of the system.

The circuit diagram of the system is shown in Fig. 2. Arduino board receives input signals from both the joystick module and the ultrasonic sensor connected to the wheelchair. After analyzing these inputs, the Arduino converts them into digital signals, which are then transmitted to the wheelchair's motors. The motors, in response, interpret and execute these commands, facilitating the wheelchair's movement based on user instructions. Importantly, the motors also play a crucial role in implementing commands related to obstacle avoidance, using information detected and identified by the wheelchair's sensor during navigation. In essence, the Arduino acts as the central control unit, orchestrating the integration of user inputs, sensor data, and motor responses for the effective operation of the smart wheelchair. With this robotic wheelchair, persons with physical disabilities may move about freely and independently without any help from others.

RESULTS AND DISCUSSIONS

The hardware of the wheelchair is shown in Figure 3.

Figure 3: Hardware Realization of the system.

The testing of the smart wheelchair aimed to validate its adherence to the algorithm and its ability to avoid obstacles. In the forward direction test, an obstacle was placed in front of the wheelchair, and upon receiving a forward command through the joystick, the system halted the motors when the sensor detected the obstacle within 20 cm as shown in Figure 4.

Figure 4: The wheelchair-detecting obstacle at about 20cm

When the command was issued for the wheelchair to move to the right, it responded since there was no obstacle to its right as indicated in Figure 4.

Similarly, the wheelchair successfully responded to a backward command when faced with a backward obstacle.

Figure 5: The wheelchair responding to the command to move right to navigate an obstacle

For right and left directions, the wheelchair effectively remained stationary when a command was given towards the side with an obstacle. However, it demonstrated proper avoidance by changing direction when a command was issued away from the obstacle. The wheelchair showcased the ability to navigate around obstacles by processing joystick commands intelligently.

In scenarios where commands were given for right movement while obstacles were present on the right and in front, the smart wheelchair adeptly avoided both obstacles until it was safe to execute the right turn with the assistance of the joystick. The testing covered various joystick command scenarios, demonstrating the wheelchair's proficiency in avoiding static and dynamic obstacles. Additionally, motion scenarios were examined without the obstacle avoidance feature, resulting in contact with obstacles and requiring additional input for safe navigation along the path. Table 1 illustrates the joystick movement in response to the ultrasonic sensor and the corresponding action taken while Table 2 shows the system response following measured distance.

Within the distance range of 5cm to 25cm, obstacles fall within the critical range, triggering the system's anticipated response of stopping the motors and activating the buzzer for 1 second. However, at a distance of 30cm, no obstacles are detected within the critical range, allowing the system to operate under normal conditions as shown in Figure 6 indicating a green colour.

In the case of forward movement, as shown in Table 3, both Motor A and Motor B are anticipated to operate at a speed of 100, indicating a forward direction. During backward movement, both Motor A and Motor B are anticipated to operate at a speed of -100, indicating a reverse direction. For left movement, Motor A is expected to operate at -50, while Motor B is at 50, generating a turning motion in that direction. Conversely, for right movement, Motor A is expected to operate at 50, while Motor B is at -50, creating a turning motion in the opposite direction. The graphical representation of Table 3 is shown in Figure 7 showing the time motor A is active and the time motor B is active in the system test.

Table 1: System Testing

Joystick	Ultrasonic Sensor	Action
Right	OFF	Go according to the joystick command
	ON	Don't take the right action from the joystick
Forward	OFF	Go according to the joystick command
	ON	Don't take the forward action from the joystick
Backward	OFF	Go according to the joystick command
	ON	Don't take the backward action from the joystick
Left	OFF	Go according to the joystick command
	ON	Don't take the left action from the joystick

Normal operating speed is denoted as High Speed as shown in Table 4. As the joystick input decreases from High Speed to Minimal Speed, there is a gradual reduction in the expected motor speed.

Figure 8 shows a reduction in the motor speed from 100 RPM to zero.

Table 2: Distance and System Response

Distance (cm)	System Response
0 -25	Obstacle Detected - Motors Stop, Buzzer Activated for 1s
30	No Obstacle - Normal Operation

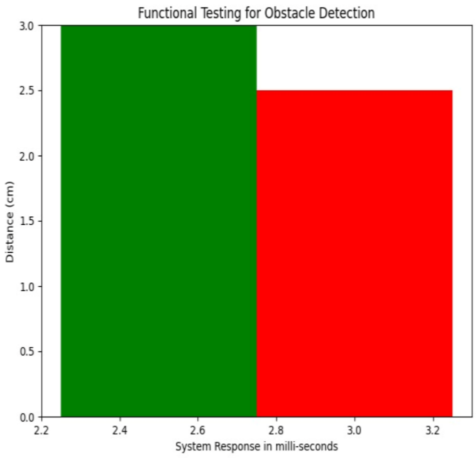

Figure 6: Functional Testing for Obstacle Detection.

