Suez Canal Engineering Energy and Environmental Science Journal
Faculty of Engineering – Suez Canal University
Year 2024, Volume 2, NO. 1, pages 1– 26

Wheelchair Review: Types, Operation Techniques, and Safety Aspects

1 ***M. Sayed*** *Department of Mechanical Engineering, Faculty of Engineering, Suez Canal University, Ismailia, Egypt, email: mohamed_hti2007@yahoo.com*
2 ***T. Mansour*** *Department of Mechanical Engineering, Faculty of Engineering, Suez Canal University, Ismailia, Egypt, email: tmansour@eng.suez.edu.eg*
3 ***A. El Domiaty*** *Department of Mechanical Engineering, Faculty of Engineering, Suez Canal University, Ismailia, Egypt, email: ali_aldemiaty@eng.suez.edu.eg*
4 ***MG Mousa*** *Department of Mechanical Engineering, Faculty of Engineering, Mansoura University, Mansoura, Egypt, email: mgmousa@mans.edu.eg*
5 ***Ali A. S.*** *Department of Mechanical Engineering, Faculty of Engineering, Suez Canal University, Ismailia, Egypt, email: ahmed_salaheldin@eng.suez.edu.eg*
**M. Sayed, Email address: mohamed_hti2007@yahoo.com*
DOI: 10.21608/sceee.2024.266762.1016

Article Info:

Article History:
Received: 02\02\2024
Accepted: 22\04\2024
Published: 30\07\2024

DOI: 10.21608/sceee.2024.266762.1016

Abstract

Increasing numbers of elderly, disabled, and injured people all over the world are leading them to use wheelchairs to carry out their daily activities. The right selection of the wheelchair according to the condition of the user helps to improve his/her morale during everyday life, which can lead to enhancing the therapeutic status of the user. This paper aims to clarify the different types of wheelchairs and identify the suitable type of wheelchair, operation method, and safety aspects for the user. An organized review of the literature is presented based on the collected data from the different international research projects for different wheelchairs and their technology. We are honored to present a novel classification for the different types of wheelchairs and a vision to classify the chosen wheelchair for use or research. We also illustrate guides for operating Smart Powered Wheelchairs based on different types of disabilities and needs, as well as some safety aspects of using wheelchairs. We conclude our research based on our vision that the type of wheelchair and the operating technique will depend on the condition and disability level of the user and his/her economic level. The safety and satisfaction of the user should be taken into consideration, whatever the selected type or operating technique of the wheelchair.

Keywords: *Types of wheelchairs, Powered Wheelchairs, Smart Electric Wheelchairs, wheelchair Operation techniques*

Suez Canal Engineering, Energy and Environmental Science Journal (2024), ***2***(1), 1-26.

1.INTRODUCTION

The world's population is rapidly increasing. Physical impairment is on the rise as a result of aging, accidents, and illnesses such as quadriplegia and paralysis. World Health Organization (WHO) research estimates that around 15% of the world's population is handicapped [1,2]. According to Japanese demographic projections, the proportion of senior individuals aged 65 and up will reach 40% in 2050 [3]. Disabled people account for 2.21% of India's population [2]. As a result of the impending aging society with fewer children, there is a need for technological help for senior people from the standpoint of welfare engineering [3]. These folks find it difficult to get about, so we're working on a wheelchair to help them [2]. For those with physical disabilities, a wheelchair is a vital mode of transportation. As a result, when disabled people want to travel to any location on their own, they will need to use a wheelchair [4].

Some people lose a limb or both legs as a result of illness or an accident, rendering them incapacitated and reliant on others for their daily needs. They are incapable

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

of completing their tasks on their own [2]. In today's society, everyone is preoccupied with their lives, and society is more geared toward capable and self-sufficient individuals. No one talks about dependent people in this fast-paced period of materialization and modernization. In our culture, we rarely consider the needs of those who are dependent. If everyone could live their lives independently, the entire globe would be a fantastic place to live [5].

Aside from these individuals, many others have lost bodily parts owing to a variety of factors such as accidents, natural disasters, or other catastrophes. These unintentional mishaps cause a great deal of disruption in their daily lives, resulting in severe mental and physical stress. They have trouble moving alone and become reliant on others. These individuals often utilize a muscularly controlled wheelchair for mobility, although manually operating the wheelchair on a daily basis is quite challenging [5]. Wenfeng Li conducted research about fatigue tracking and the classification of fatigue degrees, which has been applied to the musculoskeletal of users of Manual Wheelchairs (MWs). Wenfeng Li used neuro-fuzzy techniques during the tracking and classification system of the user's physiological and kinetic data, including Electromyography (EMG), Electrocardiography (ECG), and acceleration signals [6]. Every day, new technology enters the marketplace. The basic goal of technology is to make human existence simpler and less dependent on others. As a result, we are designing a method to help people who have trouble walking [2]. Powered Wheelchairs (PWs) can meet the demands of such people with locomotive difficulties [5].

2.TYPES OF WHEELCHAIRS

There is a tremendous need for wheelchairs and development and the research required to make them more efficient, safer, and commonly accessible. The United States Veterans Health Administration's (VHA's) Rehabilitation Strategic Healthcare Group highlighted clinical prescribing criteria, accreditation, access to new technology, device user training, practitioner credentials, national contracts, patient education, and device evaluation as areas of particular importance [7]. Although mobility is an important aspect of everyday life, it is generally only acknowledged when it is (temporarily) constrained, as it is in the case of people who are wheelchair-dependent [8].

Wheelchairs should ideally become an extension of themselves for those who use them. Wheelchairs, like prosthetic devices, replace a bodily part's function and must be specifically fitted to the user. If an individual's circumstances change, the improvements to his or her wheelchair must be adjusted. Wheelchairs may now be customized in a variety of colors, designs, and features, making them a form of self-expression. Wheelchairs enable people to execute daily duties more independently and get access to school, jobs, and community settings [9].

Wheelchairs are often classified into two categories. The first is a self-controlled wheelchair, in which the user controls the wheelchair with his or her hands and arms via a rim on the outside of the back wheel. The second kind is one that is controlled by an assistant, such as a joystick [4]. The classification of wheelchairs is shown in Figure 1.

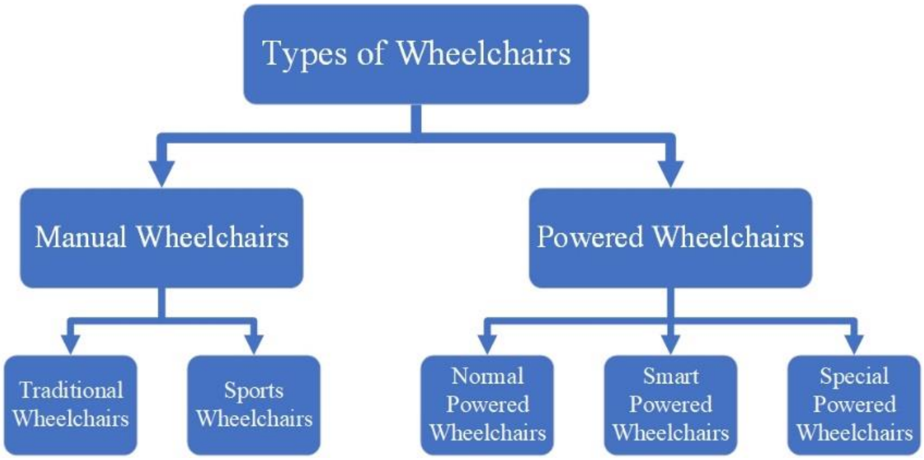


Figure 1: A block diagram shows the classification of wheelchairs.

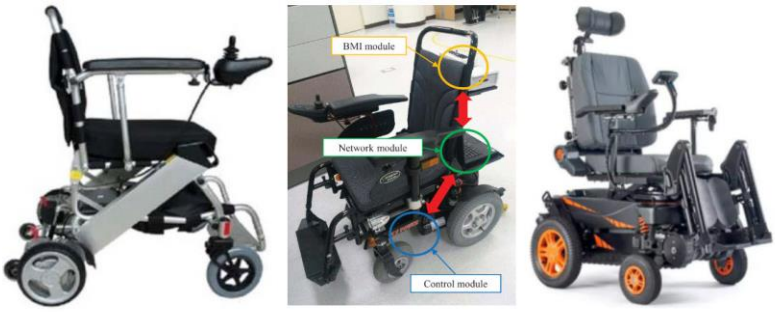
MW producers and models have been classified into two categories; the first one is customizable, and the other one is standard. Wheelchairs that were called customizable weighed less than 14 kg (30 lb) and featured a changeable axle position. These wheelchairs also had higher-quality components, such as bearings and extra adjustability, were more robust, and were much more cost-effective over time. Standard wheelchairs were defined as those that did not have these characteristics [10]. Figure 2 shows some examples of MWs.

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

(a) (b) (c)

Figure 2: Examples of MWs: (a) Standard MW, (b) Modern MW, (c) Tennis wheelchair [9,11].

PWs have been classified based on the properties of the frame and its structure or power base, and also have the feature of programmable controls and configurable features. According to the wheelchair's manufacturer and model, PWs were categorized into three categories. When a PW is said to be configurable, at least one of the following modifiable aspects is present: (1) a suspension system, (2) a motor with excellent torque and a durable chassis, or (3) advanced seating systems like tilt-in-space or standing. Standard PWs with the feature of programmable controls are the second type. Standard PWs were the last category [10]. Figure 3 shows some examples of PW.



(a) (b) (c)

Figure 3: Examples of PWs: (a) Standard PW, (b) Programmed or Smart Powered Wheelchairs (SW), (c) Special PW [12,10,13].

New alternatives and advanced wheelchair-related technology are now available to a larger number of people. New alternatives and advanced technology, on the other hand, may result in greater device prices. Simultaneously, insurers are scrutinizing durable medical equipment requests more closely [9].

2.1. Manual Wheelchairs (MWs)

Many people with lower-limb disabilities still choose MWs for indoor activities because of their rapid reflexes and small size [14]. Of all the propelling techniques, handrim propulsion interacts with the human system most closely with proprioceptive, kinaesthetic feedback, and direct visual to the user, directly expressing information on the spatial orientation of the body, position, and speed. To prescribe more advanced wheelchairs, medical boards demand quantifiable grounds, although quantification might be challenging. It's also difficult to overturn the established quo; pushrim-propelled wheelchairs have a lot more information than the alternatives. Many revisions to the basic MW design have been influenced by wheelchair sports, particularly wheelchair racing, and there is an agreement on maximizing a wheelchair's performance and the significance of adapting the wheelchair to the individual user [15].

A wheelchair is a mobility device with a tiny front wheel and a side wheel with two large tires that people use to get around in their daily lives. A person with paralysis of the legs can use a wheelchair to help them move about [16].

There are five primary fields of research on pushrim-propelled wheelchairs. First, research on the Wheelchair Skills Test (WST) and outcome measures has been conducted. These are motivated by the desire to create measurements that would allow doctors to objectively evaluate the best wheelchair for a specific user. Then there is health-related research, which focuses on the necessity for wheelchair users to maintain their physical fitness, upper body stress, and the influence on their Quality of Life (QoL). They also look at how to improve the pushrim-propelled wheelchair's performance in terms of minimizing the propulsive stresses it puts on users. There has been research on wheelchair biomechanics, the influence of the environment (such as surface type and ramps) on propulsion, and pushrim wheelchair developments [15].

2.1.1. Traditional Wheelchairs

The number of wheelchair users globally is poorly documented; it is thought that roughly 1% of the population in affluent nations uses one, but the figure is likely significantly lower in the rest of the world. Because of the increased frequency of sickness and damage in developing nations, the number of individuals who

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

require wheelchairs is significantly larger than 1%, but only 5-15 % of them will have one [15].

Basic manual push-propelled wheelchairs account for over 90% of all wheelchairs. They are the most commonly recommended chairs because they are affordable, easy to maneuver on flat surfaces (such as those found in a house), and transportable (because of their lightness and foldability). They range from the most basic 'transport' chair, which is commonly found in hospitals for short-term usage, to more sophisticated models for long-term use. Claire L. Flemmer has classified the MWs into four types: the first type is Pushrim-propelled wheelchairs, which are the normal and basic type of the MW; the second type is Crank-propelled wheelchairs which are also called (handcycle) wheelchairs, as shown in Figure 4(a), the third type is Lever-propelled wheelchairs, as shown in Figure 4(b), and the fourth type is Geared wheels in pushrim-propelled wheelchairs. In her research, she has illustrated the main features of each type [15].

(a) (b)

Figure 4: Some types of MWs: (a) Crank-propelled wheelchairs, (b) Lever-propelled wheelchairs [15].

Liping Qi has studied the relationship between using different propulsion techniques for MWs and shoulder muscle coordination patterns and wheelchair kinetics. Liping Qi compared the activity of seven muscles that generate signals by using EMG sensors on a group of 15 capable but inexperienced individuals. Liping Qi found that a noticeable improvement in a brief semi-circular propulsion training session was achieved by allowing able-bodied people to try out a pattern of their choice [17]. Wheelchair users require a diverse set of abilities. They must be able to push the chair on a range of terrain (smooth, flat, bumpy, and sloping) at various speeds (from walking to sprinting), as well as transfer, road markings, and wheelies [15]. Rick de Klerk has studied and illustrated different types of measurement and simulation devices and techniques that are used to study the forces that are applied to the user of a MW. Rick de Klerk found that there should be ergometric standardization and an increasing need for general agreement to enable suitable comparison of outcomes [18].

2.1.2. Sports Wheelchairs

Sport is increasingly being utilized to supplement traditional physiotherapy approaches for persons with impairments. Tennis, racing, basketball, and archery are all wheelchair sports that assist in increasing strength, coordination, and endurance. Another essential component of sport is that it allows handicapped people to make social connections. Participating in sports can help physically impaired people restore self-esteem, develop good mental attitudes, come to grips with their impairment, and reintegrate into society [11]. Figure 5 shows different types of sports wheelchairs.

(a) (b) (c)

Figure 5: Different types of sports wheelchairs: (a) Basketball wheelchair, (b) Rugby wheelchair, (c) Tennis wheelchair [19].

Even adapted sports equipment and sports for individuals with impairments are now being developed by sportswear manufacturers [11]. Jonathan Duvall developed an adjustable sports wheelchair for Para Table Tennis players helps the player to focus more on the game. The user of the developed wheelchair can adjust the height as well as anterior/posterior tilt while still fitting under the table. Also, the player can lock the caster wheels of the wheelchair and move forwards and backwards by using his or her non-paddle hand to be more focused [20].

Because of the growing popularity of sports, competitive games for individuals with impairments have been developed. The rules and structure of sports for handicapped individuals are tailored to the limitations imposed by disability. Paraplegia, amputation, cerebral palsy, mental disability, vision impairment, and hearing impairment are among the disabilities accepted for international competition [11].

Disabled people's particular sports requirements include (1) specialized coaching, (2) medical monitoring, (3) accessible facilities, and (4) an information service. Before participating in sports activities, disabled individuals should visit their physicians. Physically challenged people participate in sports within the limitations of their movement, and they are concerned with avoiding the problems of immobility and treating injuries that may occur as a result of sports [11].

How to Cite this Article:
Sayed, M. et al. (2024) ‘Wheelchair Review: Types, Operation Techniques, and Safety Aspects’, Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

Biomechanics is utilized in sports medicine to measure stresses and anatomic structures in order to evaluate function before and after rehabilitation and/or surgery. Biomechanical research is involved with movement analysis based on data collected from actual human body motions. Techniques in biomechanics can be classified as (1) direct methods or (2) indirect methods, depending on the physical nature of the data collected. The data collected at point (1) is directly connected to the process being studied and includes measured angles or displacements, stress/strain, forces or mechanical moments, X-ray pictures, and associated image-processing processes. Point (2), on the other hand, relates to indirect factors like blood pressure, heart rate, and electrical potential from muscles (EMG) or brain (Electroencephalography 'EEG') [11].

