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SHORT PAPER

Electronic device adaptable to motorized wheelchair as smart navigation system

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Abstract

Technological development offers new opportunities for people with disabilities, to improve their quality of life and increase their inclusion in society. Motor disability is an alteration that affects, at different levels, the movement or manipulation of a person. This paper presents the design and construction of the second version of an electronic device adaptable to a motorized wheelchair that serves as an intelligent navigation system. The first version of the electronic device only allowed for control of the wheelchair through head movements and voice commands. In this new version, the previous functions were improved and two new functions were incorporated. Muscle flexion and muscle contraction increase the options to control a motorized wheelchair by people with greater limitation of movement. The tests carried out demonstrate the viability of the prototype.

Keywords Disability · motor disability · motorized wheelchair

1 Introduction

A disability is a limitation or deficiency that affects the way some people interact and participate in daily life. This condition is considered a complex phenomenon because it involves individuals in isolation and also considers their interaction with the environment where they live. People with the same type of disability can be affected in different ways and some disabilities may be hidden or difficult to notice [19]. There are many types of disabilities, such as those that affect vision, movement, thinking, remembering, learning, communicating, hearing, mental health, and social relationships [12]. In recent years, concern for the human rights of the most vulnerable groups and the growing trend of medium- and long-term demographic aging have brought greater attention to people with disabilities [10]. Difficulties related to mobility alter the functions of movement as well as limit personal and social development. This disability usually requires the help of another person or some instrument (wheelchair, walker, etc.) or prosthesis to carry out activities of daily life. It also requires an accessible environment to achieve social inclusion [45, 20].

Motor disability is a life condition that affects the control and movement of the body. There are several problems that result from motor disability, including uncontrolled movements, coordination difficulties, limited reach, reduced force, unintelligible speech, difficulty with fine and gross motor skills, and poor accessibility to the physical environment [22]. This disability occurs when there are alterations in the muscles, bones, joints, spinal cord, or the motor area of the brain. Often the disability is not noticeable; in other cases it requires special supports such as braces, a cane, crutches, a walker or wheelchair, an orthosis or prosthesis. It is estimated that 15% of the population, approximately one billion people worldwide, live with a disability [45]. In Mexico, according to INEGI data, 6.4% of the country's population (7.65 million people) reported having at least one disability [20, 40]. The most frequent difficulty among the population with disabilities is related to mobility, since 58%

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of people in this population group experience limited walking or movement [20]. There are no official statistics about spinal cord injuries specifically, although it is known that they belong in this category. These are serious injuries that cause a loss of motor and sensory function due to damage to the nerve structures of the spinal cord. They can also cause fatigue and weakness in the arms and legs. It is necessary to help patients diagnosed with spinal cord injuries to carry out basic activities of daily life, which have personal, social, and economic impact for patients and their families [27].

The development of new technologies focused on disability is of vital importance. The use of an instrument, device or software provides individuals with some autonomy when carrying out their activities, thus increasing inclusion in society and improving their quality of life. According to statistics from the World Health Organization (WHO), in the majority of low- and middle-income countries, only between 5% and 15% of people who need support devices and technologies have access to them. This is attributable to poor production and high costs [30]. The number of people who need the help of a device to move is increasing continuously. The investments made by commercial enterprises for the production of materials, both hardware and software, are minimal; public or private institutions must take care of them [7].

Much research related to the design of wheelchairs or devices that help the mobility of disabled people is based on the generation of mathematical models to design automatic control systems [2, 33] and [3]. Some research goes a little further by modeling systems that allow a patient to be in a vertical position [38]. Other research proposes designs that can detect obstacles, rotate 360 degrees, perform functions from the owner 's voice sensor [14, 9], or help compensate for the limitations of disabled people [13]. Many people who use a wheelchair cannot use their hands, which hinders their ability to control a motorized wheelchair. Because conventional wheelchairs lack universality, several custom prototypes have been designed to cater to different capabilities. Various researchers [5] [26] have proposed using voice-based control systems. Other research proposes a control system based on facial expressions [35] or eye movements [34, 32, [16]. The research works of [18, 15, 29, 23, 21, 46] report the use of motorized wheelchair control systems through head movements. Some research projects [8] [37] focus on the development of a control system based on EOG to drive a wheelchair model. The electrooculogram (EOG) signal is one of the most commonly studied signals due to the appearance of defined signal patterns. The work reported in [17] mentions an electric wheelchair controlled by electromyography (EMG) which is placed on the arm muscles. The arm muscle signal has an electric potential difference that is read by EMG sensors. Subsequently, the data are converted from analog to digital by Arduino.