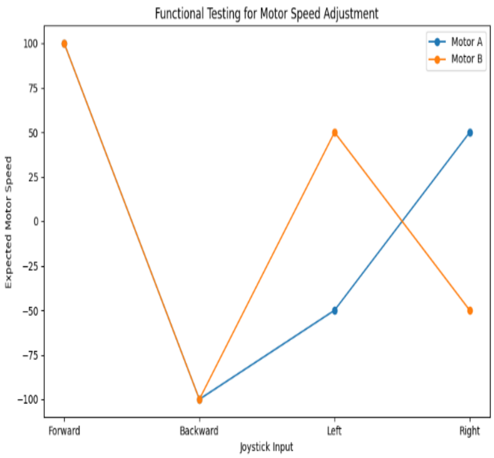

Figure 7: Functional Testing for Motor Speed Adjustment.

It was noticed that the motor speed continued to decrease gradually from high speed to the Lowest Speed until it stopped, and at the Stopped position, the motor came to a complete halt as represented in Figure 8.

Table 3: Joystick and Expected Motor Speed

Joystick Input	Expected Motor Speed (A) (RPM)	Expected Motor Speed (B) (RPM)
Forward	100	100
Backward	-100	-100
Left	-50	50
Right	50	-50

Table 4: Joystick Input Speed Condition and Expected Motor Speed

Joystick Input	Expected Motor Speed (A) (RPM)	Expected Motor Speed (B) (RPM)
High Speed	100	100
Medium Speed	50	50
Low Speed	10	10
Minimal Speed	5	5
Almost Stopped	2	2
Stopped	0	0

The project successfully developed a prototype system capable of obstacle avoidance during navigation, specifically designed for individuals with physical disabilities. Through testing, the smart wheelchair demonstrated its ability to effectively avoid obstacles and navigate safely through corridors, all while being controlled via a joystick. The wheelchair exhibited proficiency in avoiding both static and dynamic obstacles. The successful design and functionality of the prototype position it as a potential alternative to traditional manual and electric-powered wheelchairs.

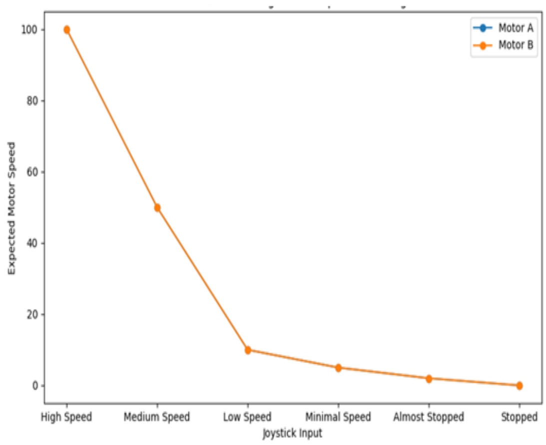

Figure 8: Functional Testing for Joystick Input Speed Condition.

CONCLUSIONS

The smart wheelchair, equipped with obstacle avoidance capabilities, has exhibited exceptional performance, successfully meeting its intended objectives. The system adeptly identifies and avoids obstacles with precision, maintaining control through joystick operation. The incorporation of an ultrasonic sensor, Arduino microcontroller, and control mechanisms has proven effective, ensuring the smart wheelchair operates optimally and guarantees safety during navigation. The system's design features robust and dependable components, promoting durability and a prolonged lifespan. Leveraging advanced technologies and efficient algorithms has enhanced the system's responsiveness, accuracy, and overall efficiency. Test results unequivocally affirm the system's capability to seamlessly control the wheelchair via joystick, promptly detecting and avoiding obstacles, offering a convenient and trouble-free solution for smart wheelchair users. The development and assembly of a smart wheelchair equipped with obstacle-avoidance capabilities have addressed certain limitations observed in conventional wheelchairs. The incorporation of an Arduino microcontroller and ultrasonic sensor for obstacle detection and avoidance, coupled with joystick control, represents a significant enhancement to the system. The obtained results indicate the successful implementation of the system, demonstrating optimal efficiency.

REFERENCES

Akash, S. A., Menon, A., Gupta, A., Wakeel, M. W., Praveen, M. N., & Meena, P. (2014, September). A novel strategy for controlling the movement of a smart wheelchair-using internet of things. In *2014 IEEE global humanitarian technology conference-South Asia satellite (GHTC-SAS)* (pp. 154-158). IEEE.