Wheelchair basketball, like other disability sports, is gaining popularity. It gives joy to people with disabilities, especially those with legs, and improves their QoL. Meanwhile, as a field of technology design, assistive technology in sports has grown in popularity [21]. L. Lei designed a new sports wheelchair for basketball sport that enhances the performance of the wheelchair by improving the position of the center of gravity of the body upon the wheelchair. L. Lei ran the computation of the finite element analysis and the result shows that the designed wheelchair is safe, comfortable, and reliable, and its intensity of it satisfies the operation requirements [22]. Many sports lovers with limitations can now play thanks to this technology. We've been working on a wheelchair with a variety of sensory sensors to improve QoL for both patients and caregivers [21].

Wheelchair racing is one of the most significant Paralympic activities, with races ranging in distance from short to long (100m to 42km). T51, T52, T53, and T54 athletes are categorized according to their injuries (C5-6, C7- 8, T1-7, and T8-S4 correspondingly). The earliest steps toward wheelchair racing research were taken in the 1980s at a laboratory using high-speed videos. Manufacturers estimated that over 10,000 wheelchair variants were developed globally in the 1980s [23]. Giuseppe Quaglia presented an innovative system of propulsion for MWs, mostly like a rowing gesture, as shown in Figure 6. Giuseppe Quaglia called the new system "Handwheelchair.q" and said that it can be used in daily life wheelchairs and will also be useful in sports wheelchairs that need speed, like racing wheelchairs [24].

Figure 6: Innovative system of propulsion for MWs [24].

Every aspect of a race has a significant impact on an athlete's performance. One of the key issues for practitioners is the opposite-direction resistance force. If these resistive forces are reduced, the athlete's velocity and performance can be improved. In wheelchair racing, the resistive forces are rolling friction and aerodynamic drag. In racing sports, aerodynamics may have a significant impact in determining first and second place. Aerodynamic forces account for nearly 90% of resistive forces at speeds greater than 5m/s, making them particularly important in sprinting events. Pedro Forte studied the effect of aerodynamic drag as a resistive force in wheelchair racing while not using a helmet and while using it. Pedro Forte used Computational Fluid Dynamics (CFD) during the study for 3D models of a head and a helmet and found that using the helmet is very useful for the user [23].

2.2. Powered Wheelchairs (PWs)

People with lower-limb impairments often have minor issues with other portions of their bodies, allowing them to maneuver their MWs with ease. They may, however, get rapidly fatigued while climbing a slope or traveling great distances. Even when traveling long distances, power support devices can lower the amount of energy required for exertion and suffering [14]. However, some people are still unable to use the Traditional wheelchair due to a hand injury or another condition [1]. As a result, there is a considerable need for power assist devices for MWs, and numerous techniques have been developed [14].

Rim motors or a supplementary wheel are commonly used in power-assistance systems as shown in Figure 7. When actuated by the user, the rim motors are placed on both sides of the wheelchair wheels and produce an assistive torque to the wheels. The passenger's force, as well as the rim-motors, rotate the wheels. This construction offers more torque at low speeds and improved operation in low-battery situations [14].

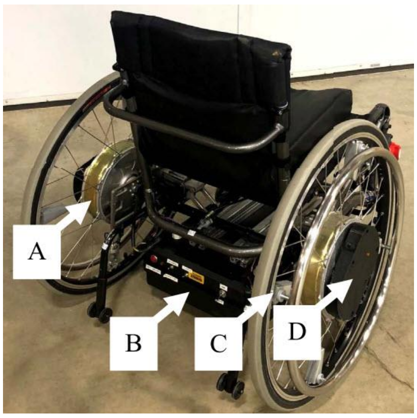


Figure 7: Power Assisted Wheelchair (PAW): A: In-hub Motor; B: Power and Control unit; C: Force sensor; D: Wheel orientation sensor [25].

Using Power Assist Wheelchairs (PAWs) has two advantages. For starters, they lessen weariness while traveling long distances. Second, they assist operators in retaining their current abilities as well as rehabilitation. To put it another way, PAWs combine the benefits of both self-propelled and PW. PAWs have grown popular as a result of these factors. However, currently available PAWs simply increase the power through the handrims and assist, leaving more to be improved. As a result, different assist approaches have been presented to enable smoother operation [3].

People with mobility limitations are typically given Assistive Technologies (AT) such as a scooter, a manual or motorized wheelchair, and a scooter to help them go around. People with more severe issues, such as limited upper body strength, are frequently provided a motorized wheelchair, which may be utilized with interfaces that need less upper body strength, such as a joystick [26].

George Klein invented the first automated PW for World War II veterans in 1953 [1]. Even more so, because this would be a mindset change rather than a technology one. Overall, there has been a significant amount of R&D on both PWs and Smart Wheelchairs (SWs) in particular, as well as assistive technology in general, for individuals with impairments [27].

2.2.1. Normal Powered Wheelchairs

The vast majority of MWs are driven by pushrims, with no gearing or power assist. They're cheap, light, collapsible, and simple to handle on a flat surface, such as indoors. Pushrim propulsion, on the other hand, is inefficient and taxing. Even physically strong users may struggle to move up ramps and on uneven surfaces like outside pathways, and their confined surroundings will limit their involvement in daily activities [15]. HyungTae Kim developed a driving module with an easy-docking mechanism to be attached to the MW to convert it to a PW, as shown in Figure 8. The developed driving module is almost like the front half of the motorcycle, which contains a front wheel driven by a brushless DC motor, a throttle grip, a brake lever, and an LCD panel that displays the current driving status [14].

Figure 8: Easy-docking mechanism: (a) 3D design of the mechanism, (b) Parts of the wheelchair driving module [14].

Normal PWs have recently gained popularity as a means of increasing mobility for those with impairments. Normal PWs are motorized wheelchairs that can be controlled using a joystick [14]. Disabled, aged, or injured individuals utilize Normal PWs all around the world. However, practically all of them are heavy, with sturdy frames, tiny wheels, and large-capacity batteries [28].

When purchasing a Normal PW, a wheelchair user must also decide on a wheelchair configuration. In cloudy places, a front-drive wheelchair is easier to manage, but a rear-drive wheelchair is better for steady high-speed driving [28]. Deepak Kumar introduced a PW full of useful options for the users that could help them in their daily lives. The proposed system by Deepak Kumar consists of a head mat, an umbrella, and a foot mat that work automatically according to the data of the integrated humidity sensor. It also contains an ultrasonic sensor used for obstacle detection [29]. A typical PW has either a front-wheel drive or a rear-wheel-drive arrangement. However, a user cannot alter the configuration of a PW unless he or she switches from one wheelchair to another. Large wheels (rear wheels) are driven in MWs and motorized wheelchairs with add-on systems [28]. M. Khalili improved using PAW for its users. M. Khalili could collect data and signals from user-pushrim interactions and use them in a learning-based classifier algorithm to be able to estimate the intent of the user of a wheelchair in real-time. M. Khalili used this information to adjust the ratio of power-assist to eliminate the need for tuning it manually at the model parameters when the user of the wheelchair changed [25].

Normal PWs are often constructed to make the most of the space beneath the chair. Transporters, or four-wheel drive wheelchairs, are useful for those with severe impairments and can travel great distances [14]. Hirokazu Seki implemented a control system based on fuzzy control to help the users of the wheelchair with the type of PAW. Hirokazu Seki improved the driving performance of the Electric PAW on large disturbance roads. The implemented system could reduce the physical power of the user of a wheelchair during large disturbance roads like grass roads, not smooth surface roads like gravel roads, and uphill roads [30].

2.2.2. Smart Powered Wheelchairs (SW)

The human hand is a vital component that allows people to execute fundamental daily tasks such as hand gestures and object manipulation. Humans suffer considerable emotional and physical pain when they lose a hand. It is estimated that 94,000 upper limb amputees exist in Europe and 41,000 upper limb amputees exist in the United States. According to the WHO, there are approximately 40 million amputees worldwide. These figures are likely to rise further as people live longer lives, resulting in a higher prevalence of diabetes and cardiovascular disease [31].

People who suffer from cognitive, motor, and sensory impairment rely on PW for movement, whether due to disability or disease. Because some people with impairments are unable to navigate their PW using a typical joystick, they employ alternate control methods like head joysticks, chin joysticks, sip-and-puff, and thinking control as shown in Figure 9. [27]. J. Andrés Sandoval-Bringas developed a general-adapted electronic control module that can be used with the PW. The implemented module can allow people with some motor disabilities to interact and be able to drive the PW because it has a multifunctional capacity to control and direct the wheelchair. The module can manage driving the wheelchair by using head or hand movements, or by using signals from muscles, or by voice commands, or through a mobile application [32]. PW users frequently struggle with daily navigating activities and might benefit from an automated guidance system [27]. Also, some people experience motor paralysis that forces them to stay in bed owing to a condition like Amyotrophic Lateral Sclerosis (ALS) or Spinal Cord Injurie (SCI) [16]. They gradually lose muscular power and frequently end up with trouble reaching and grasping, which makes the driving mechanism difficult to use, such as a joystick [33].

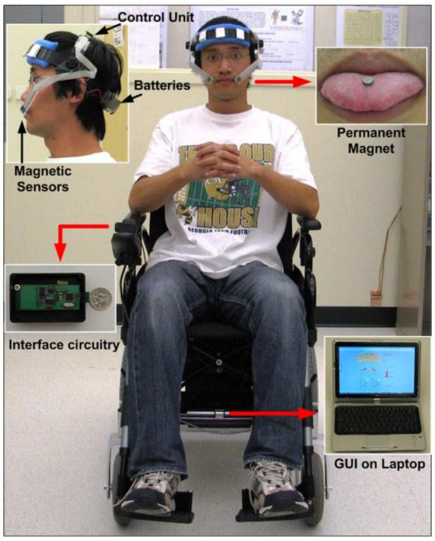


Figure 9: PW controlled by tongue motion [34].

When a person has this condition, certain routine tasks, such as raising an arm, carrying items, or transferring to another location, become impossible. These individuals require the assistance of others to carry out their tasks. To aid them in doing particular daily duties, AT should be developed. To aid this individual, an assistive device can be created that uses brain impulses or eye blinking signals as input to operate the equipment that will be utilized [16]. Yang Yu proposed a hybrid Brain-Computer Interface (BCI) control system that combines Motor Imagery (MI) and the potential of P300 for controlling PW, as shown in Figure 10. the flow of the operating process of the wheelchair. Yang Yu used a special type of wheel called Mecanum wheels to decrease the effort that was used to reach a specific place by the user of a wheelchair and used fewer commands from the BCI system [35].

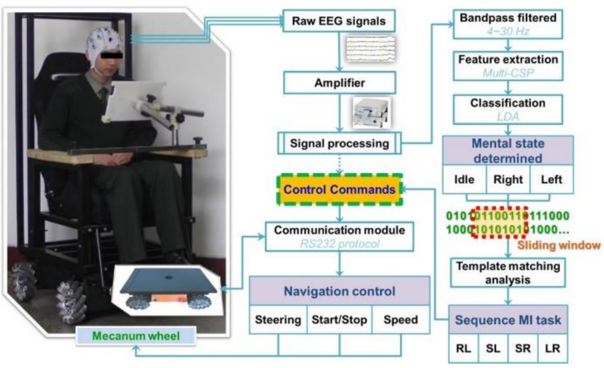


Figure 10: Brain-controlled PW with Mecanum wheels [36].

It is predicted that the existing population of people who use PW now represents just approximately half of the potential user population. The number would rise if the technology existed to allow those who are unable to handle a joystick or switch array to have the dependable and safe operation of a PW [7]. With the growing elderly population, autonomous and smart healthcare services are becoming increasingly crucial [37].

People with motor limitations caused by illnesses like ALS now have options to be much more independent and mobile thanks to advancements in PW design. However, learning to use and operate a PW often necessitates substantial expertise. Furthermore, certain people with motor disorders, such as those with ALS, are unable to control a PW properly (even with a joystick) because they lack the physical capacity to regulate their hand movement [33]. To meet the demographic of those who struggle or find it impossible to use a PW, some researchers have created SWs using technology initially designed for mobile robots [27]. D. H. De La Iglesia designed a universal control board with a low cost for controlling wheelchairs' trajectories. The proposed control board of D. H. De La Iglesia allows any systems integrator who is working on the control interface of wheelchairs to use it in their work for both research and the development of their prototypes that are used to improve the QoL and help these kinds of people in our society [38]. Even a clinical evaluation revealed that commercially available platforms are insufficient for people with severe impairments to drive a PW. In fact, given the variety of disabilities that prevent patients from benefiting from current types of mobility, innovative interfaces may be required [26].

A SW is often made up of either a regular PW base with a computer and a variety of sensors connected or a mobile robot base with a seat attached [27]. In addition to joystick control, several ways of operating a PW use whole different interfaces [26]. The electrical impulses sent by our bodies allow us to connect to a plethora of applications in the fields of Human-Machine Interface (HMI) and rehabilitation [39]. Furthermore, intelligent functions have been applied to improve their capabilities, making them useful for the regular lives led by people with disabilities [14]. One of the most difficult aspects of building a non-manual HMI for wheelchair operation is producing adequate instructions that include left and right turns, forward and reverse motions, accelerating, slowing down, and halting [40]. Gao Nuo introduced a PW based on Mecanum wheels and an intelligent BCI control system. Gao Nuo added obstacle avoidance sensors with Mecnum wheels to improve the driving and safety of the PW and make it easier for the user. Gao Nuo used Steady State Visual Evoked Potential (SSVEP) with Alpha wave in the BCI control system to improve the accuracy, recognition rate, and analysis time. Apart from this, Gao Nuo could improve the information transmission rate [41].

2.2.3. Special Powered Wheelchairs

Mobility issues are common among the elderly, and they are especially important for those who live alone.

Interventions to adjust to mobility disability fall into three categories: improving the user's ability to perform the activity by treating the diseases or impairments that are causing the disability; eliminating the need to accomplish the activity or parts of the activity through the use of personal assistance; or changing the way the activity is performed, such as through the use of assistive technology such as a cane, walker, or wheelchair [7]. Models of MWs have vastly improved since the 1950s when they were based on a "one size fits all" depot-style design for transportation. For active wheelchair users, custom-fit lightweight MWs are now available. Progress in powered, wheeled mobility continues to improve functional independence for those with severe impairments [9]. Figure 11 shows some types of special PW.

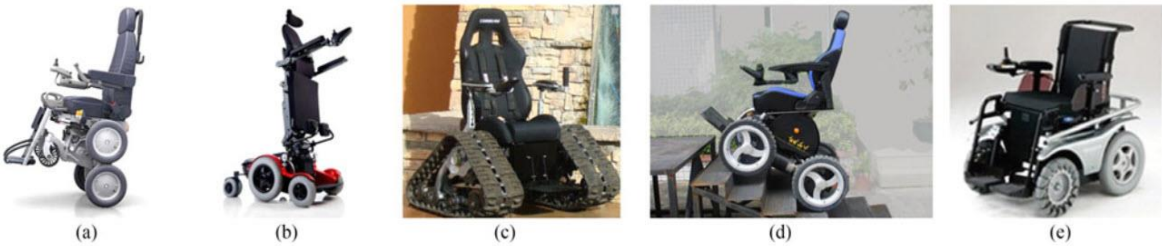


Figure 11: Some types of Special PW: (a) Stair climbing iBot, (b) Standing wheelchair, (c) The Tank Chair, (d) The Chinese stair climbing PW, (e) Patrafour by Toyota Motor [27].