In most cases, designers assume that disabled people require a "robotic-advanced" device in order to develop emotionally, cognitively and socially. These types of assumptions have caused various elements to be coupled to the redesign of a conventional wheelchair, which has generated high-cost products to which few people have access. This is especially true in Mexico where there is a high proportion of people with disabilities in the low socioeconomic and educational strata (44.6% stratum I and 35.2% stratum II) [6, 41].

Motorized wheelchairs are designed for the personal use of individuals who cannot walk or have reduced mobility. They have sufficient cognitive, physical, and visual capabilities to control the vehicle safely, both outdoors and indoors. Motorized wheelchairs consist of five elements: the battery that provides a power source, two motors that drive the wheelchair, the transmission and brake system, the control circuit and power that commands the motors, and the joystick which allows the user to direct the wheelchair [36, 11]. The majority of motorized wheelchairs have to be imported from different manufacturers without after-sales service, and lack technical information and spare parts for their maintenance. Conventional wheelchairs with motors have a control that requires a physical effort that not all users can perform. An example is users who cannot move their upper limbs or do so with difficulty. The robotic wheelchair is a motorized commercial wheelchair that has been equipped with computers and sensors. The wheelchair has two electric DC motors that drive the two rear wheels (traction wheels). The two freely moving front wheels allow the chair to rotate. There are currently various prototype wheelchairs in development for people with spinal cord injuries [24, 44], but the use of techniques for motion capture and speech recognition as a whole are not widely used in these types of projects. These techniques do not work properly due to the amount of noise that comes from being in a real and complex environment.

In order to contribute toward activities that improve the quality of life for people with disabilities and encourage social inclusion, the second version of a prototype of a low-cost adaptive electronic device has been developed. It provides direct control over a motorized wheelchair by voice commands, head tilts, muscle movements, and/or arm flexing. The first version of an electronic device adapted to a motorized wheelchair allowed a person with a motor disability to direct a wheelchair by means of head tilts detected on an accelerometer implanted in a headset, and/or through voice commands using a mobile application developed for devices that have the Android operating system [39].

2 Materials

This project was developed in the laboratory of the Group for Research and Development of Inclusive Technologies and Educational Innovation (GIDTIITEC), at the Universidad Autónoma de Baja California Sur (UABCS), méxico. For the development of the prototype, a commercial motorized wheelchair, model powerchair from the powercar brand was used. The wheelchair has two electric motors that drive the two rear wheels. Free-moving front wheels allowed the wheelchair to rotate. The maximum speed of the wheelchair is 6 km / hr forward and 3.5 km / hr in reverse. For the construction of the prototype we used:

- *Three arduino UNO board* based on the Atmega328P microcontroller. Each board has 14 digital input / output pins (of which 6 can be used with PWM), 6 analog inputs, a 16Mhz crystal, USB connection, power jack connector, terminals for ICSP connection and a reset button [4];
- *A MX2125 accelerometer,* a low cost, dual axis thermal accelerometer capable of measuring inclination, acceleration, rotation and vibration with a range of + -2 g [31];
- *A 2.2 "(5.588cm) long Flex Sensor,* with its resistivity changing when flexed. It is used to measure the angle of rotation in joints for robotic, biometric or user interface applications [42];
- *A myoelectric muscle sensor* that measures, filters, rectifies, and amplifies the electrical activity of a muscle and produces an analog signal that can be easily read by a microcontroller [43];
- *A HC-05 Bluetooth Module.* The module is ideal to use in all kinds of projects where a reliable and easy-to-use wireless connection is required. It is configured using AT commands and can work in both master and slave mode [25].