Al Rakib, M. A., Uddin, S., Rahman, M. M., Chakraborty, S., & Abbas, F. I. (2021). Smart Wheelchair with Voice Control for Physically Challenged People. *European Journal of Engineering and Technology Research*, *6*(7), 97–102. https://doi.org/10.24018/ejeng.2021.6.7.2627

Android, S. O., & Gutiérrez, I. T. D. T. (2012). Control de una Silla de Ruedas por Medio de un Dispositivo Móvil con. *Revista Tecnología Digital*, *2*(1), 1–13. http://www.capacidades.sistemastectuxtla.net/pdf/articulos/02_004_control_de_una_silla_de_ruedas_android.pdf

Babatunde O Ayobami, Monday F. Ohemu, Alex Aligbe, Opeyemi O Adekogba, & Zuleihat O. Zubair. (2023). IMPLEMENTATION OF AN OBSTACLE AVOIDANCE ROBOT FOR SURVEILLANCE. International Journal of Innovations in Engineering Research and Technology, 10(7), 28-40. https://doi.org/10.17605/OSF.IO/UY5QD

Cifuentes, A., Plaza, M., & Rondón, S. (2016). Diseño de un módulo de transformación para sillas de ruedas eléctricas en silla de ruedas inteligente.

Ciencia y Poder Aéreo, *11*(1). https://doi.org/10.18667/cienciaypoderaereo.532

Desai, S., Mantha, S. S., & Phalle, V. M. (2017). Advances in smart wheelchair technology. *2017 International Conference on Nascent Technologies in Engineering, ICNTE 2017 - Proceedings*. https://doi.org/10.1109/ICNTE.2017.7947914

Hartman, A., & Nandikolla, V. K. (2019). Human-Machine Interface for a Smart Wheelchair. *Journal of Robotics*, *2019*. https://doi.org/10.1155/2019/4837058

Minguez, J., Alcubierre, J. M., Montesano, L., Montano, L., & Saz, O. (2005). Silla de Ruedas Inteligente Controlada por Voz. *Proceedings of the Primer Congreso Internacional de Domotica, Robotica y Teleasistencia Para Todos*, *i*, 349–360.

Morales-Mancilla, J. A. (2012). Control de una silla de ruedas por medio de un dispositivo móvil con sistema operativo android. pp. 2–13

Nishimori, M., Saitoh, T., & Konishi, R. (2007). Voice controlled intelligent wheelchair. *Proceedings of the SICE Annual Conference*, 336–340. https://doi.org/10.1109/SICE.2007.4421003

Posada, R., Sanchez-Medel, L. H. (2009). Resultados del prototipo de silla de ruedas inteligente controlada por medio de instrucciones gestuales faciales. 8 Congreso Nacional de Mecatrónica pp. 82–85.

Purwanto, D., Mardiyanto, R., & Arai, K. (2009). Electric wheelchair control with gaze direction and eye blinking. *Artificial Life and Robotics*, *14*(3), 397–400. https://doi.org/10.1007/s10015-009-0694-x

Rashmi, P., Rajesh, K. M., Rachana, P., Supriya, M. C., & Hanifa, A. (2021). Development of Electric Wheelchair for Smart Navigation and Health Monitoring System. *Proceedings of the 3rd International Conference on Integrated Intelligent Computing Communication & Security (ICIIC 2021)*, *4*(Iciic), 618–626. https://doi.org/10.2991/ahis.k.210913.078

Satoh, Y., & Sakaue, K. (2007). An omnidirectional stereo vision-based smart wheelchair. *Eurasip Journal on Image and Video Processing*, *2007*(1). https://doi.org/10.1155/2007/87646

Shashidhar, R., Tippannavar, S. S., Sushma, B. S., & Shukla, P. (2023). Smart Electric Wheelchair for disabled and paralyzed person using Attention Values on Arduino. In *ICRTEC 2023 - Proceedings: IEEE International Conference on Recent Trends in Electronics and Communication: Upcoming Technologies for Smart Systems*. https://doi.org/10.1109/ICRTEC56977.2023.10111911

Simpson, R., LoPresti, E., Hayashi, S., Nourbakhsh, I., & Miller, D. (2004). The smart wheelchair component system. *Journal of Rehabilitation Research and Development*, *41*(3 B), 429–442. https://doi.org/10.1682/JRRD.2003.03.0032

Tomari, M. R. M., Kobayashi, Y., & Kuno, Y. (2012). Development of smart wheelchair system for a user with severe motor impairment. *Procedia Engineering*, *41*(Iris), 538–546. https://doi.org/10.1016/j.proeng.2012.07.209.