Currently, navigating a PW is difficult, particularly for people with limited capacity to handle the joystick controls. Instead of needing an individual to oversee every part of a SW route, the SW could manage the route on their behalf, receiving information from its surroundings and reducing the burden of micromanagement [42]. Yeontaek Jung introduced a novel algorithm for path planning that can be used in hospitals for an autonomous PW. Yeontaek Jung's study was based on meeting body acceleration constraints, collision avoidance, and following suitable paths during moving in hospitals. The most interesting thing about this investigation is that the results can be used in most systems with two-wheel actuation [43]. Yudi Zhu developed an automatic docking system for wheelchairs and nursing beds depending on a Lidar sensor and using a V-shaped artificial landmark as shown in Figure 12. While keeping the ability to turn the nursing bed over, lowering the risk of secondary damage to bedridden patients during the transfer procedure, and considerably enhancing bedridden patients' self-nursing ability [44].

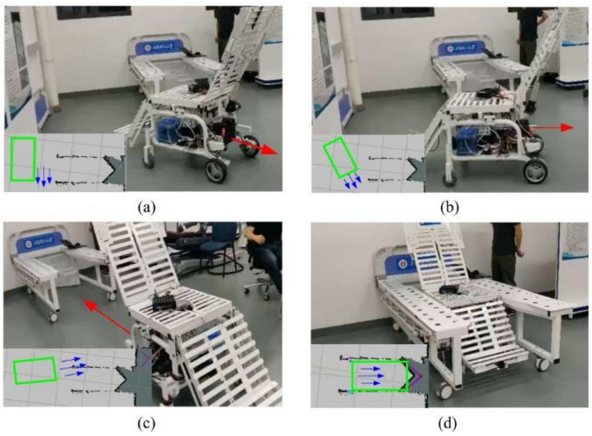


Figure 12: Automatic docking system for wheelchair/nursing-bed: (a) Ready for docking view, (b) Start docking view, (c) Entering the bed view, (d) Successful docking view [44].

The application of innovations to enhance one's QoL has yielded notable outcomes. Many features may be added to a wheelchair to improve its mobility by utilizing automation [5]. André A. Jorge studied a Hybrid PW with two locomotion systems. The first locomotion system is a conventional wheel system like the Normal PW, and the second locomotion system is a track system that allows it to traverse barriers like stairs. André A. Jorge presented the mathematical model of the track system based on its kinematic and dynamic parts and certain open-loop and closed-loop control systems, like the Lyapunov function control and Proportional-Integral-Derivative (PID) control approaches [45]. Aside from mobility, people with disabilities rely substantially on carers for eating and drinking, managing goods, and conversing with others, particularly in big groups [27].

Assistive robotics seeks to improve QoL and reduce carer dependence in patients with whom motor functions have been impaired, for example, by traumatic, vascular, and neoplastic lesions, motor neurons, and many other neurological diseases; it also aims to improve rehabilitation when the function can be regained at least partially [46]. Efficient exoskeletons, wheelchair-mounted robotic manipulators for gripping and completing fundamental operations with common objects, and meal-assisting tabletop robots have all resulted from applied research. The development of efficient HMI and concepts for robot control is a significant problem in this domain, with present solutions varying significantly in their residual motor function needs, command throughput, simplicity of use, technical complexity, and cost. On the cheap end, joystick (or micro-switch) operation is most suited for patients with at least partially retained hand function (e.g., after hemisphere stroke), as it is both cheap and effective for driving [47]. Xin Chen developed a Brain-controlled wheelchair integrated with a robotic arm and Meconium wheels to help patients with paraplegia during their daily activities, as shown in Figure 13. The developed system can recognize and encode environmental items automatically, execute autonomous route programming, and use the robotic arm to interact with environmental objects [48]. The advancements in mobile robotics have enabled the development of SWs, which offer access to new ways of developing user interfaces and even adding navigation assistance – thus addressing the challenges in learning how to navigate a wheelchair [49].

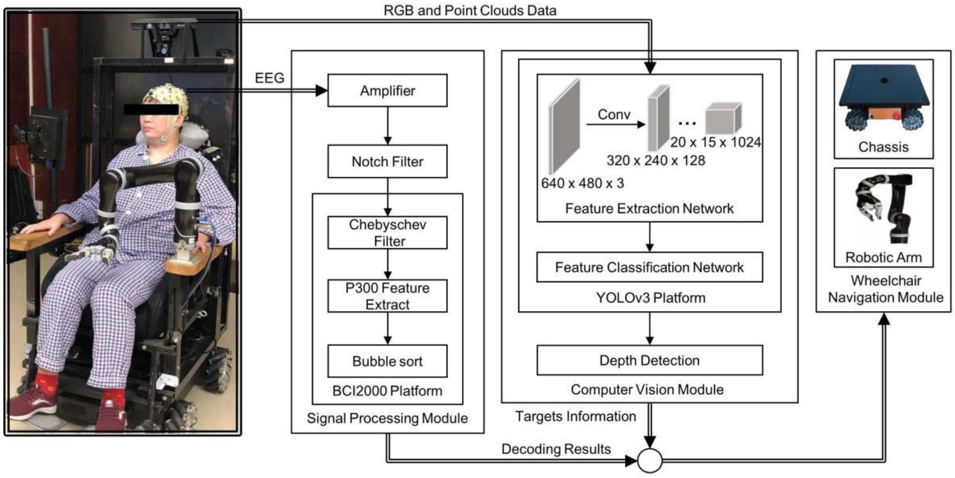


Figure 13: PW with BCI integrated with robotic arm and Mecanum wheels [48].

Wheelchairs range in price from $100 to $35 000 per unit, depending on their sophistication. Insurance companies, such as Medicare, will pay the expense of a wheelchair if it is reasonable and medically required for the treatment of a disease or injury, or to enhance the function of a bodily part. People who "cannot" ambulate in their homes are sometimes denied insurance reimbursement for these devices. Wheelchairs with sophisticated features, such as "tilt and recline" or raising seats as shown in Figure 14., need documentation of medical necessity certified by a doctor [9]. The wheelchair, too, can arrive at its destination autonomously by following a pre-programmed course [50]. These regulations urge practitioners to employ robust scientific study findings to support the prescription of newer technologies [9].

Figure 14: Special PW with tilt function [9].

Nurul Fadzlina Jamin presented control strategies used to stabilize a wheelchair of the two-wheeled type and have a movable payload on it in different conditions. Nurul Fadzlina Jamin used the concept of the double-link inverted pendulum during the investigation and used SimWise 4D to model the used wheelchair with Spiral Dynamic Algorithm for control parameter optimization [51]. More dependable and effective wheelchairs are required, as are wheelchairs that can meet the growing population of people with severe and frequently multiple impairments [7].

3.OPERATION TECHNIQUES OF SMART POWERED WHEELCHAIRS

A PW is a technological help for the majority of disabled people who have limited mobility. Its popularity grew as a result of its easy driving mechanism, which is primarily based on a joystick. If the driver is unable to use his hands, a custom interface must be designed and tailored to the driver's capabilities. As a result, a variety of joystick interfaces are created, and they are categorized into three types of driving modes. In the first, the interface design takes advantage of any upper-limb motion that may be performed. The order for the second one is sent by any action that may be performed at the lower limb level. Interfaces that benefit from motion in any area of the head fall into the third group. Other interfaces, such as those based on vision processes employing cameras to transform precise motions performed by the driver into commands operating the wheels, are more advanced. Unfortunately, these modern technologies significantly raise the cost and complexity of application [52].

Later, numerous researchers suggested and created a variety of designs to allow a user to securely and easily manage a wheelchair. Different techniques and various interfacing technologies have been explored by researchers, such as image processing, eye gaze, tongue control, the direction of the face (head arrays), oral motion, tongue pressure, EMG, Electrooculography (EOG), EEG-based BCIs, Speech Recognition (SR), and Sip-and-Puff (SnP) switches [1,33,4]. Saifuddin Mahmud developed a multi-modal HMI to increase the sector of disabled people who are using wheelchairs to control the wheelchair efficiently. He could integrate some control techniques besides using a joystick for driving the PW, like using a camera for eye tracking to operate the wheelchair, head movement tracking by using an Inertial Measurement Unit (IMU) sensor, and a smart hand-glove based on flex sensors [53].

However, each gadget has limits that prohibit it from being used in everyday life. BCIs, for instance, can assist

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

those who are severely paralyzed, but they are difficult to adapt to daily duties and are subject to motion artefacts and interference. Despite the fact that voice recognition systems make it easier to type, they are ineffective for cursor or wheelchair navigation, and they are unreliable in loud contexts. Head arrays and SnP switches are popular among tetraplegics because they are inexpensive and simple to use, although they have a limited number of instructions and require users to have a certain physical ability [33].

3.1. Image Processing Control

Many other applications have made use of image processing techniques. Eye and lip characteristics are both improved using morphological procedures, with eye features retrieved using threshold values and lip features extracted using K-mean clustering [54]. Figure 15 shows the common block diagram that is used in image processing techniques for controlling wheelchairs.

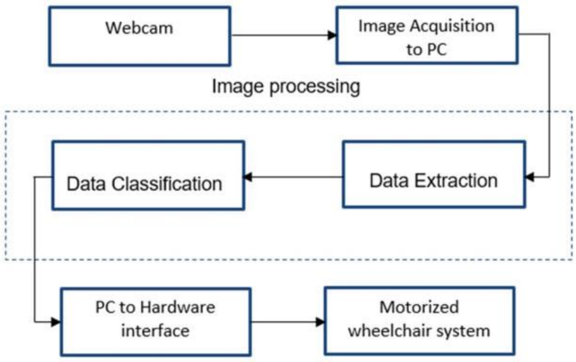


Figure 15: A block diagram of controlling a wheelchair based on image processing [54].

Gesture detection is a difficult problem that requires numerous skills, including motion modeling, motion analysis, pattern identification, and machine learning. Head Gesture refers to the posture achieved by moving the head while taking into account all of its face geometry, such as the eyes, nose, and lips. Such gestures are used to indicate cognition, emotion, and other things. Such a Head Gesture is incredibly useful and advantageous for people who are handicapped or have paralysis from the neck down [55]. Thierry Luhandjula proposed a visual solution that detects the motion of the user's hand and can be used to control wheelchairs. Thierry Luhandjula built an algorithm for visual HMI that detects the intention of the motion of the user's hand to generate commands that can be used to operate the wheelchair [56]. Head Movements are used by such people to offer hints. Recognizing motions from video sequences is one of the trickiest computer vision tasks. It gives the system the capacity to detect, interpret, and operate some devices by identifying, recognizing, and interpreting human gestures [55]. Figure 16 shows some of the filters that are used during image processing.

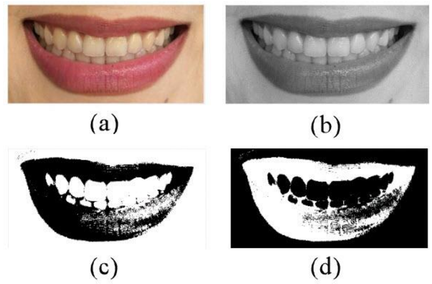


Figure 16: Some image filters that are used during image processing: (a) Input image, (b)Grayscale image, (c) Binary image, (d) Invert image [54].

The Smart Camera, also known as Gesture Cam, may considerably simplify the application system architecture for image processing activities. The integrated processing unit in the Gesture Cam, which is also called the Smart Camera, is a much superior technique to process photos at high resolution and frame rate. This is a real-time performance. The output of the smart camera is the sole visual feature or a high-level description of the user's face in four directions that has to be communicated to a central control computer; the bandwidth is modest [55].

For Face and Eye identification at the advanced level of Image Processing, the Open-Source Computer Vision (OpenCV) package is employed [57]. Some recent studies have used the Kinect sensor to identify human motion for wheelchair control [58]. The identification of gestures (hand, head, arm, eye, etc.) is an essential component of the multimodal user interface system [55].

The increased incidence of user intention misrecognition, a crowded background that varies constantly, differences in lighting conditions, and unexpected user motions are the key hurdles to adopting gestures for wheelchair control [58]. To reduce noise and conduct filling, mathematical morphology is applied [54]. To improve data, the Kalman filter technique is utilized. Currently, the Kalman filter technique is widely employed in signal processing and control systems. The Kalman filter method is being used in an increasing number of computer applications. In comparison to other algorithms, the Kalman filter method is simple to comprehend and implement through programming [59]. In contrast, real-time applications demand evaluating and improving timing performance requirements [60].

3.1.1. Face Features

People have been trying to find and use a variety of different ways and means to perfect Human-Computer Interaction (HCI) systems along with the development of computer science and information technology [61]. To make the machine understand the user's intention accurately and quickly, people have been investigating to discover and use a variety of different techniques and means to perfect HCI systems. Alternative controllers might employ head movement, facial expression, and muscular reactions surrounding the face as instruction sources [54].

Because of the demands of natural HMIs, lip reading, expression recognition, and lip movement synthesis, the challenge of quick, precise, and durable labial ministry placement is becoming increasingly critical. However, reliable lip recognition and localization are challenging due to differences in lip shape, lip color, and vulnerability to speech distortion, head movement, and lighting [61]. One of the major phases in the automatic lip-reading system is to locate the lip in video sequences. In wheelchair systems, lip contour extraction was a significant approach for HMI applications, such as lip reading and SR [62]. T. N. A Tengku Rozli implemented a control system based on image processing to identify different lip expressions to be able to produce control instructions that can be used to drive the wheelchairs as shown in Figure 17. T. N. A Tengku Rozli used a morphological processing technique to be able to extract the lips region, and then the recognized pattern will be an input for a classifier algorithm based on Artificial Neural Network (ANN) to produce the control instructions for a wheelchair. T. N. A Tengku Rozli could generate four different instructions from lip expressions that could be used to operate the wheelchair [54].

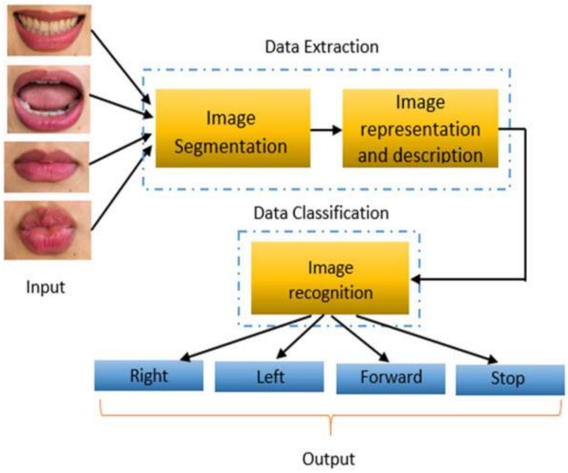


Figure 17: The flow of the image processing control used [54].

Intel sponsored OpenCV is an open-source computer vision library. OpenCV was created with an emphasis on real-time applications and computing efficiency. OpenCV is developed in C and is multi-core processor compatible [62]. The Smart Camera, or we can say it as a Gesture Cam, may be used for a variety of purposes, including video surveillance, security, HCI, and computer vision. User interface technology is an essential component of today's Information and Communications Technology (ICT) systems [55].

Face detection systems have been proposed in a variety of ways. The Haar-like features approach and the Adaboost Classifier technique are both thought to be effective methods for detecting faces [63]. Zhang-fang Hu could generate commands to operate a wheelchair by using a head gesture recognition approach using visual HMI. Zhang-fang Hu used an AdaBoost algorithm for lips detection to be able to recognize the face direction and convert it to orders that can be sent to the driver of the wheelchair [64]. ANN is also used to classify facial characteristics [54]. Principal Component Analysis (PCA) is used to aid in the detection of the mouth's shape [63]. While the Adaboost algorithm is a type of self-adaptation boosting method, the multi-weak learner is enhanced into a strong one using this approach [65].

