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COMPREHENSIVE REVIEW OF SMART WHEELCHAIRS FOR QUADRIPLEGIC PATIENTS

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Abstract. Quadriplegia is a disease that causes the person to lose them motor movements over time thus their limbs becoming unable to move. Up to date, many smart wheelchair projects have been put forward so that individuals with this disease can control their wheelchairs by their own. In this review paper, projects and patents related to smart wheelchairs are examined and evaluated. A varied of different methods have been used for the development of novel smart wheelchair technology. Some of these are based on controlling the mechanism using eye movements and head movements. Other smart wheelchair designs incorporate both brain activation and mobile device control. The purpose of this paper is to evaluate the development methods of smart chairs in detail and to compare them in terms of their effects on human health and usefulness.

Keywords. Smart wheelchair, quadriplegic patients, paralysis, hands-free controller.

1. Introduction

A wheelchair is a chair with wheels used in situations where it is difficult or impossible to walk due to illness, injury, old age problems or disability. Today, with

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the increase in the number of people with disabilities, the use of wheelchairs has increased enormously. While this device can satisfy some patients, it is insufficient for patients who cannot move more than one limb. Quadriplegic patients can be given as an example of this situation. Quadriplegics are people who cannot use any extremities. Such severely disabled patients cannot perform daily activities such as feeding, toilet use and movement in the area. Since mobility is important for a good quality of life, some projects about the smart wheelchair have been carried out to solve this problem. These projects include the ability to control the wheelchair using different methods without using body limbs. In these studies, various methods such as moving the chair with head or eye movements were used.

2. Literature View

In the paper [1], the control of the wheelchair based on eye movements was studied. A wheelchair with high certainty and reliability was designed with the Electro-oculographic (EOG) signal processing method. A low-budget signal interface development is presented for the study. Signal processing was carried out via a microcontroller which has a lower cost than a computer. Eye movements are detected by processing the EOG signals. Ag / AgCl electrodes were used at certain locations around the eye to receive the signals. The reasons for choosing these electrodes are that they do not contain any harmful element for human health, they are low-cost, and they are reliable in appropriate signal acquisition. As a security measure, emergency stop and enable buttons to have been mounted. Enable button provides the user to enable deriving wheelchair motion commands from movements of eye. The button can be placed according to the user's desire. A green LED turns on when the device is activated by the user. The emergency button immediately stops the wheelchair when pressed during movement. Eye movements are associated with wheelchair movements such as backward, forward, right and left. The accuracy of EOG signal processing and command perception has been tested by performing over a thousand eye movements on healthy people of various ages. It has been observed that the results of the tests performed in people with vision problems, in different modes (sleepy, tired, stressful) and under different lighting conditions were successful. The error probability was found to be below 1% and command missing probability was lower than 3%. Very close consecutive eye movements were tested, and it was calculated that these commands should be separated by at least 0.8 seconds to be separated. As a result, the reliability of the study has been proven due to the low-cost of the design, not being harmful to human health and the high success rates of the test results.

Another study about a wheelchair device which is controlled by eye movements is the paper [2]. According to the working principle of the wheelchair, it is controlled only depending on the change in eye movements and is designed to be used by different users. The method used in the design of the device is the use of an infrared camera attached to the user's glasses and pupil detection. Image processing provides control of the wheelchair by analyzing the person's gaze. The camera mounted on the glasses allows the user to move, maintains the illumination and minimizes vibration. As a result of testing the wheelchair on five different users on track, it has been observed that the system can successfully detect different pupils. According to the results obtained, it was seen that the mechanism gave the desired results. However, the infrared radiation of the camera used is dangerous for human health. Therefore, the device may not be preferred by some people.

In the paper [3], the control of the wheelchair with eye movements was studied. In the paper a combining Electrooculography (EOG) and Electroencephalographic (EEG) signals approach has been developed. "NeuroSky MindWave" headset for measurement of EEG signals and wet superficial electrodes for measurement of EOG signals have been used. Processing of these signals has been carried out with the help of Principal Components Analysis (PCA) and Wavelet Transform (WT) methods. The obtained results have been compared for feature extraction in terms of accuracy of classification. Classification process was carried out with the help of an artificial neural network (ANN). It has a 93% accuracy rate of classification. The output of the classifier has been used successfully to be able to control the displacement of the device in a virtual environment.

