Hassan M. Qassim[1] / Abdulrahman K. Eesee[1] / Omar T. Osman[1] / Mohammed S. Jarjees[1]

Controlling a motorized electric wheelchair based on face tilting

[1] Technical Engineering College, Northern Technical University, Mosul, Iraq, E-mail: hassanqassim@ntu.edu.iq

Abstract:
Disability, specifically impaired upper and/or lower limbs, has a direct impact on the patients' quality of life. Nowadays, motorized wheelchairs supported by a mobility-aided technique have been devised to improve the quality of life of these patients by increasing their independence. This study aims to present a platform to control a motorized wheelchair based on face tilting. A real-time tracking system of face tilting using a webcam and a microcontroller circuit has been designed and implemented. The designed system is dedicated to control the movement directions of the motorized wheelchair. Four commands were adequate to perform the required movements for the motorized wheelchair (forward, right, and left, as well as stopping status). The platform showed an excellent performance regarding controlling the motorized wheelchair using face tilting, and the position of the eyes was shown as the most useful face feature to track face tilting.

Keywords: algorithm, motorized wheelchair, microcontroller, platform

DOI: 10.1515/bams-2019-0033

Received: July 21, 2019; **Accepted:** September 20, 2019

Introduction

The amount of Disabled people, specifically paralysed ones, who are not able to perform daily life tasks are constantly increasing. Many reasons could lead to a person's disability including, but not limited to, spinal cord injury, traumatic brain injury, apraxia, cerebral palsy, multiple sclerosis and stroke [1], [2], [3]. Around the world, elderly people are the most vulnerable to these disabilities and the number of those over 60 years of age will reach 2.1 billion in 2050 in comparison with 0.9 billion in 2015 [4]. In addition, the World Health Organization (WHO) has reported a rapid increase in lower limb amputation resulting from peripheral vascular diseases and road accidents in low and middle income countries [5]. The Christopher and Dana Reeve Foundation also conducted a study in 2013 and found that there are about 1 in 50 persons living with paralysis in the United States [2].

Focusing on developing assistive techniques for these people has become indispensable. A motorized wheelchair supported by a mobility-aided technique is the aim of most researchers in this field [6]. Powered motorized wheelchairs should increase the life quality through providing self-dependence with respect to mobility [7], [8]. Most of the powered motorized wheelchairs are controlled through a hand joystick [9]. Smart motorized chairs, however, are characterized by additional techniques. For example, hand gestures can be used to create an omnidirectional motion to navigate the motorized chair. The principle is based on using an inertial measurement unit (IMU) to measure the angle of wrist tilt and acceleration in three axes supported by electromyogram (EMG) sensors to record the myoelectric signal from the forearm. Seven hand gestures were translated into seven commands to control a motorized chair [10].

However, quadriplegic patients suffering or those with cervical spinal cord injuries are not able to use their hands [9]. This shortcoming means they rely solely on their neck, head and tongue which in turn limits the use of such motorized chairs for daily maneuvers [9]. These difficulties have pushed researchers to look for reliable motorized wheelchair controlling methods. Sip-puff is an assistive technique developed by researchers to provide a good controlling unit for motorized wheelchairs. The technique depends on the air pressure through sipping (inhaling) and puffing (exhaling) [6].

A head orientation controller is another technique that has been deployed to control robotic wheelchairs. Two orientation detection (OD) units are used in this system. Each OD unit is constructed of three micro-electro-mechanical systems (MEMS) sensor: a gyroscope, an accelerometer, and a magnetometer [11]. However, these controllers have several limitations with respect to their commands [9].

Image processing has participated greatly in several biotechnology fields such as; medical images enhancement, face detection, and tracking objects [12]. It has played a major role in the field of controlling motorized

Hassan M. Qassim is the corresponding author.

wheelchairs. An eye-tracking system based on pupil position using a high-resolution webcam was used by Abu-Faraj et al. through sweeping a small search window over the entire image of the eye to find the darkest area which was considered the pupil [1]. The study conducted by Mazhar and his colleagues was also based on pupil position albeit through applying image segmentation on the received image [6], [13].