3.1.2. Eye Tracking (Eye Gaze)

A control system that detects where the user is looking and turns or moves the wheelchair towards a target location can be implemented. As a result, eye tracking and gaze recognition technologies have arisen as a revolutionary machine interaction paradigm in which a user's gaze (pupil movements) is collected and transformed into actions without the user having to take any physical action [33]. It was first employed to examine people's mental activities by analyzing their eye movements in the early nineteenth century. Researchers looked for a link between psychology and eye movements by watching and documenting changes in gaze locations [59].

Eye tracking technology appears to be a promising technique for improving communication, movement, and independence in people with motor impairments [33]. Paraplegic individuals can use an eye movement-controlled wheelchair [59]. Jannatul Mawa Akanto has proposed a control system based on image processing techniques that detect the location of the user's eye pupil that can be used to control wheelchairs based on the coordinate system of pupil movement as shown in Figure 18. Jannatul Mawa Akanto used a Raspberry Pi board that contains the control program that is written in the Python language based on the OpenCV library for the detection of the location of the user's eye pupil [66].

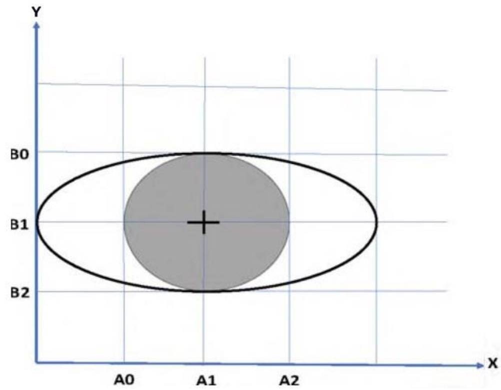


Figure 18: Pupil Movement Coordinate System [66].

The term "eye movement control" is no longer novel [59]. In 2007, a common web camera was installed on a Head-Mounted Display (HMD) to capture the user's face and transfer the video stream to a computer as the first method for operating a PW via eye movement. The computer analyses the camera footage, calculates the line-of-sight to determine where the user is looking, and then commands the PW to go to the desired place [33]. Farwa Jafar implemented a novel technique to operate wheelchairs based on eye movements by using low-cost components. She used the Keras model, which is based on deep learning and uses the transfer learning method for the classifier algorithm of the eyeball [67]. Some video-based tracking installations are head-mounted and may need a steady head, while others operate remotely and follow the head during motion [33].

Several scientific obstacles, such as the quality of eye gaze detection and tracking, the influence of ambient variables, and the substantial calibration necessary for an acceptable quality of detection or tracking, have hampered the widespread adoption of this technology [33]. Eye movement has three applications in HCI: eye control, increasing multi-channel interaction, and man-machine communication [59]. Eye trackers are effective at directing the mouse pointer on a computer screen while requiring no physical touch [33]. Aniwat Juhong achieved a control system using the user's eye movement to control appliances, operate a wheelchair, and communicate or ask for help from the caretaker by using a webcam installed on eyeglasses. Aniwat Juhong used eyeball movements for navigation and controlling a cursor on an implemented Graphical User Interface (GUI) on a Raspberry Pi screen, and the eye blink has been used for selection or entering a command in the GUI. The implemented GUI contains a control dashboard for operating a wheelchair, turning some appliances on and off, and a control panel that can be used to send SMS to the caretaker to know that the user needs help [68].

Eye tracking is a technique in which a researcher measures a person's eye movements to determine where they are looking at any one time as well as the sequence in which their eyes change from one spot to another using a camera to gather user pictures and assess user intent [57]. The needed CPU time is seldom investigated in eye movement algorithms [60]. Mohamad A. Eid introduced a novel control system for wheelchairs via eye-gaze with real-time navigation. The novel control system contains, besides the eye tracking control, a real-time algorithm for target identification, which is helpful in path planning to be able to navigate in a not-defined environment. Mohamad A. Eid used eye tracking glasses and implemented a calibration algorithm for eye tracking systems to reduce calibration overheads. To increase the safety of the user, his system is integrated with ultrasound and infrared sensors for the detection of obstacles that are near the wheelchair [33].

The Hough transform is the most widely used image processing approach for eyeball tracking. The Hough Transform is a feature extraction technique for isolating the features of a certain shape inside an image [69]. Eye tracking technology has advanced fast. The pupil is employed as a reference point for detecting eye movement and determining subject location [59].

The camera collects pictures of the eye for a given frame interval using the live acquisition approach. After that, the picture is transformed from RGB to grayscale for additional thresholding and processing. Only a portion of the face, such as the eye, is caught here, and the image may be processed immediately. By defining a threshold value, a binary picture of the eye is now formed. If a pixel's grayscale value exceeds the threshold, it is set to white(1), otherwise to black(0). Because it identifies strong edges well and yields a high Signal-to-Noise Ratio (SNR) ratio, the thresholding approach utilized here is a clever edge detector. To identify the pupil, the Hough transform is employed after edge detection to detect all the circles in the eye region and to discover the local maximum cells within a certain radius [69].

3.2. Speech Recognition (SR)

A SR has been researched extensively since the 1950s, but current advances in computer and telecommunications technology have significantly enhanced SR capabilities. A SR, in a practical sense, solves issues, increases productivity, and alters how we live. Voice control performs nearly all of the functions of a pushbutton. A SR is a difficult task; it includes a number of methods with high computing needs. Over the last few decades, a huge scientific community has been spurred by the range of applications of automated SR systems, such as for HCIs, telephony, or robotics. Many products and applications now use automatic voice recognition, from medical transcription to game control, from contact center conversation systems to information retrieval [70]. Junaid Ahmed developed software and hardware for an open-source kit using a voice command interface by using inexpensive components for wheelchairs. The system is low-cost, robust, and compact, and besides all these features, the recognition time is less than 500 ms [71].

People have lost their hands or legs, either temporarily or permanently, as a result of disease or an accident [2]. However, because speech is the most natural mode of communication, another option is to operate the wheelchair using your voice [4]. In such a case, a person who has lost their hand and leg needs a wheelchair that responds to their spoken commands [2]. Duojin Wang made a control system that included the software and hardware for a voice-operated wheelchair that can change the posture of the wheelchair. The user of his system can change the posture of the wheelchair from its normal position to laying or standing position by using his voice commands [72]. It is apparent that a wheelchair with SR is needed to assist people with physical disabilities who are unable to regulate their motions, particularly with their hands more independent [4]. Siamo University from Alcala, Spain created and utilized the first voice recognition-based wheelchair in 1999 [1]. Muhammad Tahir Qadri could recognize five words by using the Starter Kit (DSK), which is based on Digital Signal Processing (DSP). The five words which are responsible for giving the order to the wheelchair to move forward, move backward, rotate in the left direction, rotate the wheelchair in the right direction, and the stop command [70].

A SR, a current hot topic, is the ability of a computer or software to receive and interpret dictation or to understand and implement spoken commands. A SR has grown in popularity and use with the release of Artificial Intelligence (AI) and the appearance of intelligent assistants. Users can now communicate with new technological devices simply by speaking, eliminating the need to use their hands [73]. Nasrin Aktar could build a voice recognition system for handicapped people who are using wheelchairs by using Voice Module V3. The kit recognizes the voice of the user and converts the recognized voice commands to hexadecimal combinations. Nasrin added a Wi-Fi module to the kit to send the commands to the driving module of the wheelchair [1]. A SR approach is a computer tool capable of analyzing a human voice signal and detecting the information contained in it, translating it to text, or sending instructions that act on a process; in this instance, the system's on and off. To get an accurate interpretation of the received auditory message, it is important to analyze a collection of data drawn from several sources of knowledge, including syntactic, phonetic, pragmatic, lexical, acoustic, phonological, and semantic information [73].

Recognizing the speaker can make it easier to translate speech into systems that have been taught to recognize a particular person's voice, or it can be used to authenticate or validate a speaker's identity as part of a security procedure [73]. Nikunj Janak proposed a solution for handicapped people who have problems or get tired while using their upper limbs while operating a wheelchair by using voice commands. Nikunj has added a GPS and GSM module beside the voice recognition system to be able to monitor Alzheimer's patients and send their longitudes and latitudes while using their wheelchair [5].

3.3. Electroencephalography (EEG)

HMIs based on biological signals, particularly EEG HMIs, have recently shown tremendous promise in addressing this problem since they are noninvasive, affordable, and easy. BCIs are another term for EEG-based HMIs [74]. EEG-based BCIs have gotten a lot of press since they are noninvasive, easy, and economical. Wheelchair control is a significant application of EEG-based BCIs, which can enhance a handicapped user's QoL and independence. BCIs are devices that transform brain activity signals into commands for external devices. BCI systems are now finding it challenging to produce the various independent control signals required for multi-degree continuous control of a wheelchair [50]. Figure 19 shows the control schematic diagram of a brain-controlled system.

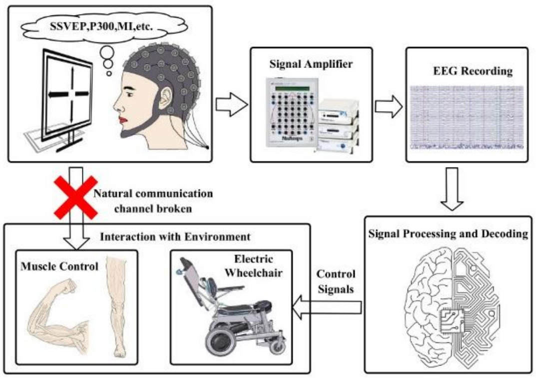


Figure 19: A brain-controlled system's control schematic diagram [75].

EEG-based HMI is a sort of BCI that uses brain signals (such as EEG) that are not generated by neuromuscular activity to transmit the user's intent. Event-Related Potentials (ERPs) e.g., P300 potential, mu/beta rhythm associated to MI, and SSVEPs are all common EEG patterns employed in BCIs [40]. Figure 20 shows some examples of EEG acquisition systems. Javeria Khan implemented a control system for wheelchairs by using EEG sensors to acquire SSVEP signals based on BCI. Javeria Khan used SSVEP signals due to the advantages of it, and because of that he could achieve an accuracy of 96% for offline control and 95% for run-time control. To make the wheelchair safer to use, sonar sensors and cameras have been integrated with the system for mapping the surrounding environment of the wheelchair and obstacle avoidance [76]. Xiaoyan Deng presented a novel shared controller that can be used for operating wheelchairs depending on a Bayesian approach using SSVEP signals based on BCI acquired by EEG sensors. A Bayesian shared control technique has been used to combine the automatic control and the brain-actuated control to improve the performance of an all-time continuous navigation wheelchair system. Using a Bayesian approach has provided an all-time shared control strategy and even system adaptation to the uncertain actions of human and machine agents [77].

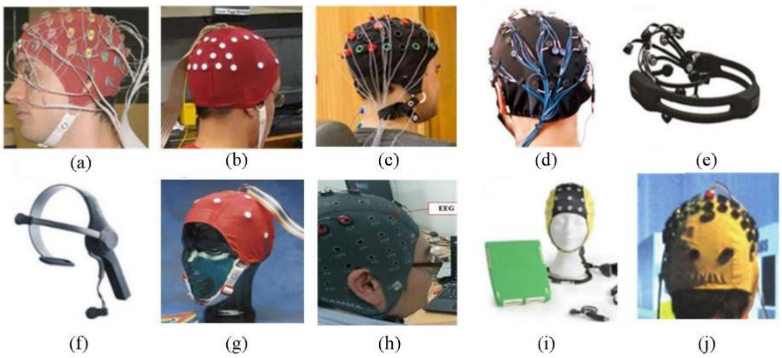


Figure 20: Example of an EEG acquisition system used in BCW applications: (a) Biosemi acquisition system, (b) BrainNet BNT-36, (c) gTec EEG system, (d) Neuroscan, (e) Epoch Emotiv headset, (f) NeuroSky Mindwave Mobile headset 2, (g) BIOPAC EEG system, (h) gTec EEG system, (i) EEGO EEG system, (j) gTec EEG system [75].

Li Junwei achieved a control system for driving wheelchairs based on EEG signals based on BCI. Li Junwei used two new techniques to analyze the acquired signals from EEG sensors; the first one is the Band Power (BP) technique, and the other is the RBF technique. The overall average result of the experimental work for the classification accuracy was 92.5 % used to generate the commands for driving a wheelchair [78]. For EEG-based wheelchair control, two types of protocols have been employed so far: synchronous and asynchronous. The potentials evoked by visual stimuli determine the EEG signals needed for synchronous control [50].

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

This synchronous protocol prevents the user from changing the wheelchair's direction or path while it travels to its destination. These synchronous protocols have great precision but slow reaction times; an effective control command is usually accomplished after several (e.g., 4) seconds. Asynchronous control protocols employ brain signals obtained from MI to allow a user to deliver an appropriate instruction (e.g., a change in direction) to a moving wheelchair or item. The user's mental processes (e.g., MI) influence these control commands [50].

To maneuver a wheelchair, multi-degree control is required. For example, to regulate the direction (left and right), speed (acceleration and deceleration), and start and stop the motion, numerous control signals are necessary. These control commands must also be generated precisely and rapidly. Several studies have proposed using multiple independent control signals based on BCIs. Hybrid BCIs with the capacity to mix numerous brain signals are intriguing because they can deliver several control commands concurrently or sequentially [50]. ZAINEB M. ALHAKEEM introduced an EEG system that produces commands that can be used for operating wheelchairs. She used non-brain source signals to be able to increase the number of commands generated from the EEG system-based BCI. ZAINEB M. ALHAKEEM produced five commands by using a classifier called a linear SVM for the detection of eye-blinks and jaw squeezing in EEG signals of the user to drive the wheelchair [79].

3.4. Electromyography (EMG)

Several researchers have used robotic and biomedical technology in rehabilitation systems. Many biomedical signals, such as EMG, have been used as one of the specialized interface ways that allow paraplegics and quadriplegics to operate assistive devices without the need for a joystick or keyboard [80]. Yuusuke Oonishi designed a new controller using EMG signals from the user's hand to drive PAW. In the past, they would do the same function to drive the PAW by using torque sensors. Yuusuke Oonishi built the control system on the estimation of the user's intention to move the wheelchair. When the user starts acting to move the handrims and the control system receives the EMG signals from the user's hand, the control system will generate the commands to move the wheelchair before the user propels the handrims [3]. EMG is a method for identifying the muscle's reaction to a nerve's electrical stimulation. The electrical activity of all the muscle-fibred motor unit action potentials induced by motion activity is the result of the EMG signal obtained from the skin surface surrounding muscle and joint locations [81].

EMG signals have been found to be useful in a variety of medical domains. Periodic monitoring of EMG signals can be used to diagnose disorders such as Huntington's disease, Myopathies, and Muscular Dystrophies, as well as to respond quickly to situations like heart attacks or strokes. The utilization of biosignals has recently paved the way for the development of muscle-computer interfaces in the HCI sector. EMG data gathered by sensors placed on superior limbs, in particular, has been utilized to operate devices using electric signals produced by the muscles [81]. Syed Faiz Ahmed implemented a control system to drive an electronic walker by using EMG signals to help disabled people navigate while standing. He used the EMG signals that were generated from the user's hand and can also operate the system by using an Android mobile phone through Bluetooth [82].

Many other EMG-based control approaches have recently been developed. Depending on whether or not the pattern classifier is utilized, they might be split into two categories. Giho Jang introduced using three EMG signals from the right and left zygomaticus major muscles and the right transversus menti muscle of the user's face for muscle-computer interface that can be used to drive wheelchairs. The developed system by Giho Jang has a good classifier algorithm that needs short preprocessing time, high recognition rate, and real-time continuous velocity control [80].