The prototype developed in paper [4] uses eye tracking method through the circular Hough transformation algorithm to control the movement of the device. The mounted camera aligns with the patient's eye and takes continuous snapshots that are processed by image processing methods in real time which, in return, controls the movement's direction. This design has different features such as detecting obstacles by using ultrasonic sensors. It has been observed that the hardware prototype developed for the wheelchair can detect eye movements correctly and successfully even in poorly lit environments with the help of an IR illuminator.

In order to solve the problems of the paper [2], paper [5] was written. The aim is to provide wheelchair control by changing eye movements. The striking feature of the paper is that while providing this control, infrared rays that are harmful to human health are not used. The recommended method is to monitor eye movements using the AD8232, i.e. Arduino Nano, together with the ECG Sensor. This technique captures the gaze direction through muscle contraction, which is called myography. This is carried out by placing the electrode pads on the forehead. After the signals received from the eyeball are processed in Arduino, they are sent to the "ThingSpeak Cloud" to enable IoT. In this way, control of the movement of the wheelchair can be achieved with online and offline modes. The operating logic of the system is simple, and the user can use it easily. The only requirement is for the user to gaze right or left to provide the movement towards the wanted direction. The system is time-efficient, it takes up a little space and it can be built at a low cost, which makes the study successful and effective. It was mentioned in the paper that, in the future, different signals obtained from different body parts of the users could be recorded and with the use of these signals, the patients could transmit the message for water, food or medicines. In addition to these methods in the design of the smart wheelchair, studies on controllability depending on the patient's head movements have also been carried out.

One of these studies examined is paper [6]. In this study, a prototype wheelchair control interface that uses an artificial neural network (ANN) to identify commands taken from head movements has been developed. This system (ANN) generates commands using fuzzy logic to detect when the user is hiding their lips, blinking or tilting their head based on images captured by a CCD camera. Switch arrays and chin operated joysticks have been incorporated in control systems for the wheelchair. However, the study has various disadvantages such as being difficult to run, not aesthetically attractive, and not giving good results in poor lighting conditions.

In paper [7], with the use of artificial intelligence and embedded LINUX, a head movement wheelchair controller is designed. The system has been implemented successfully. Mechanical attachments have been added to the end of the joystick so that the person can operate the device with his elbow or chin for ease of use. Other parts of the joystick include blink and volume control. The system provides an efficient electric wheelchair control technique for the user with improved posture and ease of use.

In paper [8], a wireless head movement wheelchair control system was proposed and applied with the help of a personal digital assistant (PDA) artificial intelligence methods on an embedded LINUX operating system. A complete system was created to sample, capture and train neural networks. According to the outcomes of the previous experiments, the system was developed by using a second neural network working in parallel to increase the rate of classification of entire commands. With this study, it has been observed that PDAs are a suitable option to design a special embedded system, and the system has given successful results. It has also been proven that it is possible to create an efficient neural network-based controller with the use of PDA. This data has been obtained by designing and testing a functional control system.

In paper [9], an electric wheelchair that can be controlled by head movements was studied. A device which has a user-friendly human machine interface (HMI) for control is proposed in the paper. Two modes of operation are based on movements of head: Mode 1 works with simply one head movement to command and Mode 2 works with four head movements. The 1st mode uses the “up” or “down” commands, while the 2nd mode uses the “up”, “down”, “right” and “left” commands. In both control modes, during the user’s control command it doesn’t need to maintain a head movement. An EEG device which is called “Emotiv EPOC” is deployed in this HMI to obtain the information of user’s head movement. The proposed HMI is compared to the joystick control of an electric wheelchair in an indoor environment. Results indicate that Control Mode 2 is reliable and can be applied quickly, achieving an average duration of 67.90 seconds for two subjects. On the other hand, Control Mode reaches an average time of 153.20 seconds for two subjects. Considering it only works with one head movement; it has poor efficiency. Even though it has some shortcomings, it is obvious that the presented HMI can be used efficiently instead of traditional joystick control.