Limbus tracking is another old tracking method whereby the reflecting light off the iris-scleral limbus can be used to measure the eye position [14].

Huang et al. also proposed a powered motorized wheelchair controller by the mean of electro-oculography (EOG) but in a different manner [15]. The process included 13 flashing buttons presented on a graphical user interface (GUI), flashing in sequence one-by-one. Each flash button is pre-defined with a command that can be selected according to the patient's blink [15]. However, sweat may have an effect on the read out of the recorded EOG signals [6].

Fuzzy logic has also been introduced to develop a speed and direction controller for motorized wheelchairs in the virtual world using Matlab-Simulink with a suggested push button and graphical user interface (GUI) [16].

Human face tracking and recognition have also been used in the field of controlling motorized wheelchairs. Vázquez et al. developed and trained an artificial neural network for controlling a motorized chair [17]. A wheelchair-mounted robotic manipulator (WMRM) is another method proposed by Jiang et al. [18]. Three controlling units were used in their study: face and hand gesture recognition, speech recognition and hybrid (speech and gesture). For tracking the user's face and hands, a three-dimensional (3D) particle filter framework was used. The filter incorporated color, depth and spatial information to track the centroids of face and hands [18].

Most of the previously mentioned techniques have some drawbacks with respect to their lower proportional commands, complexity and their high cost, this paper proposes a cost-effective and accurate controlling technique for motorized wheelchairs. An image processing algorithm based on face tilting is proposed to control a motorized wheelchair. The complete details of this controlling unit are explained in the Materials and methods section (2). The results and discussion are explained in the following sections, concluding with a section on future works.

Materials and methods

A platform was built to show the efficiency of acquiring a real-time video through a webcam and controlling a motorized wheelchair based on face tilting. The motorized wheelchair should turn to the right when the face tilts to the right, turn to the left when the face tilts to the left, and stop when the face tilts down, otherwise the motorized chair moves forward (Figure 1). Therefore, three signals are required to perform the three movements (right, left, and stopping the motorized wheelchair). The motorized wheelchair starts moving forward once the face is detected, and depending on the face tilting the motorized chair changes its action.