3 Methods

Figure 1 shows the general idea of how an Electronic Device Adaptable(EDA) works. The device is adapted to a motorized wheelchair so that it can be controlled by people with different physical movement limitations. EDA contemplates control by voice, head movements, muscle flexions, and muscle contractions. A multiplexer was designed where the four individual circuits designed for each EDA function were concentrated. This multiplexer is responsible for controlling the various inputs and generating a single output to control the wheelchair. It also has an on/off switch that controls the motor of the wheelchair.

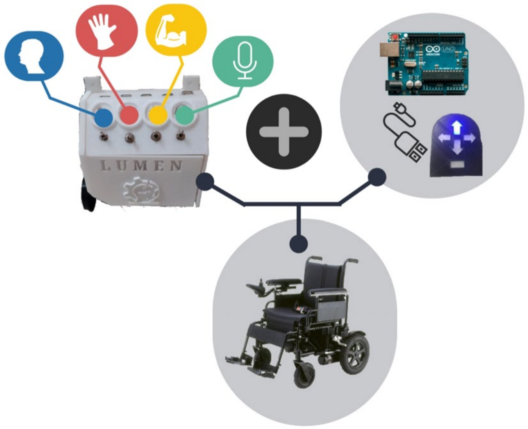

Fig. 1 Functional diagram of the Electronic Device Adaptable

3.1 Head movements

An MX2125 accelerometer, which is based on two axes, is used for control through movements of the head. It is capable of measuring angles of rotation, collisions, acceleration, rotation and vibrations in a range of up to +/- 2 g. The first Arduino UNO board, was connected to bluetooth HC-05 on digital bridge 0 and 1, which are TX and RX. The bluetooth was connected to the current (5V) and negative (GND) ports. The accelerometer was also connected on the same Arduino (MPU 6050). There is a USB input for the use of the accelerometer. Finally, a switch connected to the Arduino was included in the port. This can be seen in Fig. 2, where the connection scheme is shown.

3.2 Muscle flexions

For control through flexions, a Flex sensor was used that measures the amount of deflection or bending. On the second Arduino UNO board, the Flex sensor was connected to the analog port pin A0 to the current (5V) and the negative (GND) port. The navigation light system that is connected to the multiplexer was also connected. This can be seen in Fig. 2, where the connection scheme is shown.

3.3 Muscle contractions

For control through muscle movements a myoelectric muscle sensor was used. It measures, filters, rectifies, and amplifies the electrical activity of a muscle and produces an analogous signal. In the third Arduino UNO board the myoelectric sensor was connected. The connections were the same as in the Flex sensor, with the analog port pin A0 to the current

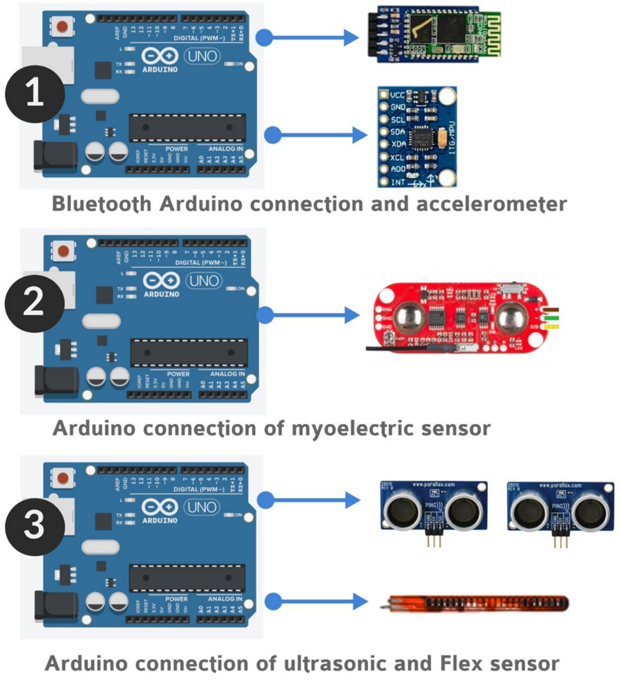

Fig. 2 Arduino connection diagrams

(5V) and the negative (GND) port. The navigation system was also connected to the multiplexer in the same way. This can be seen in Fig. 2, where the connection scheme is shown.