Another study about this subject is paper [10]. The technique used in this paper is implemented as an algorithm of a microcontroller system which provides wheelchair control with head movements. The system consists of mechanical and electronic elements. A new recognition of head motion method based on accelerometer data processing has been proposed. The control arm of the wheelchair is controlled by the mechanical actuator of the system. In the paper, an experiment contains testing of the proposed microcontroller system. For the electric wheelchair type of Otto Bock™ B400 was used. The testing process has two parts. After a short period of adjusting the system, in the first part, three examinees issued ten times each of the four commands. In the second part of the test, they performed a predefined series of ten head motions such as: looking down, looking up and looking to the right. In addition, examinees performed the movements which don’t have the purpose of issuing a command. The reason why it’s performed is that not recognizing the command where one is not intended is as important as recognizing the command where one is intended. As a result of the experiment, the microcontroller system correctly recognized the commands with a rate of 94.16%. Although the success rate at the end of the experiment is high, there are some problems with the method applied in the system. One of these problems is the random head movement of the patient. Instinctive head movements not intended to change direction reveal some mistakes. In this instance, in 13.66% of cases, the system recognizes an unintended command. In the paper, it was mentioned that in future studies additional sensors should be used to solve these problems.

In paper [11], a wheelchair device has been developed for quadriplegics by recognizing the head motions of the driver and the surface electromyography (sEMG) signal. The stop-and-go movement of the wheelchair is controlled by the EMG signal generated around the driver’s temple during tooth tightening, while the right and left cornering movement is controlled according to the measured head deflection angle with the help of a position sensor. The processing of the signal is designed to withstand poor road conditions and make head movement distinguishable from the reference coordinate. The wheelchair has been tested 10 times. It has been observed that the squeezing signals are successfully separated from the distortion signals on the speed humps and concrete pavers with the accuracy of 90 % and 100 % on low stairs. Although the design is two times slower compared to a joystick, it has been an effective study for reasons such as successful experimental results, reliability and easy learning process.

In paper [12], the control of the wheelchair with head movements was provided by a wearable technology. Head movements were detected by the gyro sensor used in direction measurement processes on a hat to be worn by the user. The wires of the sensor are connected to Arduino in multi-cores. The motion of the motorized chair was achieved by processing the data received from the sensor with Fuzzy Logic libraries on Arduino. The implemented system is based on a model chair as a demo. DC motor drivers are mounted on the chair wheels. The system that provides motion control is built on the hat. A start button is placed on the chair so that the user can control when the movement will start. According to the working logic of the system, when the individual tilts his head forward, the gyroscope will perceive this and transmit it to Arduino. As a result of the data processed on Arduino, the direction is determined, and the motion is transferred to DC motors. The horizontal position of the hat is set as the silence state and there is no movement in the motors. The advantages of the study are that the design is minimal and easy to use. In addition, due to the system used, the cost has been kept at a minimum and has been made affordable for most people.

However, there are some shortcomings in the study. The first of these is that the system is boxed on a simple model wheelchair. In a real-life application, more powerful motors should be used. The second is that the sensitivity is not sufficient level since only one sensor is used in the study. In future studies, it is planned to make changes in motors and driver circuits and increase the number of sensors to create a more effective design.

In paper [13], studies on the development of a semiautonomous electric wheelchair are explained. Development phase has been carried out in two main parts which are pattern recognition from head movements and semiautonomous driving support. Considering that the developed wheelchair can only be driven with head movements, the system opening and closing operations should also be done with head movements. In addition, switching to a mode in which the user drives the chair directly with head movements without driving support is necessary. In order to perform all these operations, 4 different head movements have been defined and a method for automatic recognition of these movements has been developed. It is considered that the defined movements are easily distinguishable from each other and can be controlled by the user easily. CHR-UM7 IMU (Inertial Measurement

Unit) sensor was used in order to detect head movements. In addition, considering that people will make the same movements in different ways and at different speeds, artificial neural networks have been used to detect these parameters. Other developments in the wheelchair are related to providing a semi-autonomous driving support for the user. In this part, the problem is examined in two separate sections as escaping from the obstacle and speed planning support. In escaping support FGM-I approach, in speed planning support fuzzy logic approach was used. The improvements have been tested on a real wheelchair. As a result, it has been observed that the system operates successfully as expected and it helps for a safe drive by supporting the user when it's necessary. In further studies, it is planned to work on additional software and hardware to make the wheelchair work fully autonomously.