The EMG signals are directly used as control inputs of the robotic devices in non-pattern-based control techniques, while they have difficulty expanding the number of motion instructions [80]. Figure 21 shows the recommended number of channels that can be used with different applications while using EMG signals. Jörn Vogel used the muscular activity of the user's hand to control the wheelchair and the robotic arm that had been fixed to it to assist the user in daily activities. Jörn Vogel could establish a control algorithm based on a real-time operating system using EMG signals from the user to meet the real-time constraints required [83]. In pattern recognition-based control approaches, EMG signals are used to extract different motion instructions using classification techniques such as ANN, neuro-fuzzy, PCA, SVM, and Linear Discriminant Analysis (LDA)-based classifiers. Several classifiers might also adjust to the users' physiological fluctuations, while control schemes based on pattern recognition have some drawbacks, such as computing complexity and cost, as compared to non-pattern-based techniques. Nonetheless, pattern recognition-based control schemes have become more significant since they can handle more instructions than non-pattern-based techniques [80].

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

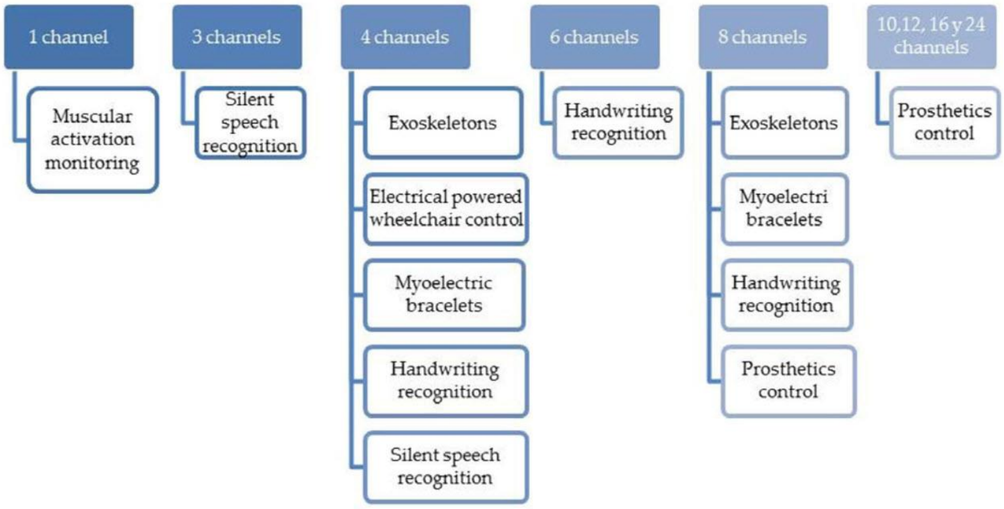


Figure 21: Recommended number of channels that can be used with different applications while using EMG signals [81].

The four primary steps of an EMG signal acquisition system while the first step is signal collection; the second stage is signal amplification; the third stage is signal filtering; and the last step in the operation is analog-to-digital conversion. According to its operating features, each step has particular needs. These specifications can be expressed in terms of the design characteristics required for EMG signal acquisition systems [81].

The SNR of surface EMG signals is poor. As a result, these signals are readily lost in the background noise. EMG sensors may generally record a maximum electric potential signal of 5 mV. As a result, in reality, these signals should be amplified (typically 500 to 2000 times) in order to be read by any ADC on the market [31]. Achmad Arifin could establish a control system for wheelchairs based on EMG signals generated from the Flexor Carpi Radialis muscles of the user's hands. Achmad Arifin used the EMG signals to generate the common commands that are used to drive the wheelchair and got a 93.75% accuracy rate of success during testing the system on a path [84].

3.5. Electrooculography (EOG)

Physical fatigue can quickly lead to Musculoskeletal Disorders (MSDs) like SCI, stroke, or paralysis, particularly in athletes who practice high-intensity training for lengthy periods of time every day [6]. Because the majority of people with muscular and neurological system impairments can still move their eyes, EOG is a good option for those who need to operate a wheelchair [16]. EOG allows both symptomatic and asymptomatic Parkinson's patients to drive a robotic wheelchair with their eyes [85] as shown in Figure 22.

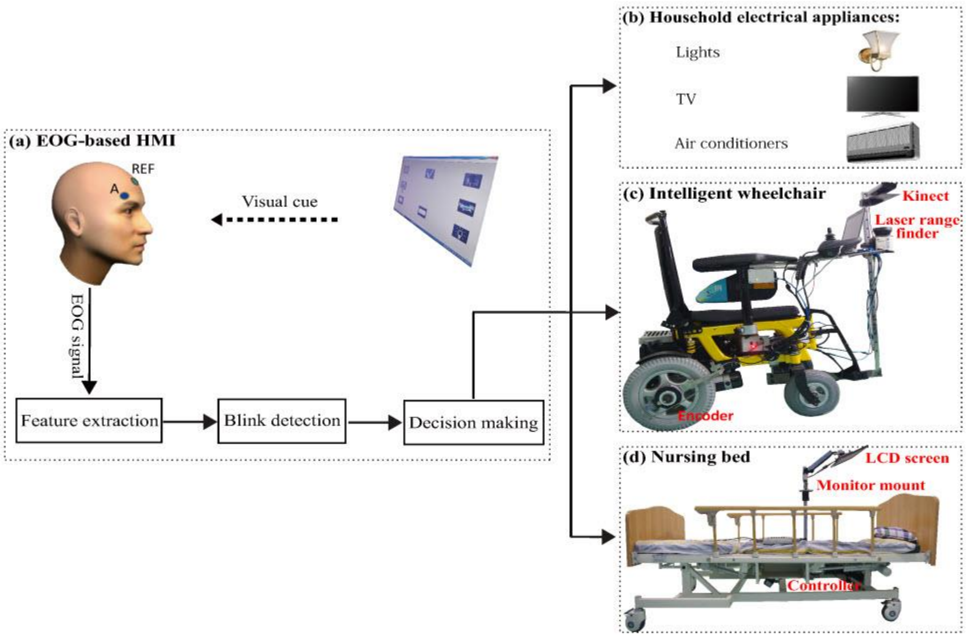


Figure 22: Some applications can be controlled using EOG signals [74].

Traditionally, most research relies on typical eye motions to produce control signals for HCI design, such as right, left, upright, downright, up, and down. Different patterns were created based on eye movement. The

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

generated patterns were transformed into control commands that were used to operate various paralyzed people's devices [86]. Biswajeet Champaty proposed a low-cost control system using EOG signals to classify eye blinks and movements to be used for driving wheelchairs. A novel algorithm has been implemented for classification, and all the commands that are used to drive the wheelchair have been sent wirelessly [87]. Various apps for neuro-disordered people have been created that use the EOG signal as a control signal to control and command various applications. The gadgets and programs listed below are some examples of how EOG signals may be used in daily life. Hospital alarm system, mouse cursor control, joystick control of mouse pointer position, Ultrasonic and Infrared Head Controller, eye recognizing system, wheelchair control, eye exercise recognizing system, myoelectric control system, eye writing recognition, mobile robot control, BCI, and tooth-click controller [86].

Non-manual HMIs have also been designed using EOG. Gaze, blink, wink, and frown are all common eye motions. All of these motions can provide a strong EOG with a high SNR. As a result, research has concentrated on using EOG-based HMIs to implement controls or communications [40]. The most basic biological signal derived from the human body is EOG. Eye blinking can also be employed to operate the wheelchair [16]. Qiyun Huang implemented a control system with 13 control commands based on the EOG signal that can be used to operate wheelchairs. The main idea of his control system is that there is a screen mounted on the wheelchair and has 13 flashing buttons, each of which flashes on in a pre-defined sequence, and the user can select any of them by blinking in sync with its flashes [40].

The dipole potential difference between the cornea and the retina generates EOG signals. The cornea is 20mV positive to the fundus of the eye, which includes the negatively charged retina [88]. This causes the electrical activity of the eye. The difference in potential can be affected by electrode contact area, electrode size, and incident light on the retina. Eye signals can range in potential from 0.05 mV to 3.5 mV; the difference in potential can be affected by electrode contact area, electrode size, and incident light on the retina. The positive pole of the eye is on the cornea, whereas the negative pole is on the retina. The utilization of signals for diverse applications is enabled via signal acquisition through electrodes connected to the subject's skin. For nearly 50 years, conventional electrodes such as wet gel and hydrogel have been the gold standard [85]. Gu Jialu studied using two-channel EOG-based HCI to generate a sequence of commands from the user's eye movements to control wheelchairs. The data has been collected by using golden plated electrodes from the vertical eye movement and also from the horizontal eye movement. Gu Jialu studied using ANN to analyze the extracted signals from the EOG system and convert them to a sequence of commands that can be used to control the wheelchair while he got an average classification accuracy of 90.72% [86].

Several studies have been conducted in recent years to build and develop HCI systems employing EOG with the aid of a digital amplifier and electrodes [86]. The EOG signals have been employed in a variety of SW for direction control, where the HCI is a key component; for example, human brain control of a PW using an EOG signal, which employs a closed loop feedback system with an HMI [88].

3.6. **Tongue Postures**

People who have high tetraplegia (C1-C4) can't use their limbs to do things like manage a computer, use a smartphone, or drive a wheelchair [89]. In the motor cortex of the human brain, tongue and mouth signals have the same level of importance as the signals of fingers and hands. As a result, they are capable of complex manipulation tasks by nature. The hypoglossal nerve connects the tongue to the brain, and it is often spared significant damage in SCIs. The tongue muscle, like the heart muscle, does not quickly become fatigued. Finally, the tongue may be accessed without invasive surgery and is unaffected by the posture of the rest of the body, which can be adjusted for optimal user comfort [34]. R. Chandra studied using two different types of antennas (a monopole and a loop antenna) while using the 2.45 GHz Industrial, Scientific and Medical (ISM) band to be mounted on the tongue to operate wheelchairs. R. Chandra could determine the position of the tongue by determining the link loss between the in-mouth antenna and an external antenna mounted on the wheelchair. R. Chandra found that using a T-shaped monopole antenna, or even using a rectangular loop antenna, is more suitable in size and even in performance when using the 2.45 GHz ISM band as an in-mouth device [90].

For the reasons stated above, a variety of Tongue-Computer Interfaces (TCIs) have been developed, including Tongue-Touch Keypad (TTK), Tongue Mouse, Tongue Point, and a new inductor-based device. These gadgets, on the other hand, necessitate large components within the mouth, which might obstruct the user's speech, swallowing, and respiration. TTK and Tongue Point both require tongue contact and pressure at the tip, which can cause tongue fatigue and discomfort over time. Jouse2 or Integra Mouse are examples of tongue-or mouth-operated joysticks. These systems may be used while the user is seated, and grabbing the mouth joystick requires a certain amount of head movement if the stick is not to be maintained constantly within the mouth, which can be painful [91]. Figure 23 shows the first type of Tongue Drive System (TDS).

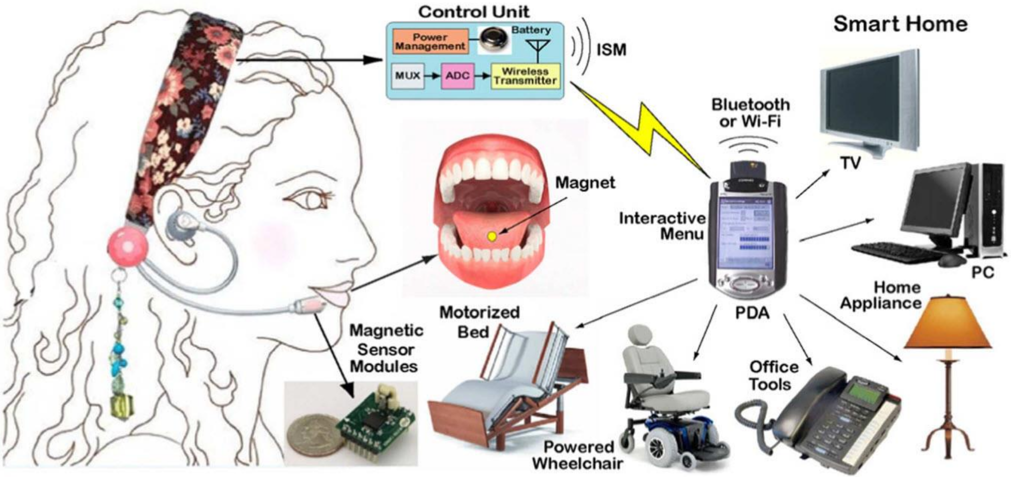


Figure 23: Block diagram of the eTDS [91].

The TDS was designed to add some advantages by enhancing the usability and functionality of a wearable AT and sending the commands from it wirelessly. The idea of TDS simply involves detecting a small piece of magnet that is fixed well with a special adhesive on the user's tongue by detecting its magnetic field by using a magnetic sensor and assigning it to a command [92]. It is freely accessible in the mouth while remaining hidden from view, providing the user with some privacy [93]. Ali Jafari proposed a low-power eTDS based on the user's voluntary tongue movements to control their Personal Computer (PC), smartphone, or even wheelchair. It consists of a wearable headset that contains magnetic sensors around the mouth that detect the position of a magnet stuck on the user's tongue and the control unit. Ali Jafari could increase the battery life by processing the raw data from the magnetic sensors with a Field-Programmable Gate Arrays (FPGA) processor at the control unit of the headset and converting it to user-defined commands, which leads to reducing the power consumption used by the transmitter [94].

Tissue adhesives can be used to temporarily adhere the magnet to the tongue. However, for long-term use, the user should get a tongue piercing with a magnetic tracer. Alternatively, the magnet can be implanted under the tongue mucosa after being coated with biocompatible materials like titanium or gold [34]. Magnetic sensors detect these changes, which are wirelessly relayed to a smartphone or a small PC, which may be worn by the user or linked to his or her vehicle [95]. Figure 24 shows the second type of TDS.

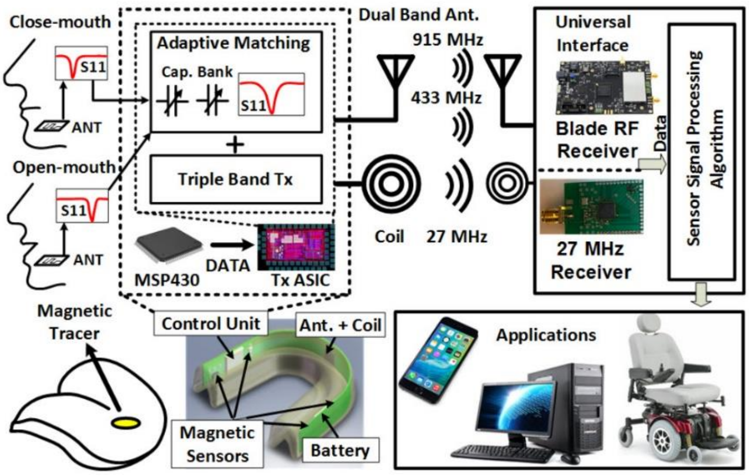
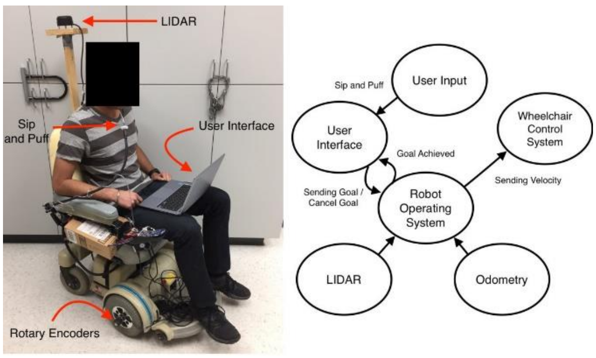


Figure 24: Block diagram of the iTDS [96].