3.4 Control by voice

To achieve communication with the multifunctional electronic module through voice commands, a mobile application was designed, and a Bluetooth module HC-05 was incorporated. The mobile application can also be used as a navigation system. Upon entry, the user can see the arrows indicating the direction in which the wheelchair can move. The user is also able to see the option of voice command and can select the control mode of the wheelchair by voice or by navigation system. The interface of the mobile application can be seen in Fig. 3, left.

3.5 Navigation light system

To control the wheelchair through muscle movements and flexions, a navigation light system was incorporated. It can be mounted on the front of the wheelchair. The system includes five movement lights: forward, left, backward, right, and stop. The operation of the navigation light system is cyclical, illuminating each of the options for a second and allowing the user to select their displacement using the Flex sensor or the myoelectric sensor. Figure 3 (right) shows the navigation light system.

Figure 4 shows the block diagram of the complete prototype. The user generates the signals according to the way the wheelchair will be controlled. In the case of the accelerometer, the control signal can be entered directly since it is operated with digital levels. In the case of voice control, the mobile application transfers the instructions directly to the microcontroller. For the flex sensor and the myoelectric sensor, instructions are transmitted by the luminous navigation system. The microcontroller generates the necessary sequences to control the motors through a power stage powered by 12V 45Ah batteries that are built into the wheelchair. The system is self-regulating through the user who combines the control actions according to the direction desired. Figure 5 shows photographs taken during the development of the prototype.

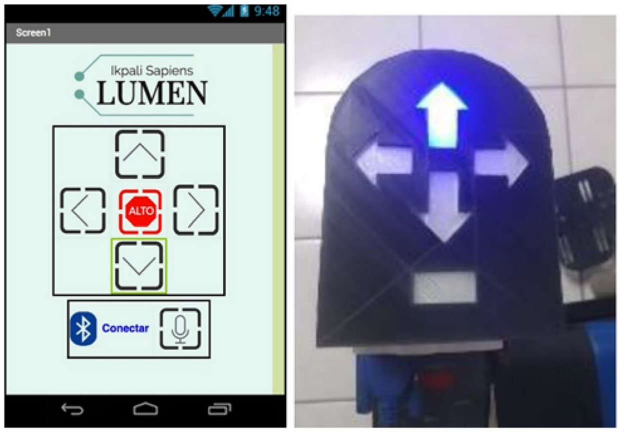

Fig. 3 App and navigation system

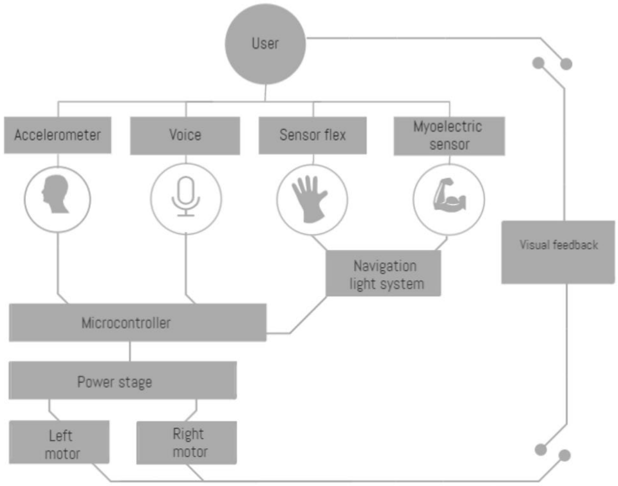

Fig. 4 Prototype block diagram

Fig. 5 Moments of work for the development of EDA

Fig. 6 Electronic Device Adaptable

4 Results

Figure 6 shows the completed EDA prototype, which can be attached to any side or the lower area of the wheelchair.