Another study on wheelchair control with head movements is paper [14]. In this paper, an inertial sensors-based interface placed on the patient's head is proposed. The mentioned interface is based on head movements that provide speed commands and continuous direction to guide the wheelchair. However, the inertial interface used poses some difficulties. The first of these are the simultaneous movements of the wheelchair and head, each of which has its own coordinate system. The second is the unlimited and free movement of the head. For this reason, the two coordinate systems must be combined and some security properties are needed to provide only acceptable commands. It needs to be supported with an intelligent navigation system that realizes the trajectory of the wheelchair. This system has innovative features which allow the user to put his head in the most relaxed position, define a customized initial neutral position. In this way, it is ensured that the system detects abnormal posture. This technique developed can solve the problems with the wheelchair perceiving the random head movements as a command.

In paper [15], a smart wheelchair design that works according to head movements was carried out using a cost-effective web camera. In this way, using wearable hardware was not necessary. For the study, a home environment and a smart wheelchair are prepared in GAZEBO simulation environment. GAZEBO simulation environment is an open-source code software platform which makes it possible to design robots and to test algorithms quickly with realistic scenarios. An encoder, a laser sensor, a camera and a user interface unit have been added to the wheelchair. Experimental studies were carried out on a personal computer with Ubuntu 16.04 and ROS Kinetic. In the study, only one computer webcam with a resolution of 1.3 megapixels is used. Wheelchair design has two modes which are semi-autonomous and autonomous. In autonomous mode, the user can interface the destination point with head movements and goes to the target point with ROS route planners. In semi-autonomous mode, the control of the robot is provided with head movements and the user transports it to the desired point. In the study, tests for each mode have been carried out. Before starting tests, the robot's environment map information has been obtained by using the mapping algorithm with the help of laser sensor. Consequently, it has been observed that control of robots is easily provided. The mechanism is easy to use, effective and not harmful to human health. Thanks to these features the project is promising. In future studies, developing a user interface unit, improving the mobility of the robot and real-time tests are planned.

In paper [16], an automated wheelchair which has a guide sensor, guided by a magnetic ferrite marker which is resistant to the dirt, is presented. Results showed that the device is safe, comfortable and stable. In paper [17], SENARIO project designed a sensor-aided intelligent navigation system which provides successful navigational aid to the wheelchair users. The autonomous mobile robot SENARIO, supports both fully and semi-autonomous navigation. Experiments about fully autonomous mode are very promising. In paper [18], a wheelchair system which moves cooperatively with the caregiver to reduce a caregiver's burden is developed. In future projects, it is planned to search for realistic predictions of wheelchair functions and to develop the project by using simple logic combinations. In paper [19], a Human-Machine Interface (HMI) based on the signals produced by brain activity or eye blinks is presented. Even though the system is very effective in detecting both brain and muscular signals, safety should be improved. Paper [20] describes a novel Home Lift, Position, and Rehabilitation (HLPR) Chair to provide independent patient mobility for indoor tasks. It is designed at the National Institute of Standards and Technology (NIST). In paper [21], development of a user-friendly multimodal interface, which is integrated into the "Intellwheels" project is discussed. It was seen that the developed interface was very flexible when enabling the user to define distinct types of command sequences. In paper [22], a solution to the crossing of a door problem in unknown environments for a robotic wheelchair commanded through a Human-Machine Interface (HMI) is proposed. Common situations such as obstacle avoidance were considered in the experiments.

In paper [23], a motion control technique based on the method of potential field, which enables the device to take a convenient position with respect to the caregiver depending on the case is proposed. In paper [24], a framework that can help users to overcome conditions such as passing through tight spaces with the use of a hierarchical semi-autonomous control strategy is proposed. Experiments showed that the wheelchair can move effectively without any collision. In paper [25], a smart wheelchair which has a lifting function is presented to assist a caregiver when transferring the patient. It is mentioned that the proposed device is both suitable for outdoors and indoors. The results show that this device is well maneuverable like a forklift. In paper [26], an assisted navigation system based on collaborative control, which uses a P300-based BCI to select steering commands is presented. As a result of the experiment, the system showed a successful performance in terms of navigation and online BCI accuracy.