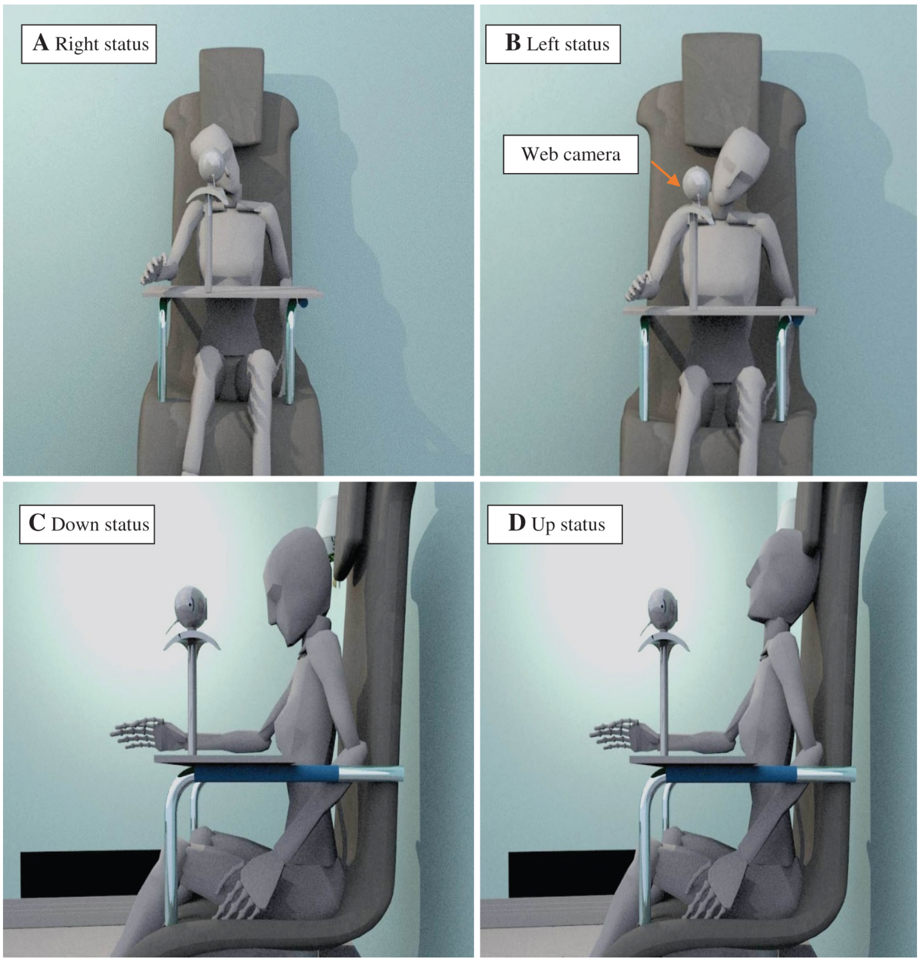

Figure 1: Clarification of the four positions of face tilting.
(A) refers to the right status of the face tilting, (B) refers to the left status of the face tilting, (C) refers to the down status of the face tilting, and (D) refers to the up status of the face tilting.

The platform was first tested on light emitting diodes (LEDs) to ensure its efficiency before its implementation in a real motorized wheelchair. Four LEDs with different colors were used to refer to the four positions of the motorized wheelchair (Figure 2).

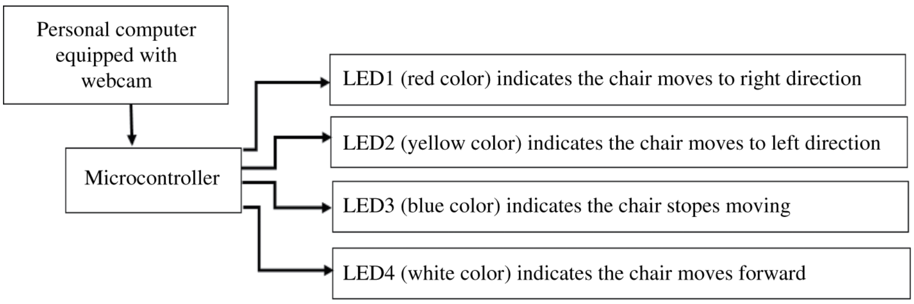

Figure 2: The first implementation of the platform using four LEDs.

The platform consists of two parts, the software part and the hardware part.

Software

The platform algorithm was built using Matlab 2015. The algorithm was designed to acquire a real-time video of a person's face through a webcam and to detect its tilting, then translating this tilting to the required signals. The webcam of a personal computer (PC) was placed above the user's legs facing the person and captured the face tilting in real-time as shown in Figure 1B. The required controlling signals are generated and sent to the microcontroller through a serial USB port when the person tilts his/her face.

The algorithm processes the video acquired through the webcam and detects the position of the face. The first detected position of the face is set as a reference position. The algorithm divides the first captured image into pixels, then identifies the face's position and location according to the whole image. The algorithm continues capturing video (sequence of images) through the webcam and decides if the face has tilted to the right, the left, or has tilted down. Tilting the face for 20 pixels right, left, or down out of its original position, which has been set as the reference position, is enough to clarify the tilting of the face.

Once the algorithm detects the new position of the face, the required signal is sent to the microcontroller. In case the face has moved to a position not in the recognized positions (positions in which the face cannot be detected such as backwards), no signals will be generated and it will wait for a recognized position. Furthermore, if the face moved upwards the motorized wheelchair continues its forward movement.