With the EDA attached to the motorized wheelchair, various tests were carried out in order to verify the operation of the control system.The participants received written information about the study and were asked to give their written consent to be included. The study received ethical approval from the Ethics Committee of the Research Group for the Development of Inclusive Technologies and Educational Innovation (GIDTIITEC), which belongs to the Academic Department of Computer Systems of the Universidad Autónoma de Baja California Sur. The study had the participation of ten volunteers, who had no experience with motorized wheelchairs, or the sensors used in the prototype. Depending on the mode selected for wheelchair control, the switches were activated. Preliminary tests were performed for each of the implemented functions.

Table 1 Response test results using head movement

Head movement	Control command	Correct	Accuracy (%)
Left	Left turn	9	90
Right	Right turn	9	90
Up	Back movement	9	90
Down	Forward movement	10	100
Average Accuracy		92.5%	

Table 2 Response test results using muscle flexions

Control command	Correct	Incorrect	Accuracy (%)
Left turn	9	1	90
Right turn	8	2	80
Back movement	8	2	80
Forward movement	9	1	90
Average Accuracy		85%	

1. Head movements. Ten (10) users participated in head movement detection tests. The EDA was able to capture signals from the head movements registered by the accelerometer, process them, and execute the wheelchair travel orders. The head tilt control worked as expected. Users made the corresponding turns by tilting their heads to the right or left. When users tilt their heads forward or backward the wheelchair moved accordingly. While the head was kept straight, the wheelchair stopped moving. The test performed with the accelerometer is shown on the lower right corner of Fig. 7.

   Table 1 shows test results using head movements.
2. Muscle flexions. The EDA was able to capture signals from the flexing of fingers registered by the flex sensor, process them, and execute movement orders through the light navigation system. The light navigation system begins to cycle through each of the available options. When the light illuminates the desired movement option, users flex their finger to start the wheelchair with the

Table 3 Response test results using muscle contractions

Control command	Correct	Incorrect	Accuracy (%)
Left turn	9	1	90
Right turn	8	2	80
Back movement	8	2	80
Forward movement	7	3	70
Average Accuracy		80%	

Table 4 Response test results using voice command

Voice command	Correct	Incorrect	Accuracy (%)
Left	10	0	100
Right	10	0	100
Go	10	0	100
Reverse	9	1	90
Stop	10	0	100
Average Accuracy		98%	

illuminated option. They must keep it flexed until they want to stop the movement of the wheelchair. The test performed with the flex sensor is shown in the upper left corner of Fig. 7.

Table 2 shows test results using flex finger movement.

3. Muscle contractions. The EDA was able to capture signals from the contraction of arm muscles registered by the myoelectric muscle sensor, process them, and exercise the wheelchair travel commands through the light navigation system. The light navigation system begins to cycle through each of the available options. When the light illuminates the desired movement option, the user makes a muscle contraction to start the wheelchair with the illuminated option, and must keep the muscle contracted until they want to stop the movement of the wheelchair. The test performed with the myoelectric muscle sesnsor is shown in the photo in the upper right corner of Fig. 7.

   Table 3 shows test results using muscle contractions.
4. Voice control. The EDA was able to capture the signals from the voice commands registered by the mobile application, processed them, and executed the wheelchair travel orders. The voice control responded correctly to the different voices of the people who used the wheelchair. The test performed with the mobile device is showin in the photo on the lower left corner of Fig. 7.

   Table 4 shows test results using voice command.
5. Light navigation system. The EDA was able to capture the signals coming from the navigation control system by lights activated by flexing or contracting muscles, process them, and executed the wheelchair travel orders.

