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Multi-Controlled Wheelchair for Upper Extremities Disability

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Abstract: People with motor disabilities are trying to be more autonomous by using an electric wheelchair with a conventional joystick control. However, a problem arises when these people are suffering from upper extremities disability such as tetraplegia. Several methods were implemented such as voice control, chin control, eye-blink, sip-and-puff, but each has its advantages and disadvantages. Furthermore, in some situations a method is preferred to others. In this paper, we suggest a methodology that incorporates multiple control methods for a wheelchair. Voice control, eye-blink and sip-and-puff controllers will all be included in the same wheelchair. The user has the option to choose which one he will use whenever he wants. This helps the individual with disability to be more autonomous because he decides the method that suits him better at any particular time.

Keywords: Mobility, Smart Controller Interface, Disability, Assistive Technology, Embedded Systems, Sip-and-Puff, Eye-Blink, Voice Control

Introduction

A motor physical disability is a limitation on a person's physical movements and activities. People with motor disability have a major problem to deal with mobility. Luckily, assistive devices such as electric wheelchairs help these people to gain being mobile and autonomous. Otherwise, they will be dependent on others to move around. Controlling a wheelchair is an easy task. A conventional joystick is used to control the speed and direction of the motor's movement. The further you push in a certain direction, the faster the wheelchair will move similar to a gas pedal in a car (Sorrento *et al*., 2011).

However, many people with lower motor disability have also high motor disability, which means that they are not able to control their hand movements. This adds up to the challenge since the conventional electric wheel chair needs hands control over the joystick. For these people, a different wheelchair's control is needed. Currently, many such controllers exist. Examples include chin control, voice control, tilt control, eye-blink and sip-and-puff control to name a few (SPD, 2017). The problem is that each one of the mentioned control is not ideal. It can be good in some situations, bad in others. For example, voice control may not be suitable for noisy environments. Sometimes, the user gets tired and cannot use a certain control after a while, such as using tilt control will give neck muscle fatigue after a few moves. From this perspective and in order to solve the mentioned problem, an idea was to implement multiple control options at the same time, giving the user the ability to activate one at a time and at any time.

The challenges that will be encountered in building such a system are determining the correct and most suitable combination of hardware and software required to build the system. Furthermore, the system needs to be relatively low cost; otherwise no one will be able to buy it. The system needs to be simple to use, functional and customizable, so that it can handle future improvements to its hardware and software. Also, there should be an easy way to switch between input control methods, keeping in mind that the user has upper extremities disability which means that the switch must be doable by the user.

The rest of this paper is divided as follows. Section 2 is a literature review. Section 3 is the system flowchart. Section 4 is the system design. Section 5 shows the implementation for each controller on its own as the combined system is still to be done in a future step. In section 6, preliminary tests were done for each individual controller. Section 7 is conclusions and future work.

Literature Review

Several control types for electric wheelchairs exist in the market and research. Each one differs in terms of usage and cost. Perhaps the standard joystick controlled type is the most famous and used one (Saharia *et al*., 2017). Power wheelchairs are similar structurally, each having the following four basic parts: Chair with wheels, motor, battery, drive system and controller. Lightweight

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power wheelchairs use a 2-pole motor, while the heavy duty power wheelchair uses a 4-pole motor. The 4-pole motor offers more carrying power and also allows for additional important options. Power wheelchairs use Sealed Lead Acid batteries (SLA). They can either be wet or dry cell batteries that have an output of 4 to 5 amps. The battery can be recharged using a standard electrical outlet when the chair is not being used. A drive mechanism for a wheelchair includes at least one clutch and at least one gear set contained within a central hub housing operatively coupled to the drive surface of the main wheel being driven. The joystick or handle is used to steer and control the power wheelchair (Boninger, 2011). A conventional joystick generally consists of a gimbal knob, an on/off switch, a speed control and a battery gauge. To use the joystick, the user pushes the gimbal in the direction he wants and the further he pushes in a direction the faster the wheelchair will move in that direction (Rossen *et al*., 2012).