In paper [27], the principles of participatory research and employ qualitative methods to develop “the Power Mobility Clinical Driving Assessment (PMCDA)” and “Power Mobility Screening Tool (PMST)” are adopted. It was seen that further study is required to determine credibility. In paper [28], a therapist-monitored wheelchair skills home training program delivered over a computer tablet is developed. Further improvements to the current program are planned in future studies. In paper [29], a design called “the robotic assisted transfer device (RATD)” which helps with transferring patients from their electric powered wheelchair to other places is discussed.

In paper [30], the control of the wheelchair was carried out with a mobile device. Control of the wheelchair provided using PIC18F4550 and “MIT App Inventor 2” program. The interface of the system is made using the MIT App Inventor 2 android program. As a safety measure, a PIR sensor is placed at the back of the chair in case the user moves back. The system works with nine different commands: forward, backward, right, left, accelerate, slow down, stop, close and run to provide movement. In the designed interface, connection between the Bluetooth and the control card is provided by clicking the Bluetooth symbol. After the connection is established, the system works with the on / off button. Control of the chair in the desired directions can be provided with the buttons. The main goal of this study is to decrease the high costs of control cards. In order to solve this problem PIC18F4550 which is a space-saving equipment is used. In addition, with added Bluetooth feature, remote control of the device is provided. Thanks to these features, an easy-to-use and cost-effective prototype was created.

In paper [31], the modelling approach of the wheelchair on two-wheels using FLC-PSO has been discussed. Simulation outcomes show that the FLC-PSO is more efficient than Fuzzy Logic Control (FLC) in terms of settling time and overshoot. In paper [32], a device has been developed for transferring a patient from a chair to any other surface. Results showed that the device made the process with less effort. In paper [33], a smart wheelchair system (SWS) navigation in urban environments with a mapping service which produces large-scale landmark maps is presented. It has been found to be effective in terms of safety. In paper [34], development of a 4-wheel wheelchair with decreased vibration and wheel slippage is presented. The test results reported are based on 5 users traversing a path with static obstacles.

In paper [35], a design consisting of two major controllers, namely the head and the audio controller is proposed. The voice controller has two voice recognition modules that use dynamic time warp DTW and hidden Markov model HMM to implement voice recognition. Testing processes were carried out in three languages, German, Chinese and English, at two different decibels, 72 and 42 dB. The sound controller has been tested with a motion command and it is suitable for use of different parameters such as sound and light alarm. The head tilt controller is the second controller. It uses an advanced direction-finding module BNO055 to track the user's head direction and wheelchair direction based on Euler angles. It has an auto-calibrated algorithm to calibrate the control commands and arrange the speed of the wheelchair motors when the road is uneven. The head tilt controller has been tested for outdoor and indoor practices. Test results have been found to be successful. In addition, the low-cost design of the wheelchair is another advantage of the study.

In paper [36], a haptic guidance solution for power wheelchair assisted navigation which provides obstacle avoidance is proposed. While testing and while driving the device on the obstacle course, the collision number decreases with the activation of haptic guidance. However, the game controller used to validate the robotic solution isn't adapted to wheelchair control.

In paper [37], a Human Machine Interface (HMI) which allows the user to drive the wheelchair using facial expressions is proposed. The classification accuracy can expect 98.6% and it can offer an average recall rate of 97.1%.

In paper [38], a speaker and speech dependent system with "Mel Frequency Cepstral Coefficients (MFCC)", "Artificial Bee Algorithm (ABC)" and "Feed forward back propagation neural network (FFBPN)" is used to control the wheelchair. The success rate achieved was 87.4%.