Table 5 Security system test results

Mode selected	Correct	Incorrect	Accuracy (%)
Head movement	10	0	100
Muscle flexions	10	0	100
Muscle contractions	10	0	100
Voice command	10	0	100
Average Accuracy		100%	

Fig. 7 Functional tests EDA

A precision parameter is used to evaluate the performance of the selected mode to control the movement of the wheelchair. In the mode for detecting the user's head movement, accuracy is the overall success rate when the user makes a particular head movement and the system responds with the corresponding control commands on the wheelchair. The results of the response test, presented in Table 1, show that the success rate of a particular head movement with average precision is 92.5%. In muscle flexions mode, precision is the overall success rate when the user selects a particular movement through finger flex and the system responds with the corresponding control commands on the wheelchair. The results of the response test, presented in Table 2, show that the success rate in flexing muscles with average precision is 85%. In muscle contraction mode, precision is the overall success rate when the user through muscle contractions selects a particular movement and the system responds with the corresponding control commands on the wheelchair. The results of the response test, presented in Table 3, show that the success rate in contracting muscles with average precision is 80%. In voice control mode, precision is the overall success rate when the user through voice commands selects a particular movement and the system responds with the corresponding control commands on the wheelchair. The results of the response test, presented in Table 4, show that the success rate in voice control with average precision is 98%.

For safety reasons, an automatic stop mechanism was installed on the wheelchair. As part of the safety mechanism, two HC-SR04 ultrasonic sensors were installed in the wheelchair to detect unevenness or the presence of an object that obstructs traffic in those areas where there is not a good angle of vision. Taking a reverse movement as an example, when one of these sensors is activated a signal is sent to the microcontroller and the motors are stopped immediately. In order to verify the operation of the security mechanism, various tests were carried out to detect obstacles, steps and unevenness in the four implemented modalities. In all cases the system worked correctly, as can be seen in Table 5.

5 Conclusions

According to UN data, 80% of people with disabilities in the world live below the poverty line [28]. A study carried out by the Adecco and Keysight Foundation shows that approximately 55% of people with disabilities continue to encounter barriers to using conventional technological tools, and most of these barriers are economic [1]. For this reason, it is essential to develop accessible technology for low-income people.

This paper presented the design and construction of an electronic device adaptable to a motorized wheelchair, serving as a navigation system.The tests carried out demonstrate the viability of the prototype. This prototype, unlike other similar devices, was developed with very little investment, making it low-cost and therefore accessible to people with limited resources. The prototype also provides flexibility to change the way the wheelchair is controlled, in order to adapt to the different needs of each individual.

The implementation of an accelerometer with a gyroscope is considered an improvement point of the project. The commands to turn right or left can be made by turning the head to both sides and not by tilting the head to the right or left, as is done with currently used accelerometers

As a future enhancement, a mobile application could collect additional data which would allow users to monitor and analyze health information such as heart rate, temperature, and oxygenation, among others.

Undoubtedly, Information and Communication Technologies (ICT) are a powerful tool toward social inclusion, especially in developing countries.

Declarations

Conflict of interest On behalf of all the authors, the corresponding author states that there is no conflict of interest.