Knowing that a conventional joystick is not suitable for a person who cannot use his hands such as tetraplegic, other ways are used to control the wheelchair. All the wheelchair parts are kept the same except for the controller. Even the joystick control can be left, with just an extension to another special controller. The extra controller can be connected to the drive system or to the joystick controller. In a previous work (Riman, 2018), we did the connection to the other joystick controller in order to avoid voiding the wheelchair's warranty. Below is a list of some typical control methods for the electric wheelchair.

Head Motion Controller

Head motion controlled wheelchair is a type of electric wheelchair. The idea is to design a wheelchair tilt communicator system that works by head movements. It can be used by disabled persons who cannot move their hands and legs but can move their heads. Furthermore, it works by using tilts sensors and wireless modules (Prasat *et al*., 2017). In addition, the wheelchair can carry the disabled person with a weight up to 100 kg (Nehru, 2012).

Eye-Blink Controller

This type of controller controls the electric wheelchair by how many times the eye blinks. The eye blinking mechanism is designed to produce these commands: Forward, backward, right, left and stop. The system involves three stages: Image detection, image processing and sending signals to the wheelchair controller. The eye blinks are detected using a camera and sensor that are placed in front of the user. The sensor will send the data to microcontroller which will control operation and functions of the camera. The signals then are sent to a Raspberry Pi computer, where the images are processed. The corresponding output signals are then sent to the wheelchair controller to start moving the wheelchair (Riman, 2018; Purwanto *et al*., 2009).

Sip-and-Puff Controller

The Sip-and-puff controller is an assistive technology that sends signals using air pressure by Sipping (inhaling) or puffing (exhaling) through a tube in order to move the electric wheelchair. The idea of this design is based on a pressure sensor (absolute air pressure) connected to a microcontroller. The sensor measures the pressure and sends it to the microcontroller. Then the microcontroller converts the analog signal into digital signals and sends it to an embedded computer to specify the desired action. Then the action is transferred to the wheelchair controller to move it (Mougharbel *et al*., 2013). The system was further tested for effectiveness (Erdogan and Argall, 2017).

Chin Controller

The chin control wheelchair is designed for people who cannot control their hand easily. It is basically controlled by the chin. The chin sits in a cup shape joystick and moves by the neck rotation. This type of wheelchair offers a freedom for some disabled people and lets them depend more on themselves. It works by pushing the joystick by your chin in any direction you want. The pushed chin cup joystick distance controls the wheelchair's speed (Authors, 2012).

Voice Controller

Another type is the voice controlled wheelchair. This system is designed to control the wheelchair through the voice recognition (Wani *et al*., 2017). The components of this system are: Speech recognition software connected to a computer, microcontroller, motors to move the wheelchair and ultrasonic sensors to detect if there is any obstacle in front of the wheelchair to stop it (Pires and Nunes, 2002).

Hand Controller

Hand switch is a type of electric wheelchair control. It is enable people who suffer from disability to move freely from one place to another by using their hand through the joystick. The joystick is located at the end of the electric wheelchair armrest. However, some disabled people are not comfortable in using this joystick. Of course, there is an alternative solution, which is using the round ball knob instead of the joystick. It is easy to control and simpler that the standard joystick. Moreover, it is soft and has more sensitive touch. It also gives a greater chance for those people who have limited range of motion in their hand (Hoveround, 2012). There is also another way to use hand gestures to control the wheelchair (Jha and Khurana, 2016). Using this way, the user does not even need to touch the joystick. He just waives his hand in different directions.