Processing real-time video requires a high-speed processor and enough random access memory, A PC with the following specifications was used:

(lower specifications could affect the algorithm's efficiency)

- Model: HP Pavilion g6 Notebook PC
- Processor: Intel(R) Core™ i5-2410M @2.30GHz
- Installed memory (RAM): 3.00 GB
- System type: 64-bit operating system
- Total available graphical memory: 2533 MB
- Dedicated video memory: 1280
- HP webcam with a resolutions of (1280 × 960) was used. Lower resolution decreases the algorithm accuracy.

Hardware

A motorized wheelchair with two servo motors attached to the back wheels was used, if the two motors are running the motorized wheelchair will move forward, otherwise it will stop. In addition, if the right wheel's motor is running while the left wheel is not, the motorized wheelchair will turn to the left. The right direction is achieved when the left wheel's motor is running while the right wheel is not. Table 1 shows the required directions and the action of the servo motors. The servo motors require a 24 V DC with a current of 9 amp maximum. The speed of the motorized wheelchair was set to 5 km/h.

Table 1: Command control.

Direction	Action
Forward	Both SERVO MOTORS rotate forward
Left	Right servo motor rotates forward
Right	Left servo motor rotates forward
Stop	Both servo motors are stopped

The microcontroller was programed to receive the commands from the PC and to translate these commands to the required controlling signals. Two relays were connected to the microcontroller to run on/off the two motors.

Figure 3 shows the flow chart of the proposed platform which is started by acquiring the real-time video and ended by sending the signals to the motor.

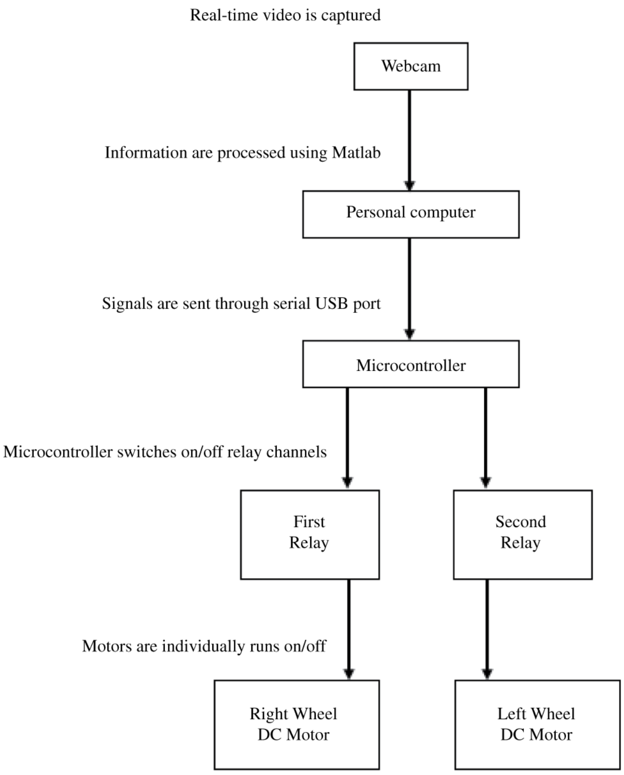

Figure 3: Flow chart of the proposed platform.

The proposed algorithm was tested on four adult participants each having different facial features to check its efficiency on different features. The four participants were three males (one with no facial hair and the other two having a mustache and a beard, respectively) and one female.

Results and discussion

The amount of the real-time response identifies the efficiency of the proposed algorithm, in other words, how fast the wheelchair responds to the face tilting. The desired real-time response has to be in the order of milliseconds (ms) (less than 1 s) to get the desired movement as quickly as possible [19]. The real-time response of the DC motors controlled by Matlab was discussed by Tang [19]. Tang identified the real-time response to be in the range of (0.4–0.55 s), which is the time required for the motor to achieve the steady state.