In paper [39], an improved mobile platform structure equipped with an omnidirectional wheelchair, a target recognition module, a lightweight robotic arm and an auto-control module is proposed. The outcomes show that the system works effectively and smartly. In paper [40], a vision-based control interface is presented which allows the user to command the system at different levels of abstraction. In paper [41], the number of eye blinks based on various types of eye movement is presented for wheelchair control. The wheelchair presented has shown "False Command Rate (FCR)" of 2.1% to 13.2%. In paper [42], a wireless-based wheelchair system that can be controlled with hand movements is developed. Wireless technologies and sensors have been integrated with microcontrollers. In paper [43], a motorized attendant wheelchair with haptic interface is presented with power assistance and excellent maneuverability. At heavy load, the task completion times of the motorized wheelchair with attendant propelled wheelchair and the haptic interface were similar. In paper [44], a voice control intelligent wheelchair movement using Convolutional Neural Networks (CNNs) is introduced. The tests showed good results with 95.30% accuracy. In paper [45], a smart wheelchair with manual and automation modes is developed. As a result of the experiment, it was seen that the proposed wheelchair had a higher recognition rate than other applications with a success rate of 94%. In paper [46], a smart wheelchair with an object detection and tracking system is presented based on deep learning for object detection (YOLOv3). Experimental results have been found to be effective. In paper [47], a technique for automatically generating the optimal travel route based on costs associated with routes is proposed. The results showed that the method produces safety travel routes while driving. In paper [48], an update on the improving of the “Intelligent Power Wheelchair (IPW)” upgrade kit is described. The new IPW edition is designed to be lighter, modular and multi-functional. In paper [49], a design is presented to improve the maneuvering tasks of an intelligent wheelchair. The important feature of the device is that during navigation intervention is not necessary.

In paper [50], a system called Connected Driverless Wheelchair is presented. The prototype can receive transfer demands directly from the hospital information management system, pick up patients from their beds, avoid obstacles and drop patients of at the operating room. Consequently, the wanted designed was successfully obtained. In paper [51], a multifunctional wheelchair called “ReChair” is proposed. It integrates mobility and multiposture transformation. The device is cost effective and easy to use. In paper [52], a smart wheelchair mobile robot with the use of Particle Swarm Optimization Proportional controller (PSO-P) was proposed. As a result, the simulation of the controller showed a successful correlation of the trajectory track for various loading conditions.

3. IMPLEMENTATIONS

Obstacle detection with machine learning is implemented in a wheelchair to detect the objects placed on the route of the wheelchair and warn the user to avoid collision with the obstacle. FPGA (Field Programmable Gate Array) were considered for image processing and object detection tasks. Unlike commonly used microprocessors, FPGAs can handle multiple tasks simultaneously while microprocessors do tasks one by one. This gives FPGA advantage against microprocessors in image processing and object detection [53]. However, FPGA is more complicated to use and has less accessible resources. Because of its easier use and popularity, the final decision was to use Raspberry Pi. Raspberry Pi’s RAM can only display 1-2 frames per second after processing images. In order to increase the number of frames per second, Coral USB Accelerator is used. This device allows machine learning models to work faster by functioning as a preprocessor [54] [55]. To compare and choose the software tools in object detection, “Mobile Object Detection using TensorFlow Lite and Transfer Learning” article is used [56]. Custom model created by selected and defined images will be used for object detection with “Tensorflow Lite”. Multiple images of obstacles that the wheelchair can come across will be found and labeled one by one. “LabelImg” application will be used for labeling the images for the machine learning model. For the model to work properly, selected images should be of higher quality and distinguishable. Images will be captured by a camera connected to the Raspberry Pi using OpenCV library. Camera modules designed for Raspberry Pi will be used for capturing images since it is easier for them to connect with the Raspberry Pi. Object recognition algorithm will determine the distance and location of the object relative to the camera using the size of the rectangle drawn around the object by the algorithm. If the object is further to the middle of the image than a selected threshold value, the object will not be considered as it is on the route of the wheelchair and the user will not be warned about the object.