References

1. Adecco, F.: Tecnologías y discapacidad (2017). https://fundacionadecco.org/wp-content/%20uploads/2016/07/Informe-Tecnolog/%C3/%ADa-yDiscapacidad.-Fundaci/%C3%B3n-Adecco-y-Keysight2017.pdf. Accessed March 23 (2019)
2. Ahmad, S., Siddique, N., Tokhi, M.: Modelling and simulation of double-link scenario in a two-wheeled wheelchair. Integr. Computer-Aid Eng. **21**(2), 119–132 (2014)
3. Ajuda, S.C., Torra-Sorribes, M.: Wheelchair that can be raised and converted into a stretcher (2013). https://www.google.com/patents/WO2009010602A1?cl=en. Accessed June 20 (2018)
4. Arduino: Arduino uno rev3 (2020). https://store.arduino.cc/usa/arduino-uno-rev3. Accessed September 6 (2019)
5. Babri, O., Malik, S., Ibrahim, T., Ahmed, Z.: Voice controlled motorized wheelchair with real time obstacle avoidance. In: Proceedings of the Third International Conference on Communications and Information Technology (ICCIT), IEEE (2012)
6. Bravo, L., Granados, W.: Design of a mobility device por disabled people using the method of quality function deployment. Ingeniería (2014)
7. Cabero, Almenara, J.: Tics for equality: the digital divide and disability. In: Anales de La Universidad Metropolitana, **8**, 15–43 (2008)
8. Champaty, B., Jose, J., Pal, K., Thirugnanam, A.: Development of eog based human machine interface control system for motorized wheelchair (2014)
9. Chauhan, R., Jain, Y., Agarwal, H., Patil, A.: Study of implementation of voice controlled wheelchair. In: 2016 3Rd International Conference on Advanced Computing and Communication Systems (ICACCS), **1**, 1–4. IEEE (2016)
10. de Derechos Humanos, C.N.: AtenciÓn a las personas con discapacidad (2019). https://www.cndh.org.mx/programa/32/atencion-las-personas-con-discapacidad. Accessed September 18 (2019)
11. Ding, D., Cooper, R.: Electric powered wheelchairs. Control Syst. Mag. pp. 22–34 (2005)
12. Erdem, R.: Students with special educational needs and assistive technologies: a literature review. Turkish Online J. Educ. Technol-TOJET **16**(1), 128–146 (2017)
13. Ferati, M., Babar, A., Carine, K., Hamidi, A., Mörtberg, C.: Participatory design approach to internet of things: Co-designing a smart shower for and with people with disabilities. In: International Conference on Universal Access in Human-Computer Interaction, pp. 246–261. Springer (2018)
14. Fezari, M., Bousbia-Salah, M., Bedda, M.: Voice and sensor for more security on an electric wheelchair. In: 2006 2nd International Conference on Information and Communication Technologies, **1**, 854–858. IEEE (2006)
15. Fusco, D.A., Balbinot, A.: Prototype for managing the wheelchair movements by accelerometry. Sens. Transducers **126**(3), 31 (2011)
16. Gautam, G., Sumanth, G., Karthikeyan, K., Sundar, S., Venkataraman, D.: Eye movement based electronic wheel chair for physically challenged persons. Int. J. Sci. Technol. Res. **3**(2), 206–212 (2014)
17. Hardiansyah, R., Ainurrohmah, A., Tyas, F.H., et al.: The electric wheelchair control using electromyography sensor of arm muscle.