The real-time response of our proposed algorithm starts by detecting the face and ends by sending the signal to the microcontroller. Matlab provides a function that gives an accurate real-time response. Considering our wheelchair is turned to move forward once the user's face is detected, therefore the real-time response for three movements (right, left, and stopping status) was calculated for the four participants as shown in Table 2A–D.

Table 2: Represents the wheelchair's real-time response for the four participants, (A) refers to the female participant, (B) refers to the participant with no facial hair, (C) refers to participant having a mustache, and (D) refers to participant having a beard.

Type of the movement	Real-time response in seconds
(A)	
Right	0.52876
Left	0.54552
Stop	0.51354
(B)	
Right	0.53867
Left	0.50562
Stop	0.54221
(C)	
Right	0.49895
Left	0.54387

Stop	0.52965
(D)	
Right	0.53652
Left	0.51539
Stop	0.49354

As shown in Table 2, the obtained real-time responses for the four participants are similar. Consequently, the performance of the platform has the same efficiency for the four participants.

Furthermore, the average real-time response required to process a single frame starting by detecting the face until the commands sent to the microcontroller was calculated and identified as 0.53 s. The processing time of a single frame was calculated by taking the time of 10 processed frames, then the average time was considered as the required time for processing a single frame as shown in Table 3.

Table 3: Real-time response required for processing a single frame.

Frame No.	Time required for processing a single frame in seconds
Frame1	0.488403
Frame2	0.528005
Frame3	0.546694
Frame4	0.542747
Frame5	0.52876
Frame6	0.558667
Frame7	0.549608
Frame8	0.545999
Frame9	0.547376
Frame10	0.550144
Average time	0.5386403

It has been mentioned that the efficiency of the proposed algorithm depends on the real-time response. Consequently, it can be said that the proposed platform with a real-time response of 0.538 s showed an excellent performance in controlling the motorized wheelchair's movements [19].

In the case of the webcam discovering more than one face (such as a person standing behind the wheelchair), the proposed algorithm was designed to detect the nearest face. In addition, the distance between the face and the webcam has to be in the range of (50–75 cm), otherwise the efficiency of the proposed algorithm will be compromised.

To ensure a clear capturing of real-time video, adequate light is required. In addition, excessive weight of the user could decrease the motor's speed to less than 5 km/h. The proposed motorized wheelchair has a maximum speed of 10 km/h. The speed, however, was set at 5 km/h which is enough for maneuvering and moving in an indoor environment.

Many features can be identified and extracted from the person's face such as the mouth, nose and eyes, all of these feature can be used to show the tilting of the face. However, using eye position, which was used in this study, provides a higher accuracy to identify the tilting of the face compared to the other features.

Conclusion and future work

Controlling a motorized wheelchair based on a face tilting platform was built, tested, and validated. The platform showed excellent performance. The platform's algorithm was based on simple manipulating of face tilting, where small change of face tilting can be detected and translated to an action. The eye position was shown the most useful facial feature to track face tilting. The development of the algorithm to make the user able to increase or decrease the motorized wheelchair speed based on face tilting can be considered as a future work of this study.

Acknowledgment

The authors would like to thank Mr. Mothana Aziz and Mr. Ali Alhafidhth for their cooperation and help in the implementation of this project.

Ethical Approval: The conducted research is not related to either human or animal use.

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: None declared.

Employment or leadership: None declared.

Honorarium: None declared.

Conflict of interests: The authors declare no conflict of interest.