4. Products

Various devices have been produced to control wheelchairs with head or eye movements. One of them is the Total Control Head Array system of "Permobil" [57]. The mechanism includes telescope arms and proximity sensors. In this way, movement is achieved by detecting head movements. Its minimal design provides convenience for the user. Another product made in this field is Dual Pro and Switched Head Arrays device of Sunrise Medical [58]. The product consists of two headings which allow movement in the direction of pressure. In addition, the device has proximity and pressure sensors. The speed of the wheelchair can be adjusted from the back of the headrest. The fact that the product can be used with a wide variety of wheelchairs and the ease of installation provide convenience for the patient. "Tobii Dynavox's" product [59], which has a different control mechanism than these devices, has an eye tracking system. Although this system serves many purposes, it can be advantageous for disabled individuals when integrated into a wheelchair. Another device produced in this area is called "Gyroset Vigo" [60]. It is a set that includes a pad, and headphones placed behind the head. With head movements, the wheelchair's control can be provided. Bluetooth, light and minimal design and an emergency stop function are among the advantageous features of the product. It is also stated that the patient can easily use the device because of a very short training period. In Türkiye, there are also several brands that produce wheelchairs such as Belmo [61], Poylin Medical [62] and Kifas Orthopedic Products [63]. Particularly Poylin Medical manufactures many high-tech devices such as foldable wheelchairs, multi-functional wheelchairs and land-type battery powered wheelchairs.

5. Conclusion

While the standard wheelchairs used today are sufficient to meet the needs of some users, they are not sufficient for patients who cannot use more than one limb. In this case, they cannot provide their movements without outside help. Various smart wheelchair projects have been carried out to solve this issue. There are enormous researches about designs that have different mechanisms that provide control depending on head or eye movements. In addition, minimal and useful designs that can be used on a wheelchair are produced. Although the studies have certain shortcomings, there are promising projects that can improve the quality of life of quadriplegic patients.

6. TABLES

TABLE 1. Short examination of the papers with success rates.

Paper	Aim	Advantages	Disadvantages	Accuracy
Wheelchair Control by Head Motion [10]	Implementation of an algorithm of a microcontroller system that provides standard wheelchair control with head movements.	1.The system has a low price. 2.It is suitable for use with various types of electric wheelchairs. 3.It can be learned in a short process.	1.In 13.66% of cases, the system recognizes an unintended command. 2.The control of the wheelchair motors should be integrated in order to test the feasibility of this design in real conditions.	94.16%
Development of hands-free wheelchair device based on head movement and bio-signal for quadriplegic patients [11]	Design of a wheelchair device by recognizing the driver's head motion and the surface electromyography (sEMG) signal	1. The experimental results were successful. 2. It is able to detect the user's control intention. 3. It is robust against the poor road conditions.	The device took twice as much time to complete a track compared to a joystick.	100% on concrete pawers, 90% on speed bumps
Voice Control Intelligent Wheelchair Movement Using CNNs [44]	Design of a voice control intelligent wheelchair movement using Convolutional Neural Networks (CNNs)	It is considered reliable and efficient.	1.Quality of the data should be improved. 2.Number of words used is limited.	95.30%

TABLE 2. Short examination of the papers.

Paper	Aim	Advantages	Disadvantages
Head movements-based control of an intelligent wheelchair in an indoor environment [9]	A user-friendly human machine interface (HMI) for hands-free control is presented.	Control Mode 2 works quickly and effectively.	Control Mode 1 has poor performance even though it requires only one head movement
Kafa Hareketleri ile Kontrol Edilebilen Tekerlekli Sandalye [12]	The design of a wheelchair controlled by head movements by a wearable technology.	1.The system is minimal and easy to use. 2.The cost has been kept low.	1.Motors are not powerful enough for a real-life application. 2. The sensitivity is not sufficient.
Engelli İnsanlar için Akıllı Tekerlekli Sandalyenin Baş Hareketleri ile Kontrolünün Gerçekleştirilmesi [15]	A wheelchair design that works according to head movements with a cost-effective web camera.	1.The mechanism is easy to use. 2.It is not harmful to human health. 3. The control of the robot is provided easily.	The mobility of the robot should be improved.
A Smart-hand Movement-based System to Control a Wheelchair Wirelessly [42]	The design of a wireless-based wheelchair system that can be controlled with hand movements is developed	1.The design is cost effective. 2. It has a very competitive performance and efficiency.	Its response accuracy needs to be improved.
Deep Learning-Based Object Detection, Localisation and Tracking for Smart Wheelchair Healthcare Mobility [46]	A smart wheelchair design with an object detection and tracking system based on deep learning for object detection	The use of two cameras has added value to the work	1.Object detection neural network should be updated to a more recent version 2.The quality of the dataset should be improved.