In: 2016 International Conference on Information and Communication Technology and Systems (ICTS), pp. 129–134. IEEE (2016)
18. Hinkel, III, J.B.: Head-guided wheelchair control system. In: Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility, pp. 313–314 (2010)
19. INEGI: Instituto Nacional de Estadistica, Geografia e Informatica (2010 (Accessed February 3, 2019)). http://cuentame.inegi.org.mx/poblacion/discapacidad.aspx
20. INEGI: Instituto Nacional de Estadistica, Geografia e Informatica (2019 (Accessed September 18, 2019)). Discapacidad. La discapacidad en M'excico datos al (2014)
21. Jameel, H.F., Mohammed, S.L., Gharghan, S.K.: Wheelchair control system based on gyroscope of wearable tool for the disabled. In: IOP Conference Series: Materials Science and Engineering, **745**, 012091. IOP Publishing (2020)
22. Krahn, G.L.: Who world report on disability: a review. Disabil. Health J. **4**(3), 141–142 (2011)
23. Lee, G., Kim, K., Kim, J.: Development of hands-free wheelchair device based on head movement and bio-signal for quadriplegic patients. Int. J. Precis. Eng. Manuf. **17**(3), 363–369 (2016)
24. Mazo, M., Rodríquez, F., Lázaro, L., Ureña, J., García, J., Snatiso, E., Revenga, P., Jesús, G.: Wheelchair for physically disabled people with voice, ultrasonic and infrared sensor control. Auton. Robots pp. 203–224 (1995)
25. Mechatronics, H.: Arduino and hc-05 bluetooth module tutorial (2019). https://howtomechatronics.com/tutorials/arduino/arduino-and-hc-05-bluetooth-module-tutorial/. Accessed July 6 (2019)
26. Naeem, A., Qadar, A., Safdar, W.: Voice controlled intelligent wheelchair using raspberry pi. Int. J. Technol. Res. **2**(2), 65 (2014)
27. Nas, K., Yazmalar, L., Şah, V., Aydın, A., Öneş, K.: Rehabilitation of spinal cord injuries. World J. Orthop. **6**(1), 8 (2015)
28. Nations, U.: People with disabilities fight against exclusion (2018). https://www.un.org/development/desa/es/news/social/report-on-disability-and-development.html. Accessed Octuber 15 (2019)
29. Neto, A.Z., Mesquita, A., Spindola, M.M., Magnani, M.: Prototype of a wheelchair controlled by cervical movements. In: 2014 IEEE International Conference on Bioinformatics and Bioengineering, pp. 134–140. IEEE (2014)
30. Organization, W.H.: Assistive technology (2018). https://www.who.int/news-room/fact-sheets/detail/assistive-technology/
31. Parallax: Tilt and acceleration with the mx2125 (2020). http://learn.parallax.com/tutorials/language/propeller-c/propeller-c-simple-devices/tilt-and-acceleration-mx2125. Accessed January 10 (2020)
32. Patel, S.N., Prakash, V.: Autonomous camera based eye controlled wheelchair system using raspberry-pi. In: 2015 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS), pp. 1–6. IEEE (2015)
33. Prusas, B., Mansoor, K., Engelhardt, L., Walgers, B., Pirtilä, S.I., Lukoschek, L., Defez, Garcia, B., Lengua, Lengua, I., Peris, Fajarnes, G.: Design of an add-on device for transform a standard wheelchair on an affordable and motorized (2020)
34. Purwanto, D., Mardiyanto, R., Arai, K.: Electric wheelchair control with gaze direction and eye blinking. Artif. Life Robot. **14**(3), 397 (2009)
35. Rabhi, Y., Mrabet, M., Fnaiech, F.: A facial expression controlled wheelchair for people with disabilities. Comput. Methods Programs Biomed. **165**, 89–105 (2018)
36. Rabhi, Y., Mrabet, M., Fnaiech, F.: Intelligent control wheelchair using a new visual joystick. J. Healthcare Eng. **2018** (2018)
37. Rajesh, A.N., Chandralingam, S., Anjaneyulu, T., Satyanarayana, K.: Eog controlled motorized wheelchair for disabled persons. Int. J. Med. Health Biomed. Bioeng. Pharm. Eng. **8**(5), 302–305 (2014)
38. Salcedo, L., Torres, C., Urriolagoitia, G., Romero, B.: Rediseńo para la optimización de una silla de ruedas eléctrica de dos posiciones. 10° Congreso Nacional de Mecatrónica (2011)
39. Sandoval-Bringas, J.A., Carreño-León, M.A., Espiritu-Jimenez, M.A., Durán-Encinas, I., Chávez, A.: Construcción de un prototipo de silla de ruedas motorizada de bajo costo para personas con lesión medular. Res. Comput. Sci. **108**, 135–142 (2015)
40. SEDESOL: Diagnstico sobre la situación de las personas con discapacidad en m'exico (2016). https://www.gob.mx/publicaciones/articulos/diagnostico-sobre-la-situacion-de-las-personas-con-discapacidad-en-mexico?idiom=es. Accessed July 12 (2019)
41. Shore, S., Juillerat, S.: The impact of a low cost wheelchair on the quality of life of the disabled in the developing world. MedSciMonit pp. 534–542 (2012)
42. Sparkfun: Sparkfun start something (2020). https://www.sparkfun.com/products/10264. Accessed November 6 (2019)
43. Tdrobotica: tdrobotica (2020). https://tienda.tdrobotica.co/biomedicos/397-sensor-de-musculo-mioelectrico.html. Accessed October 15 (2019)
44. Wang, D., Yu, H.: Development of the control system of a voice-operated wheelchair with multi-posture characteristics. In: 2017 2nd Asia-Pacific Conference on Intelligent Robot Systems (ACIRS), pp. 151–155. IEEE (2017)
45. WHO: World Health Organization (2019 (Accessed September 18, 2019)). http://www.who.int/disabilities/worldreport/2011/es/
46. Yunardi, R.T., Dina, N.Z., Agustin, E.I., Firdaus, A.A.: Visual and gyroscope sensor for head movement controller system on meal-assistance application. Majlesi J. Electr. Eng. **14**(3), 39–44 (2020)