References

[1] Abu-Faraj ZO, Mashaalany MJ, BouSleiman HC, Heneine JD, Al Katergi WM. Design and development of a low-cost eye tracking system for the rehabilitation of the completely locked-in patient. International Conference of the IEEE Engineering in Medicine and Biology Society 2006. Available at: 10.1109/iembs.2006.260280. Accessed 2 Jul 2019.
[2] Stats about paralysis. Christopher & Dana Reeve Foundation, 2013. [Online]. Available at: https://www.christopherreeve.org/living-with-paralysis/stats-about-paralysis.
[3] Kennedy PR, Adams KD. A decision tree for brain-computer interface devices. IEEE Trans Neural Syst Rehabil Eng 2003;11:148–50.
[4] Cutti A, Lettieri E, Verni G. Health technology assessment as theoretical framework to assess lower-limb prosthetics – issues and opportunities from an international perspective. J Prosthet Orthot 2019;31:55–73.
[5] Hassan AM, Alamgir H, Jahan Akhtar N, Hossain Z, Islam R, Sohrab HM. Characterisation of persons with lower limb amputation who attended a tertiary rehabilitation centre in Bangladesh. Disabil Rehabil 2019;29:1–7.
[6] Lin CS, Ho CW, Chen WC, Chiu CC, Yeh MS. Powered wheelchair controlled by eye-tracking system. Opt Appl 2006;36:2–3.
[7] Brandt Å, Iwarsson S, Ståhle A. Older people's use of powered wheelchairs for activity and participation. J Rehabil Med 2004;36:70–7.
[8] Davies A, De Souza LH, Frank AO. Changes in the quality of life in severely disabled people following provision of powered indoor/outdoor chairs. Disabil Rehabil 2003;25:286–90.
[9] Thorp EB, Abdollahi A, Chen D, Farshchiansadegh A, Lee M, Pedersen JP, et al. Upper body-based power wheelchair control interface for individuals with tetraplegia. IEEE Trans Neural Syst Rehabil Eng 2016;24:249–60.
[10] Kundu A, Mazumder O, Lenka P, Bhaumik S. Hand gesture recognition based omnidirectional wheelchair control using IMU and EMG sensors. J Intell Robot Syst 2018;91:529–41.
[11] Ruzaij MF, Neubert S, Stoll N, Thurow K. Auto calibrated head orientation controller for a robotic-wheelchair using MEMS sensors and embedded technologies. IEEE Sensors Applications Symposium (SAS) 2016. Available at: 10.1109/sas.2016.7479886.
[12] Qassim HM, Basheer NM, Farhan MN. Brightness preserving enhancement for dental digital X-ray images based on entropy and histogram analysis. J Appl Sci Eng 2019;22:187–94.
[13] Mazhar O, Shah T, Khan M, Tehami S. A real-time webcam based Eye Ball Tracking System using MATLAB. IEEE 21st International Symposium for Design and Technology in Electronic Packaging (SIITME) 2015. Available at: 10.1109/siitme.2015.7342312.
[14] Russo JE. The limbus reflection method for measuring eye position. Behav Res Meth Instru 1975;7:205–8.
[15] Huang Q, He S, Wang Q, Gu Z, Peng N, Li K, Zhang Y, et al. An EOG-based human-machine interface for wheelchair control. IEEE Trans Biomed Eng 2018;65:2023–32.
[16] Sankardoss V, Geethanjali P. Design and low-cost implementation of an electric wheelchair control. IETE J Res. 2019;1–10. DOI: 10.1080/03772063.2019.1565951.
[17] Vázquez JE, Martin-Ortiz M, Olmos-Pineda I, Olvera-Lopez A. Wheelchair control based on facial gesture recognition. Internat J Info Technol Syst Approach 2019;12:104–22.
[18] Jiang H, Zhang T, Wachs JP, Duerstock BS. Enhanced control of a wheelchair-mounted robotic manipulator using 3-D vision and multimodal interaction. Comp Vis Image Underst 2016;149:21–31.
[19] Tang J. Real-time DC motor control using the MATLAB interfaced TMS320C31 Digital Signal Processing Starter Kit (DSK). In: Proceedings of IEEE International Conference on Power Electronics and Drive Systems. Hong Kong: IEEE, 1999;321–6.