Hangue Park implemented a new intraoral Tongue Drive System (iTDS) in the form of a dental retainer to track the position of a magnet tracer mounted on the tongue and send the collected data by using a dual-band transmitter to the controller to drive the wheelchair. The design of the implemented iTDS was very suitable for inside the mouth and contains a small battery to supply the system with power and it can be charged wirelessly to have a closed package of iTDS that is safe to be used inside the user's mouth [97]. A sensor signal processing algorithm on the small PC identifies sensor signals and turns them into user control instructions, which are subsequently wirelessly conveyed to the user's environment's target devices [34]. Fanpeng Kong invented the iTDS with an arch-shaped, and this iTDS is very suitable to be used inside the user's mouth as a dental retainer, which can be fixed inside the mouth onto the lower teeth. The package of the iTDS is hermetically sealed with special materials usually used inside the mouth, such as dental acrylic and Polydimethylsiloxane (PDMS). Fanpeng Kong used a flexible antenna with a band of 2.4 GHz with iTDS, which sends the signals to an external receiver. Fanpeng Kong could achieve a high transfer rate to make the system suitable for typing on PCs and smartphones [98]. To begin utilizing the TDS, users must first calibrate the system to eliminate Electromagnetic Interference (EMI) and then train the TDS by specifying the appropriate tongue locations in their mouth that they wish to connect with up to six distinct instructions. The tongue resting posture, which is usually connected with neutral instruction, is likewise detected by the TDS [99].

3.7. Sip-and-Puff (SnP) Switches

Individuals with serious injuries can use PW to regain mobility. The majority of Normal PWs include a joystick located on the armrest that is used to control the wheelchair's mobility. Due to reduced movement in their limbs, people with ALS, widely known as Lou Gehrig's illness, are unable to use ordinary PW. ALS is a neurodegenerative illness that affects the motor neurons that regulate muscular movement. As the disease develops, people with ALS lose fine motor function in their limbs, rendering them unable to use typical joystick-controlled PW. As a result, ALS patients are either immobile for lengthy periods of time or rely on others for mobility. The aging process causes a loss in motor function in senior adults, decreasing their autonomy and mobility. Most of the rich nations' populations are aging, whereas life expectancy in underdeveloped countries is rising due to improved healthcare and nutrition. As the global population ages, there will be greater demand for solutions to the problem of decreased mobility. Poor QoL is associated with less mobility and autonomy. Frustration, worry, and despair are all symptoms of limited mobility [100].



(a) (b)

Figure 25: Using SnP for controlling a wheelchair: (a) Wheelchair based on SnP controller, (b) A block diagram of the SnP control system for a wheelchair [100].

Individuals with severe impairments can gain some movement and liberty by using SnP-operated wheelchairs. SnP-operated wheelchairs, on the other hand, are inconvenient to use and cause tiredness and pain after continuous usage [100]. Chinemelu Ezeh studied using a probabilistic technique for mixing two trajectories, while the first one is the user's trajectory and the second one is the path planner's trajectory to improve using some interfaces for driving wheelchairs on a virtual wheelchair system. The first approach is using Probabilistic Shared Control (PSC), and the second approach is linear blending, while both of them are used for collision avoidance mechanisms. He found that using the PSC approach reduced collisions the most while operating the wheelchair by using a SnP switch [26]. Imad

SnP devices employ air pressure from the user's lips to create signals that hardware and software can decipher. These gadgets can be installed on a wheelchair or on the head using a headset [100]. This interface turns on two normally-opened switches. The first one shuts when the driver blows a puff, and the second one closes when a sip is produced. A digital signal is generated by a series of sips and puffs, which is processed by a controller to safely drive the wheelchair to the chosen path. Depending on the driver's ability and the environment in which the wheelchair is operated, other algorithms might be used [52].

Harkishan Singh Grewal introduced an autonomous wheelchair based on the SnP controller as shown in Figure 25. To make a low-cost solution, he used two Arduino boards, rotary encoders, and an open-source software integrated with a LIDAR unit, which is used for the autonomous navigation system, and a USB SnP device. The user can easily choose from a list the required destination by using a SnP device, and the wheelchair will achieve it while avoiding even moving obstacles. He could achieve good results from his experimental work [100].

Mougharbel illustrated the optimal adaptation results of the controller parameters for his system to reduce the effort while operating the wheelchair by using a SnP device for a given trajectory to follow or even for an unknown trajectory. He presented three different types of controllers to minimize the number of generated commands by using SnP devices to drive wheelchairs [52].

3.8. IMU Devices

Many people have lost control of their upper and lower limbs owing to quadriplegia, paralysis, or age-related side effects. Instead of utilizing a typical joystick control system, this sort of user requires unique control methods to utilize PW [101]. Individuals who have had damage at the C4 neurological level can breathe practically normally. Generally, they have the ability to move their necks and even their heads. For individuals with this sort of disability, a PW that demands neck motions is useful [102].

Various approaches can be employed to use head movement as a control for the wheelchair. Infrared and ultrasound devices were utilized as controllers to detect head movement. Other researchers utilized cameras to detect head gestures as a wheelchair interface. Many academics have recently proposed using the accelerometer, orientation device, and sensors as a controller for intelligent rehabilitation [101]. The wheelchair may be readily navigated by using head movement [53] as shown in Figure 26. Gesture recognition may give a more natural alternative.

Particularly in instances when standard methods of machine communication are impractical [103].

Figure 26: IMU with a head gesture for controlling wheelchairs [103].

Mohammed Faeik proposed a novel auto-calibrated head gesture for controlling wheelchairs by using two orientation detection units based on IMU sensors. The first IMU sensor reads the orientation of the wheelchair and considers it the reference of the system. It is used to counteract the variations in orientation caused by non-straight roadways and correct for the ramp's rising and decreasing speed using a speed compensation algorithm. The second IMU sensor is fixed on the head gesture to measure the Euler angles of the user for speed and direction control and uses an ARM Cortex M3 microcontroller in his system [101].

The IMU package, worn by the user in the form of a hat or other headgear, captures data on head motions [103]. The IMU, on the other hand, is an electronic device that uses a combination of an accelerometer sensor and a gyroscope sensor to capture and communicate data about the angular velocity and movement of a body. Guilherme Marins proposed an economic solution for controlling a wheelchair by capturing the movements of the user's head by using an IMU sensor. Guilherme used three techniques for data classification: the first one is Euclidean distance; the second one is Mahalanobis distance; and the third one is the ANN, and he used the Arduino Uno to collect the data from the IMU [102].

Such data may be used to determine the individual head's location and movement in relation to the directions of rotation Roll and Pitch [102]. The user's head tilts about the X and Y axes to identify the moving direction of the wheelchair. The controller does not employ head motions around the Z-axis to allow the user to move his head around without impacting the system's control [101].

It is also critical that gesture recognition be performed in near real-time, and because of this reason, the gesture recognition system may be used in situations where a machine is given orders. Normally, the gesture recognition algorithm generally consists of six steps: gathering data, preprocessing the collected data, feature extraction (pattern identification), comparison to a database of gesture patterns or templates, and the last step is decision making and final output. Ubeyed Mavus and Volkan Seze developed a SW that can be operated through a head gesture recognition system based on an IMU sensor. Their system is based on the Dynamic Time Warping (DTW) algorithm, and they used a new approach to get the optimum threshold values, and they got a percentage success rate of 85.68 percent. Depending on the methodology and the based algorithm, some of these stages can be avoided according to the designer's vision in some cases. A gesture that indicates a command to a machine should be complicated in general because a simple gesture might be executed mistakenly, resulting in less-than-ideal results at best and harmful conditions at worst [103].

3.9. Hybrid Control

People with motor illnesses like paraplegia and muscular dystrophy are unable to talk or move because their voluntary muscles are not controlled. The most common method is to use a MW. However, for seriously disabled people whose hand motor capability is significantly impaired, it has to be developed further by taking the user's condition into account in order to give a welfare robotic device. There are numerous techniques for regulating a wheelchair utilizing biological signals for this purpose, including EEG, EMG, and EOG [104]. Hybrid technologies enable impaired people to provide more meaningful and durable control signals by combining their MI brain processes with other functions [105]. The acquired results for feature extraction were compared to increase and enhance the classification accuracy [104]. When various modalities are incorporated into an HMI, it improves the interface's operational and controllability. The interface will be useful for integrating various communication modalities in a range of environments and scenarios. As a result, a variety of people with a variety of limitations can benefit from using this interface. A multi-modal HMI can give the best interface for operating a machine. It offers numerous potential techniques of control, and by combining them, it creates an excellent methodology for individuals. In other words, it opens a variety of possibilities for people with severe impairments who have limited control over their movements and actions [53].

In most circumstances, the majority of people who are suffering are conscious and have normal mental capacities. Furthermore, they can still move their eyes, therefore EOG is ideal for people who need to maneuver a wheelchair [104]. EOG signals are becoming increasingly used for controlling robots. Furthermore, the EOG signal is a fairly weak bioelectricity signal that is frequently disturbed by the external environment, and because of the disturbance of the invalid EOG signal, the EOG signal's accuracy is poor, and the recognition rate is low. The high rate of detection of eye movement signals compensates for the poor rate of recognition of eye signals. Tongbo Li discussed a hybrid system that can be used to control wheelchairs to help handicapped people based on combining the EOG signals with signals from a vision system for eye tracking. Tongbo Li found that combining the EOG signals with signals from the eye tracker system could improve the accuracy of the classification recognition, which reflects on the final decision of the controller [106].

Several articles focus on constructing prototypes that use EOG signals to regulate wheelchair activity or simply eye movement. The wheelchair can function with a variety of input techniques such as gestures, speech, and manual control in general, but only with patients with mild limitations. Marlene Alejandra implemented a hybrid control system by using EOG signals and the commands from a SR system to operate a wheelchair. Marlene used the EOG signal from the user's eye to control the direction of the wheelchair, while the commands from the voice signal are used to start and stop the wheelchair's movement. Those who do not have or have extremely limited movement, on the other hand, should be able to regulate their surroundings via signals such as EEG, EOG, or both [73]. Simon Dahl investigated using a machine learning technique for a hybrid combined signals from an EOG system and an EEG system for remotely controlling wheelchairs. The final results of Simon Dahl show that combining the EOG signals with EEG signals can improve the accuracy of the final decision of the system to control a wheelchair, and this can decrease the error while driving a wheelchair [105]. Mohamed Djeha proposed a recognition method for patterns based on the combination of EEG and EOG signals to operate wheelchairs. He used the combined signal to classify the movements of the user's eye into four directions to get more accuracy in the detection of the eye direction, and used the final output to move the wheelchair. Mohamed used ANN to perform the classification and got a percentage of 93 for a classification accuracy rate [104].

The fundamental issue in developing a real-time system, such as one to operate a wheelchair, is to create a computationally fast structure that can discern between the intended actions of its operator. Recent technological advancements have produced hybrid BCI systems that combine EEG with other physiological signals, such as EOG, EMG, and so on, to increase the accuracy and speed of typical single-modality based BCI systems [105]. Ludovico Minati studied creating a hybrid control system by using four different sources of signal to control a robot arm mounted on a wheelchair with 5+1 DOF. Ludovico combined EOG signals, EMG signals from the jaw, EEG signals, and signals generated from head movement by using a Consumer-Grade wearable device to control the assistive robotic arm. His wearable device is sending the collected signals to the controller wirelessly [47]. As a result, novel HCIs are required. The HMI approach based on bioelectricity signals is a hotspot in the present HCI technology research and development and provides a large area for the creation of novel HCI technologies [106].

4.SAFETY ASPECTS DURING USING WHEELCHAIRS

Many people who depend on wheelchairs for movement are unable to transition from their wheelchairs to car seats and must travel while sitting in their wheelchairs. Most wheelchairs aren't built to withstand the kinds of forces that occur in car accidents. The traits that make wheelchairs user-friendly are often the same ones that make wheelchairs unsuitable for effective safe sitting on buses or vans. Ultra-light wheelchairs, for example, may not have brake systems or armrests. It is difficult to steady the wheelchair occupant during transit due to the lack of brake systems and armrests [9]. Po-Ju Chang presented an intelligent Anti-lock Braking System (ABS) for PW to reduce the braking distance, enhance riding safety, and reduce the braking time just by a click from the user to the stop command. The ABS of Po-Ju Chang include an algorithm based on adaptive fuzzy-neural inference and an intelligent system for friction coefficient estimation. Based on the data from the gyroscope and the estimation of the friction coefficient of the road, the ABS can calculate the parameters of the wheelchair and adjust the control signal for the braking system [107].

Nationally, about 1500 people who use wheelchairs are wounded or killed in wheelchair transportation incidents, based on the National Highway Traffic Safety Administration. The bulk of these occurrences, however, happened when the person was seated in his or her wheelchair during transportation. Vans were involved in 48% of the incidents, while passenger automobiles were involved in 40%. Incidents happened less often (12%) when people in wheelchairs were transported by bus. There is a need for greater research to develop technology and therapies that will make transporting people who remain sitting in their wheelchairs throughout travel safer [9].

People with severe impairments make up a significant percentage of wheelchair users. According to studies, people have a tough time learning to navigate a standard PW; up to 10% have great difficulties or find it impossible to use one; another 10% find steering duties impossible without help; and 40% have problems with steering tasks [49]. JOELLE PINEAU developed a technological tool using a machine learning approach for the automatic classification and detection of not-safe events while using PW. JOELLE PINEAU has recorded the real-time data of the 3D acceleration of the PW for the trials of over 35 different activities of the users by using a data-logging platform to use it for a classification algorithm. JOELLE PINEAU could detect unsafe events under varied operating conditions with a percentage of 98 [108].

People who are unfamiliar with wheelchairs benefit from new wheelchair user training. This training assists in the development of skills to limit the risk of accidents, particularly in public settings like streets, schools, workplaces, hospitals, malls, and supermarkets [109]. A navigation system is also used to avoid obstacles identified by an array of sensors [50]. Bing-Fei Wu designed a safety controller module that detects uphill and ramps to be used with PWs to avoid the user's misjudgment of slope angle, which reflects on the wheelchair speed with ramps. Bing-Fei Wu used a deep learning algorithm for slope angle classification and got a higher recognition rate than other known models, with an accuracy of 97.1%. The module calculates the safe speed automatically in real-time for the wheelchair based on the detected slope angle by the classifier [110].

A human must feel at ease utilizing a SW as an extension of themselves in order for it to be helpful. In the construction and usage of powered devices, ethical, privacy, and physical safety considerations must be carefully examined. In order to avoid accidents and give a more customized experience, a SW should be responsive to each person's particular demands [42]. Improved signal processing, alternate input systems, and attaching sensors to the wheelchair to identify impediments in the environment all show promise in enabling more people with autonomous mobility [7]. Louise Devigne proposed a wearable vibrotactile haptic to help the users of PW who have problems with their driving abilities to decrease the danger to themselves while driving and even to the surrounding environment. The ultrasonic sensors surrounding the wheelchair send their signals to the wearable vibrotactile haptics, which consists of four vibrotactile actuators evenly spaced between each other to provide the user with navigation information during driving. The wearable vibrotactile haptics can be easily adapted to different limbs, and the experimental work showed that the collisions were reduced by 49% [111].