TABLE 3. Classification of the methods of the papers - Part 1.

Papers	EOG Sig. Pro.	Image P.A.	EEG Sig.Pro.	Sensors	Deep L.	Robotics	MCU	Mechanic	POA	TMLA
[42]				*			*			
[41]		*		*						
[2]		*								
[45]					*					
[50]						*				
[30]				*						
[20]								*		
[51]				*						
[22]			*							
[43]								*		
[8]				*						
[36]						*				
[3]	*		*							
[19]			*							
[28]									*	
[14]				*						
[29]								*		
[32]								*		
[40]				*						*
[18]				*						
[31]										*
[27]									*	
[5]				*						
[17]				*						
[38]					*					
[49]				*						

EOG Sig. Pro.: *EOG Signal Processing*
Image P.A.: *Image Processing Analysis*
EEG Sig.Pro.: *EEG Signal Processing*
Deep L.: *Deep Learning*
MCU: *Microcontrollers*
POA: *Participant Oriented Approach*
TMLA: *Traditional Machine Learning Approach*

TABLE 4. Classification of the methods of the papers - Part 2.

Papers	EOG Sig. Pro.	Image P.A.	EEG Sig.Pro.	Sensors	Deep L.	Robotics	MCU	Mechanic	POA	TMLA
[23]				*						
[34]						*				
[48]				*						
[46]					*					
[11]				*						
[26]						*				
[47]								*		
[25]					*					
[52]							*	*		
[7]				*						
[10]				*			*			
[37]						*				
[9]						*				
[21]						*				
[35]							*			
[33]						*				
[13]					*					
[44]					*					
[12]				*						
[39]			*							
[15]				*						
[6]					*					
[24]				*						
[4]		*								
[16]				*						
[1]	*						*			

EOG Sig. Pro.: *EOG Signal Processing*
Image P.A.: *Image Processing Analysis*
EEG Sig.Pro.: *EEG Signal Processing*
Deep L.: *Deep Learning*
MCU: *Microcontrollers*
POA: *Participant Oriented Approach*
TMLA: *Traditional Machine Learning Approach*

TABLE 5. Classification of the aims of the papers - Part 1.

Papers	Nav.	Tr. Head	Tr. Eye	T.P.	Caregiver	Face.	Voice.	Target.	Ma. Skills.	Oth.
[42]										*
[41]										*
[2]			*							
[45]									*	
[50]				*						
[30]										*
[20]				*						
[51]							*			
[22]	*									
[43]									*	
[8]		*								
[36]	*									
[3]			*							
[19]										*
[28]										*
[14]		*								
[29]				*						
[32]				*						
[40]	*									
[18]					*					
[31]										*
[27]										*
[5]			*							
[17]	*									
[38]							*			
[49]									*	

Nav.: *Navigation*
Tr. Head.: *Tracking head movements*
Tr. Eye.: *Tracking the eye movements*
T.P.: *Transfer the patient*
Caregiver.: *Following the caregiver*
Face.: *Facial expression recognition*
Voice.: *Voice recognition*
Target.: *Target recognition*
Ma. Skills.: *Improving maneuvering skills*
Oth.: *Others*

TABLE 6. Classification of the aims of the papers - Part 2.

Papers	Nav.	Tr. Head	Tr. Eye	T.P.	Caregiver	Face.	Voice.	Target.	Ma. Skills.	Oth.
[23]					*					
[34]	*									
[48]										*
[46]								*		
[11]		*								
[26]	*									
[47]				*						
[25]	*									
[52]										*
[7]		*								
[10]		*								
[37]						*				
[9]		*								
[21]						*				
[35]							*			
[33]	*									
[13]		*								
[44]							*			
[12]		*								
[39]								*		
[15]		*								
[6]		*								
[24]	*									
[4]			*							
[16]										*
[1]			*							

Nav.: *Navigation*
Tr. Head.: *Tracking head movements*
Tr. Eye.: *Tracking the eye movements*
T.P.: *Transfer the patient*
Caregiver.: *Following the caregiver*
Face.: *Facial expression recognition*
Voice.: *Voice recognition*
Target.: *Target recognition*
Ma. Skills.: *Improving maneuvering skills*
Oth.: *Others*

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