Additionally, there is a significant risk of mechanical overuse. Long-term wheelchair usage has a number of drawbacks, including not just pain and discomfort but also the danger of leading a physically sedentary lifestyle. As a result, severe secondary impairments (obesity, diabetes, and cardiovascular issues) may develop as a result [8]. Elhassan Mohamed studied the effect of the vibration of the PW during use and its impact on the user's body. Elhassan Mohamed built his study according to the vibration limits of the international standards of ISO-2631. Elhassan Mohamed found after his investigation that the comfort and user's health are affected by terrain surfaces and user's weight, and the health risk for lightweight users is greater than for heavyweight users while they can dampen low vibration [112]. Other types of physical activity, as well as the awareness of training, rehabilitation, active living, and sports on health and wellbeing, may play a preventative role here, as may wheelchair quality, including ergonomic fit to the person. The International Classification of Functioning, Disability and Health (ICF) model, a stress–strain–work volume model, and the ergonomics model, which links human-activity-assistive technology, are all important to the principles, structure, and goals of mobility research [8].

5.CONCLUSION

If we could decrease the number of unused people in each institution due to their physical disability and support them with suitable AT, that would lead to an increase in the performance of the institution. Encouraging disabled people's activities and roles in our society, as well as supporting them and raising their morale, can all help to improve their health. Using the traditional types of wheelchairs and AT increases the difficulty of the patient's healing process and can lead to a worsening of the illness. Using SWs is the new generation of using PWs while giving the user different operation opportunities to help him/her during the tasks of daily life. Helping disabled people by inventing new AT is a good thing to do, but considering their safety is an important point that should be taken into consideration during this.

An AI algorithm is a very common type of algorithm that is used with classifiers to identify the intention of the user while using SW. Each disability type may be appropriate for some number of SW operation techniques. The high degree of disability is decreasing the number of operation techniques that can be used with the SW. Using EEG signals with BCI could be the most suitable type of operation technique for most users' disabilities. While EEG signals can be used with many types of disabilities, they need sophisticated kinds of signal filters and high-speed processors to run AI classifiers. In addition, the EEG-based systems need a lot of training to use, and it is not that easy to use them. With all the technologies that we have and all the knowledge that we know, achieving a comfortable and suitable assistive device at a suitable price while considering the safety of the user and the surrounding environment will remain a difficult equation.

Credit Authorship Contribution Statement

M. Sayed: Investigation, Conceptualization, Methodology, Resources, Roles/Writing - original draft.
T. Mansour: Project administration, Methodology, Resources, Supervision, Writing - review & editing.
A. El Domiaty: Supervision, Writing - review & editing.
MG Mousa: Supervision, Writing - review & editing.
Ali A. S.: Resources, Supervision, Writing - review & editing.

Declaration of competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Reference

[1] Nasrin Aktar; Israt Jahan; and Bijoya Lala, "Voice Recognition based Intelligent Wheelchair and GPS Tracking System", International Conference on Electrical, Computer and Communication Engineering (ECCE), 2019, PP. 7130-7140.

[2] Akshay B. Satpe; Mr. S. V. Khobragade; and Dr. S. L. Nalbalwar, "Wheelchair Control Using Hand Movement & Voice with Obstacle Avoidance", Second International Conference on Intelligent Computing and Control Systems (ICICCS), 2018, PP. 1175-1178.

[3] Yuusuke Oonishi; Sehoon Oh; and Yoichi Hori, "A New Control Method for Power-Assisted Wheelchair Based on the Surface Myoelectric Signal", IEEE Transactions on Industrial Electronics, 2010, Vol. 57, PP. 3191-3196.

[4] Sumet Umchid; Pitchaya Limhaprasert; and Sitthichai Chumsoongnern, "Voice Controlled Automatic Wheelchair", 11th Biomedical Engineering International Conference (BMEiCON), 2018, PP. 1-5.

[5] Nikunj Janak Gor; and Prof. Amutha Jeyakumar, "Voice Controlled Motorized Wheelchair with Real Time Location Monitoring", International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), 2017, PP. 1163-1167.

[6] Wenfeng Li; Xinyun Hu; and Raffaele Gravina, "A Neuro-Fuzzy Fatigue-Tracking and Classification System for Wheelchair Users", IEEE Access, 2017, Vol. 5, PP. 19420-19431.

[7] Rory A. Cooper; Rosemarie Cooper; and Michael L. Boninger, "Trends and Issues in Wheelchair Technologies", Assistive Technology: The Official Journal of RESNA, 2008, Vol. 20, PP. 61-72.

[8] Lucas H.V. van der Woude; Sonja de Groot; and Thomas W.J. Janssen, "Manual wheelchairs: Research and innovation in rehabilitation, sports, daily life and health", Medical Engineering and Physics, 2006, Vol. 28, PP. 905-915.

[9] Rory A. Cooper; Michael L. Boninger; and Donald M. Spaeth, "Engineering Better Wheelchairs to Enhance Community Participation", IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, 2006, Vol. 14, PP. 438-455.

[10] Peter Cody Hunt; Michael L. Boninger; and Rory A. Cooper, "Demographic and Socioeconomic Factors Associated With Disparity in Wheelchair Customizability Among People With Traumatic Spinal Cord Injury", Archives of Physical Medicine and Rehabilitation, 2004, Vol. 85, PP. 1859-1864.

[11] Adrian Danila, "Model Identification for Assisted Tennis Training of the Sportsmen with Kinetic Disabilities", International Conference and Exposition on Electrical and Power Engineering (EPE), 2016, PP. 281-286.

[12] B.M. Sayed; Mohamed Fanni; and Abdelfatah M. Mohamed, "Design of a Novel all Terrains Wearable Vehicle", 3rd International Conference on Information Science and Control Engineering (ICISCE), 2016, PP. 923-928.

[13] Weijun Tao; Junyi Xu ;and Tao Liu, "Electric-powered wheelchair with stair-climbing ability", International Journal of Advanced Robotic Systems, 2017, Vol. 14, PP. 1-13.

[14] HyungTae Kim; GwanYeon Kim; and JoonHmm Lee, "A Motorized and Easy-docking Wheelchair Drive for Persons with Lower-Limb Disabilities", IEEE International Conference on Industrial Technology (ICIT), 2015, PP. 52-56.

[15] Claire L. Flemmer; and Rory C. Flemmer, "A review of manual wheelchairs", Disability and Rehabilitation: Assistive Technology, 2016, Vol. 11, PP. 177–187.

[16] Ilham A.E. Zaeni; Arizal Ismoyo Wijanarko; and Ahsan Walad, "Applying Neural Network on Wheelchair Control System using Eye Blink and Movement Command", 3rd International Conference on Information and Communications Technology (ICOIACT), 2020, PP. 416-420.

[17] Liping Qi; James Wakeling; and Simon Grange, "Patterns of Shoulder Muscle Coordination Vary Between Wheelchair Propulsion Techniques", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2014, Vol. 22, PP. 559-566.

[18] Rick de Klerk; Riemer Jakobs K. Vegter; and Vicky L. Goosey-Tolfrey, "Measuring Handrim Wheelchair Propulsion in the Lab: A Critical Analysis of Stationary Ergometers", IEEE Reviews in Biomedical Engineering, 2019, Vol. 13, PP. 199-211.

[19] Burton M; Subic A; Mazur M; and Leary M, "Systematic Design Customization of Sport Wheelchairs using the Taguchi Method", Procedia Engineering, 2010, Vol. 2, PP. 2659-2665.

[20] Jonathan Duvall; Benjamin Gebrosky; and Jeffrey Ruffing, "Design of an adjustable wheelchair for table tennis participation", Disability and Rehabilitation, 2021, Vol. 16, PP. 425-431.

[21] Kai Nakamura; and Kazuyuki Kojima, "Development of Trajectory Tracking System for Wheelchair Basketball", IEEE 7th Global Conference on Consumer Electronics (GCCE), 2018, PP. 490-491.

[22] L. Lei; T.M. Guan; and L.J. Shan, "Structure Design and FE Analysis of a Newly Basketball Wheelchair", Advanced Materials Research, 2008, Vol. 44-46, PP. 685-690.

[23] Pedro Forte; Pedro G. Morouço; and Tiago Barbosa, "CFD Analysis of Head and Helmet Aerodynamic Drag to Wheelchair Racing", 1st International Conference on Technology and Innovation in Sports, Health and Wellbeing (TISHW), 2016, PP. 1-6.

[24] Giuseppe Quaglia; Elvio Bonisoli; and Paride Cavallone, "The Design of a New Manual Wheelchair for Sport", Machines, 2019, Vol. 7, PP. 1-14.

[25] M. Khalili; G. Kryt; and H. F. M. Van der Loos, "A Comparison Between Conventional and User-Intention-Based Adaptive Pushrim-Activated Power-Assisted Wheelchairs", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2021, Vol. 29, PP. 2511-2520.

[26] Chinemelu Ezeh; Pete Trautman; and Catherine Holloway, "Comparing shared control approaches for alternative interfaces: a wheelchair simulator experiment", IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2017, PP. 93-98.

[27] Jesse Leaman; and Hung Manh La, "A Comprehensive Review of Smart Wheelchairs: Past, Present and Future", IEEE Transactions on Human-Machine Systems, 2017, Vol. 47, PP. 486-499.

[28] Yu Munakata; Aki Tanaka; and Masayoshi Wada, "A Five-wheel Wheelchair with an Active-caster Drive System", IEEE 13th International Conference on Rehabilitation Robotics (ICORR), 2013, PP. 1-6.

[29] Deepak Kumar; Reetu Malhotra; and S. R. Sharma, "Design and Construction of a Smart Wheelchair", Procedia Computer Science, 2020, Vol. 172, PP. 302-307.

[30] Hirokazu Seki; and Naoki Tanohata, "Fuzzy Control for Electric Power-Assisted Wheelchair Driving on Disturbance Roads", IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 2012, Vol. 42, PP. 1624-1632.

[31] Mohsen Jafarzadeh; Daniel Curtiss Hussey; and Yonas Tadesse, "Deep learning approach to control of prosthetic hands with electromyography signals", IEEE International Symposium on Measurement and Control in Robotics (ISMCR), 2019, PP. 1-11.

[32] J. Andrés Sandoval-Bringas; Mónica Carreño-León; and Miguel Angel Espiritu, "Design of a multifunctional

electronic module adaptable to a motorized wheelchair for people with motor disabilities", International Conference on Inclusive Technologies and Education (CONTIE), 2019, PP. 201-204.

[33] Mohamad A. Eid; Nikolas Giakoumidis; and Abdulmotaleb El Saddik, "A Novel Eye-Gaze-Controlled Wheelchair System for Navigating Unknown Environments: Case Study With a Person With ALS", IEEE Access, 2016, Vol. 4, PP. 558-573.

[34] Xueliang Huo; and Maysam Ghovanloo, "Using Unconstrained Tongue Motion as an Alternative Control Mechanism for Wheeled Mobility", IEEE Transactions on Biomedical Engineering, 2009, Vol. 56, PP. 1719-1726.

[35] Yang Yu; Zongtan Zhou; and Yadong Liu, "Self-Paced Operation of a Wheelchair based on a Hybrid Brain-Computer Interface Combining Motor Imagery and P300 potential", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2017, Vol. 25, PP. 1-10.

[36] Yang Yu; Yadong Liu; and Jun Jiang, "An Asynchronous Control Paradigm Based on Sequential Motor Imagery and Its Application in Wheelchair Navigation", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2018, Vol. 26, PP. 2367-2375.

[37] Han-Yen Yu; Jiann-Jone Chen; and Chung-Hsien Kuo, "The Human-Environment Interface Design with a Vision Assistance Module for a Smart Wheelchair", International Conference on Advanced Robotics and Intelligent Systems (ARIS), 2014, PP. 91-96.

[38] D. H. De La Iglesia; G. Villarrubia; and J.F. De Paz, "Design And Implementation Of A Low-Cost Universal Control For Intelligent Electric Wheelchairs", IEEE Latin America Transactions, 2018, Vol. 16, PP. 1328-1336.

[39] Aadesh Guru Bhakt Dandamudi; Dhage Navaneet Rao; and Vijay Padmakar Aravilli, "Single Channel Electromyography Controlled Wheelchair Implemented in Virtual Instrumentation", 3rd International Conference on Computing Methodologies and Communication (ICCMC), 2019, PP. 1040-1045.

[40] Qiyun Huang; Shenghong He; and Qihong Wang, "An EOG-Based Human-Machine Interface for Wheelchair Control", IEEE Transactions on Biomedical Engineering, 2018, Vol. 65, PP. 2023-2032.

[41] Gao Nuo; Zhai Wenwen; and Lu Shouyin, "Asynchronous Brain-computer Interface Intelligent Wheelchair System Based on Alpha Wave and SSVEP EEG Signals", IEEE 4th International Conference on Signal and Image Processing, 2019, PP. 611-616.

[42] Zainab Alibhai; Taylor Burreson; and Matthew Stiller, "A Human-Computer Interface For Smart Wheelchair Control Using Forearm EMG Signals", 3rd International Conference on Data Intelligence and Security (ICDIS), 2020, PP. 34-39.

[43] Yeontaek Jung; Yoonjae Kim; and Woo Hyung Lee, "Path Planning Algorithm for an Autonomous Electric Wheelchair in Hospitals", IEEE Access, 2020, Vol. 8, PP. 208199-208213.

[44] Yudi Zhu; Qiaoling Meng; and Hongliu Yu, "Wheelchair Automatic Docking Method for Body-Separated Nursing Bed Based on Grid Map", IEEE Access, 2021, Vol. 9, PP. 79549-79561.

[45] André A. Jorge; Luis A. M. Riascos; and Paulo E. Miyagi, "Modelling and Controlling of a Hybrid Motorized Wheelchair on Flat and Inclined Surfaces", 6th International Conference on Control, Decision and Information Technologies (CoDIT), 2019, PP. 750-755.

[46] Teodiano Freire Bastos-Filho; Fernando Auat Cheein; and Sandra Mara Torres Müller, "Towards a New Modality-Independent Interface for a Robotic Wheelchair", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2014, Vol. 22, PP. 567-584.

[47] Ludovico Minati; Natsue Yoshimura; and Yasuharu Koike, "Hybrid Control of a Vision-Guided Robot Arm by EOG, EMG, EEG Biosignals and Head Movement Acquired via a Consumer-Grade Wearable Device", IEEE Access, 2016, Vol. 4, PP. 9528-9541.

[48] Xin Chen; Yang Yu; and Jingsheng Tang, "Clinical Validation of BCI-Controlled Wheelchairs in Subjects With Severe Spinal Cord Injury", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2022, Vol. 30, PP. 579-589.

[49] Dorian Cojocaru; Liviu Florin Manta; and Ionel Cristinel Vladu, "Using an Eye Gaze New Combined Approach to Control a Wheelchair Movement", 23rd International Conference on System Theory, Control and Computing (ICSTCC), 2019, PP. 626-631.

[50] Jinyi Long; Yuanqing Li; and Hongtao Wang, "A Hybrid Brain Computer Interface to Control the Direction and Speed of a Simulated or Real Wheelchair", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2012, Vol. 20, PP. 720-729.

[51] Nurul Fadzlina Jamin; Nor Maniha Abdul Ghani; and Zuwairie Ibrahim, "Movable Payload on Various Conditions of Two-Wheeled Double Links Wheelchair Stability Control Using Enhanced Interval Type-2 Fuzzy Logic", IEEE Access, 2020, Vol. 8, PP. 87676-87694.

[52] Imad Mougharbel; Racha El-Hajj; and Houda Ghamlouch, "Comparative study on Different Adaptation Approaches Concerning a Sip and Puff Controller for a Powered Wheelchair", Science and Information Conference, 2013, PP. 1-7.

[53] Saifuddin Mahmud; Xiangxu Lin; and Jong-Hoon Kim, "A Multi-Modal Human Machine Interface for Controlling a Smart Wheelchair", 7th Conference on Systems, Process and Control (ICSPC), 2019, PP. 10-13.

[54] T. N. A Tengku Rozli; S. Z. Yahaya; and M. K. Osman, "Lip Expressions Based Control via Image Processing", 9th IEEE International Conference on Control System, Computing and Engineering (ICCSCE), 2019, PP. 193-198.

[55] Rushikesh T. Bankar; and Suresh S. Salankar, "Head Gesture Recognition System Using Gesture Cam", Fifth International Conference on Communication Systems and Network Technologies, 2015, PP. 535-538.

[56] Thierry Luhandjula; Karim Djouani; and Yskandar Hamam, "A hand-based visual intent recognition algorithm for wheelchair motion", 3rd International Conference on Human System Interaction, 2010, PP. 749-756.

[57] Shyam Narayan Patel; and V. Prakash, "Autonomous Camera based Eye Controlled Wheelchair system using

Raspberry-Pi", International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), 2015, PP. 1-6.
[58] Noriyuki Kawarazaki; and Masahiro Yamaoka, "Face Tracking Control System for Wheelchair with Depth Image Sensor", 13th International Conference on Control Automation Robotics & Vision (ICARCV), 2014, PP. 781-786.
[59] Dianchun Bai; Zhicheng Liu; and Qing Hu, "Design of an Eye Movement-Controlled Wheelchair Using Kalman Filter Algorithm", IEEE International Conference on Information and Automation (ICIA), 2016, PP. 1664-1668.
[60] Fatma Ben Taher; Nader Ben Amor; and Mohamed Jallouli, "An extended Eye Movement Tracker system for an electric wheelchair movement control", IEEE/ACS 12th International Conference of Computer Systems and Applications (AICCSA), 2015, PP. 1-7.
[61] Zhang-fang Hu; and Yu-jiao Ding, "Lips Detection Based On Skin Model And Adaboost Algorithm In The Human-Wheelchair Interaction", International Conference of Information Technology, Computer Engineering and Management Sciences, 2011, PP. 169-172.
[62] Zhang Yi; Liu Quan-jie; and Li Yan-hua, "Intelligent Wheelchair Multi-modal Human-machine Interfaces in Lip Contour Extraction Based on PMM", IEEE International Conference on Robotics and Biomimetics (ROBIO), 2009, PP. 2108-2113.
[63] Ngo Ba Viet; Nguyen Thanh Hai; and Ngo Van Thuyen, "Hands-Free Control of an Electric Wheelchair Using Face Behaviors", International Conference on System Science and Engineering (ICSSE), 2017, PP. 29-33.
[64] Zhang-fang Hu; Lin Li; and Yuan Luo, "A Novel Intelligent Wheelchair Control Approach Based On Head Gesture Recognition", International Conference on Computer Application and System Modeling (ICCASM 2010), 2010, PP. 159-163.
[65] Yuan Luo; Zhang-fang Hu; and Lin li yizhang, "A novel head gesture recognition means in the human-wheelchair interaction", International Conference on Computer Application and System Modeling (ICCASM 2010), 2010, PP. 555-559.
[66] Jannatul Mawa Akanto; Md. Kamrul Islam; and Ajijul Hakim, "Eye Pupil Controlled Transport Riding Wheelchair", 2nd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST), 2021, PP. 413-417.
[67] Farwa Jafar; Syeda Farwa Fatima; and Hafiza Ramsha Mushtaq, "Eye Controlled Wheelchair Using Transfer Learning", International Symposium on Recent Advances in Electrical Engineering (RAEE), 2019, PP. 1-5.
[68] Aniwat Juhong; T. Treebupachatsakul; and C. Pintavirooj, "Smart eye-tracking system", International Workshop on Advanced Image Technology (IWAIT), 2018, PP. 1-4.
[69] Adarsh Rajesh; and Megha Mantur, "Eyeball Gesture Controlled Automatic Wheelchair Using Deep Learning", IEEE Region 10 Humanitarian Technology Conference (R10-HTC), 2017, PP. 387-391.
[70] Muhammad Tahir Qadri; and Syed Ashfaque Ahmed, "Voice Controlled Wheelchair Using DSK TMS320C6711", International Conference on Signal Acquisition and Processing, 2009, PP. 217-220.
[71] Junaid Ahmed Ansari; Arasi Sathyamurthy; and Ramesh Balasubramanyam, "An Open Voice Command Interface Kit", IEEE Transactions on Human-Machine Systems, 2016, Vol. 46, PP. 1-7.
[72] Duojin Wang; and Hongliu Yu, "Development of the Control System of a Voice-Operated Wheelchair with Multi-posture Characteristics", 2nd Asia-Pacific Conference on Intelligent Robot Systems (ACIRS), 2017, PP. 151-155.
[73] Marlene Alejandra Domínguez Sucres; Sarahí Soledad Franco Pérez; and Ilse Valeria Gómez Zavala, "EOG-based interface and speech recognition for wheelchair control", IEEE International Conference on Engineering Veracruz (ICEV), 2019, PP. 1-4.
[74] Rui Zhang; Shenghong He; and Xinghua Yang, "An EOG-based Human Machine Interface to Control a Smart Home Environment for Patients with Severe Spinal Cord Injuries", IEEE Transactions on Biomedical Engineering, 2019, Vol. 66, PP. 89-100.
[75] Hongtao Wang; Fan Yan; and Tao Xu, "Brain-Controlled Wheelchair Review: From Wet Electrode to Dry Electrode, From Single Modal to Hybrid Modal, From Synchronous to Asynchronous", IEEE Access, 2021, Vol. 9, PP. 55920-55938.
[76] Javeria Khan; Muhammad Usman Ghani Khan; and Razi Iqbal, "Robust Multi-sensor Fusion for the Development of EEG Controlled Vehicle", IEEE Sensors Journal, 2021, Vol. 21, PP. 15635-15642.
[77] Xiaoyan Deng; Zhu Liang Yu; and Canguang Lin, "A Bayesian Shared Control Approach for Wheelchair Robot With Brain Machine Interface", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2020, Vol. 28, PP. 328-338.
[78] Li Junwei; S. Ramkumar; and G. Emayavaramban, "BRAIN COMPUTER INTERFACE FOR NEURODEGENERATIVE PERSON USING ELECTROENCEPHALOGRAM", IEEE Access, 2018, Vol. 7, PP. 2439-2452.
[79] ZAINEB M. ALHAKEEM; RAMZY S. ALI; and RAED A. ABD-ALHAMEED, "Wheelchair Free Hands Navigation Using Robust DWT_AR Features Extraction Method With Muscle Brain Signals", IEEE Access, 2020, Vol. 8, PP. 64266-64277.
[80] Giho Jang; Junghoon Kim; and Sungon Lee, "EMG-Based Continuous Control Scheme with Simple Classifier for Electric-Powered Wheelchair", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, 2016, Vol. 63, PP. 3695-3705.
[81] Bernabe Rodríguez-Tapia; Israel Soto; and Daniela M. Martínez, "Myoelectric Interfaces and Related Applications: Current State of EMG Signal Processing—A Systematic Review", IEEE Access, 2020, Vol. 8, PP. 7792-7805.
[82] Syed Faiz Ahmed; Athar Ali; M. Kamran Joyo; and M. Rehan, "Mobility Assistance Robot for disabled persons using Electromyography(EMG) Sensor", IEEE International Conference on Innovative Research and Development (ICIRD), 2018, PP. 1-5.

How to Cite this Article:
Sayed, M. et al. (2024) 'Wheelchair Review: Types, Operation Techniques, and Safety Aspects', Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.

[83] Jörn Vogel; Annette Hagengruber; and Maged Iskandar, "EDAN: An EMG-controlled Daily Assistant to Help People With Physical Disabilities", IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2021, PP. 4183-4190.

[84] I Wayan Nudra Bajantika Pradivta; Achmad Arifin; and Fauzan Arrofiqi, "Design of Myoelectric Control Command of Electric Wheelchair as Personal Mobility for Disabled Person", International Biomedical Instrumentation and Technology Conference (IBITeC), 2019, PP. 112-117.

[85] Saswat Mishra; Yongkuk Lee; Dong Sup Lee; and Woon-Hong Yeo, "Fractal-Structured, Wearable Soft Sensors for Control of a Robotic Wheelchair via Electrooculograms", IEEE 67th Electronic Components and Technology Conference (ECTC), 2017, PP. 212-217.

[86] Gu Jialu; S. Ramkumar; G. Emayavaramban; and M. Thilagaraj, "Offline Analysis for Designing Electrooculogram Based Human Computer Interface Control for Paralyzed Patients", IEEE Access, 2018, Vol. 6, PP. 79151-79161.

[87] Biswajeet Champaty; Jobin Jose; Kunal Pal; and Thirugnanam A., "Development of EOG Based Human Machine Interface control System for Motorized Wheelchair", Annual International Conference on Emerging Research Areas: Magnetics, Machines and Drives (AICERA/iCMMD), 2014, PP. 1-7.

[88] Konica Kuntal; Indrajit Banerjee; and Prabha P Lakshmi, "Design of Wheelchair based on Electrooculography", International Conference on Communication and Signal Processing (ICCSP), 2020, PP. 0632-0636.

[89] Md Nazmus Sahadat; Nordine Sebkhi; and David Anderson, "Optimization of Tongue Gesture Processing Algorithm for Standalone Multimodal Tongue Drive System", IEEE Sensors Journal, 2019, Vol. 19, PP. 2704-2712.

[90] R. Chandra; and A. J. Johansson, "Antennas and Propagation for In-Mouth Tongue Controlled Devices in Wireless Body Area Networks", IEEE Antennas and Wireless Propagation Letters, 2014, Vol. 14, PP. 1518-1521.

[91] Xueliang Huo; Jia Wang; and Maysam Ghovanloo, "A Magneto-Inductive Sensor Based Wireless Tongue-Computer Interface", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2008, Vol. 16, PP. 497-504.

[92] Jeonghee Kim; Hangue Park; and Joy Bruce, "Assessment of the Tongue-Drive System using a Computer, a Smartphone, and a Powered-Wheelchair by People with Tetraplegia", IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2016, Vol. 24, PP. 68-78.

[93] Behnaz Yousefi; Xueliang Huo; and Jeonghee Kim, "Quantitative and Comparative Assessment of Learning in a Tongue-Operated Computer Input Device—Part II: Navigation Tasks", IEEE Transactions on Information Technology in Biomedicine, 2012, Vol. 16, PP. 633-643.

[94] Ali Jafari; Nathanael Buswell; and Maysam Ghovanloo, "A Low-Power Wearable Stand-Alone Tongue Drive System for People With Severe Disabilities", IEEE Transactions on Biomedical Circuits and Systems, 2018, Vol. 12, PP. 58-67.

[95] Md Nazmus Sahadat; Shreyas Dighe; and Fatima Islam, "An Independent Tongue-Operated Assistive System for both Access and Mobility", IEEE Sensors Journal, 2018, Vol. 18, PP. 9401-9409.

[96] Fanpeng Kong; Muhammad Zada; and Hyoungsuk Yoo, "Adaptive Matching Transmitter with Dual-Band Antenna for Intraoral Tongue Drive System", IEEE Transactions on Biomedical Circuits and Systems, 2018, Vol. 12, PP. 1279-1288.

[97] Hangue Park; Mehdi Kiani; and Hyung-Min Lee, "A Wireless Magnetoresistive Sensing System for an Intraoral Tongue-Computer Interface", IEEE Transactions on Biomedical Circuits and Systems, 2012, Vol. 6, PP. 571-585.

[98] Fanpeng Kong; Md. Nazmus Sahadat; and Maysam Ghovanloo, "A Standalone Intraoral Tongue-Controlled Computer Interface for People with Tetraplegia", IEEE Transactions on Biomedical Circuits and Systems, 2019, Vol. 13, PP. 848-857.

[99] Jeonghee Kim; Xueliang Huo; and Julia Minocha, "Evaluation of a Smartphone Platform as a Wireless Interface Between Tongue Drive System and Electric-Powered Wheelchairs", IEEE Transactions on Biomedical Engineering, 2012, Vol. 59, PP. 1787-1796.

[100] Harkishan Singh Grewal; Aaron Matthews; and Richard Tea, "Sip-and-Puff Autonomous Wheelchair for Individuals with Severe Disabilities", 9th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 2018, PP. 705-710.

[101] Mohammed Faeik Ruzaij; Sebastian Neubert; and Norbert Stoll, "Auto Calibrated Head Orientation Controller for Robotic-Wheelchair Using MEMS Sensors and Embedded Technologies", IEEE Sensors Applications Symposium (SAS), 2016, PP. 1-6.

[102] Guilherme Marins; Diego Carvalho; and André Marcato, "Development of a Control System for Electric Wheelchairs based on Head Movements", Intelligent Systems Conference (IntelliSys), 2017, PP. 996-1001.

[103] Ubeyde Mavuş; and Volkan Sezer, "Head Gesture Recognition via Dynamic Time Warping and Threshold Optimization", IEEE Conference on Cognitive and Computational Aspects of Situation Management (CogSIMA), 2017, PP. 1-7.

[104] Mohamed Djeha; Fazia Sbargoud; and Mohamed Guiatni, "A Combined EEG and EOG Signals Based Wheelchair Control in Virtual Environment", 5th International Conference on Electrical Engineering - Boumerdes (ICEE-B), 2017, PP. 1-6.

[105] Simon Dahl Thorsager Olesen; Rig Das; and Mathias Dizon Olsson, "Hybrid EEG-EOG-based BCI system for Vehicle Control", 9th International Winter Conference on Brain-Computer Interface (BCI), 2021, PP. 1-6.

[106] Tongbo Li; Junyou Yang; and Dianchun Bai, "A New Directional Intention Identification Approach for Intelligent Wheelchair Based on Fusion of EOG Signal and Eye Movement Signal", IEEE International

Conference on Intelligence and Safety for Robotics (ISR), 2018, PP. 470-474.

[107] Bing-Fei Wu; Po-Ju Chang; and Yung-Shin Chen, "An Intelligent Wheelchair Anti-lock Braking System Design with Friction Coefficient Estimation", IEEE Access, 2018, Vol. 6, PP. 73686-73701.

[108] JOELLE PINEAU; ATHENA K. MOGHADDAM; and HIU KIM YUEN; PHILIPPE S. ARCHAMBAULT, "Automatic Detection and Classification of Unsafe Events During Power Wheelchair Use", IEEE Journal of Translational Engineering in Health and Medicine, 2014, Vol. 2, PP. 1-9.

[109] Yuri Motta Lopes Rodrigues Silva; Walter Charles Sousa Seiffert Simões; and Eduardo Lázaro Martins Naves, "Teleoperation Training Environment for New Users of Electric Powered Wheelchairs Based on Multiple Driving Methods", IEEE Access, 2018, Vol. 6, PP. 55099-55111.

[110] Bing-Fei Wu; Yung-Shin Chen; and Ching-Wei Huang, "An Uphill Safety Controller with Deep Learningbased Ramp Detection for Intelligent Wheelchairs", IEEE Access, 2018, Vol. 6, PP. 28356 - 28371.

[111] Louise Devigne; Marco Aggravi; and Morgane Bivaud, "Power wheelchair navigation assistance using wearable vibrotactile haptics", IEEE Transactions on Haptics, 2020, Vol. 13, PP. 52-58.

[112] Elhassan Mohamed; Konstantinos Sirlantzis; and Gareth Howells, "Investigation of Vibration and User Comfort for Powered Wheelchairs", IEEE Sensors Letters, 2022, Vol. 6, PP.

How to Cite this Article:

Sayed, M. et al. (2024) ‘Wheelchair Review: Types, Operation Techniques, and Safety Aspects’, Energy and Environmental Science Journal, 2(1), pp. 1–26. doi:10.21608/sceee.2024.266762.1016.