Table 1: Comparison of different wheelchair controllers

Type	Power use	CPU Speed	Causes user's fatigue	Used with upper limb disability	Added controller cost
Joystick	Low	Low	heavy use	No	No
Eye-blink	Avg. (IR)	High	heavy use	Yes	75 USD
Sip-and-puff	Avg.	High	light use	Yes	140 USD (Boninger, 2011)
Voice	High	High	light use	Yes	160 USD (Purwanto *et al*., 2009)
Head motion	Avg.	High	light use	Yes	150 USD (Nehru, 2012)
Chin	Low	Low	light use	Yes	100 USD
Hand	Low	Low	heavy use	No	No

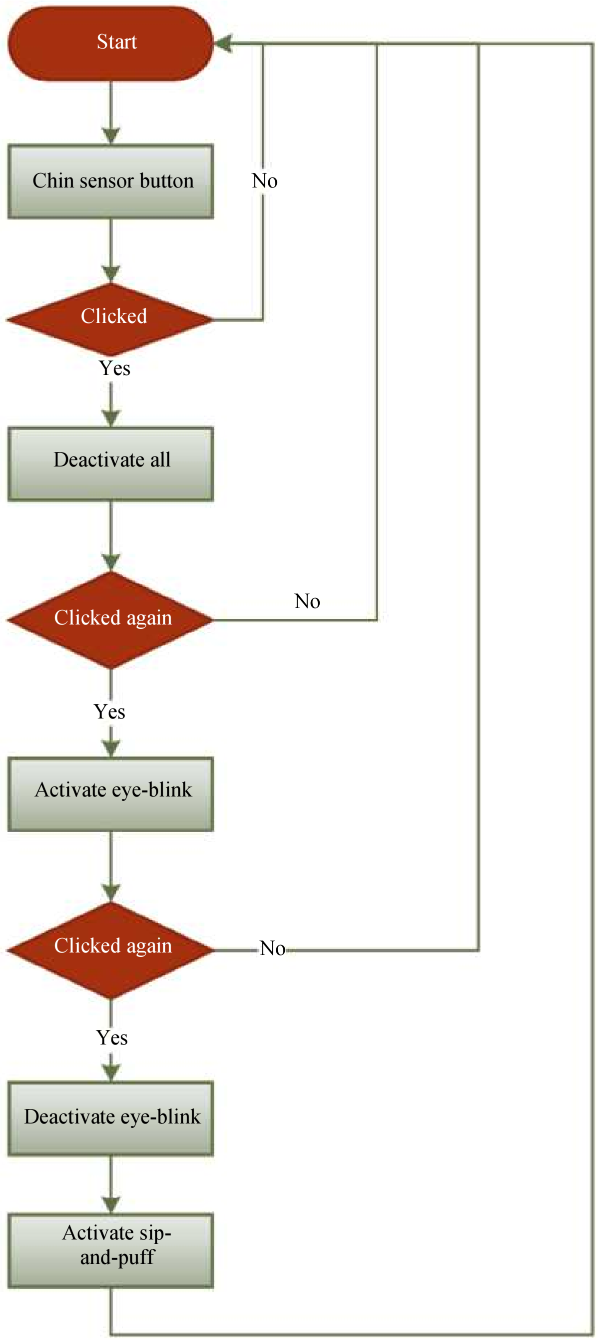

Fig. 1: System's flowchart

As a comparison of the above mentioned types, Table 1 describes and compares these different types (Arshak *et al*., 2006).

System Flowchart

As seen in the previous section, there are many ways to control a wheelchair, each having its own advantages and special characteristics. The problem with non-conventional methods is that the user gets tired after a while or is not able to use them in some environments, such as voice control in a noisy place. In this research, we will combine two methods in one wheelchair, giving the user the freedom to choose at any time one controller to use. We chose the eye-blink and sip-and-puff controllers for several advantages listed earlier. A special chin button can be used to change from one type to the other. Following is a detailed explanation for each one of the two controllers and the circuit used to activate one and deactivate the other. The chin button operation to switch between controllers is explained in the flowchart of Fig. 1. With one click, all systems are deactivated. Another click activates the eye-blink controller. A third click will deactivate eye-blink controller and activate the sip-and-puff-controller.

Upon activating the eye-blink controller, the wheelchair will be moved according to the user's eye blinks. Blinking the right eye will turn the wheelchair in the right direction, while blinking the left eye will turn the wheelchair in the left direction. Blinking both eyes will cause the wheelchair to stop if it was moving in any direction (right, left, forward) and will cause it to move forward if it is stopped. The next flowchart (Fig. 2) shows the whole process.

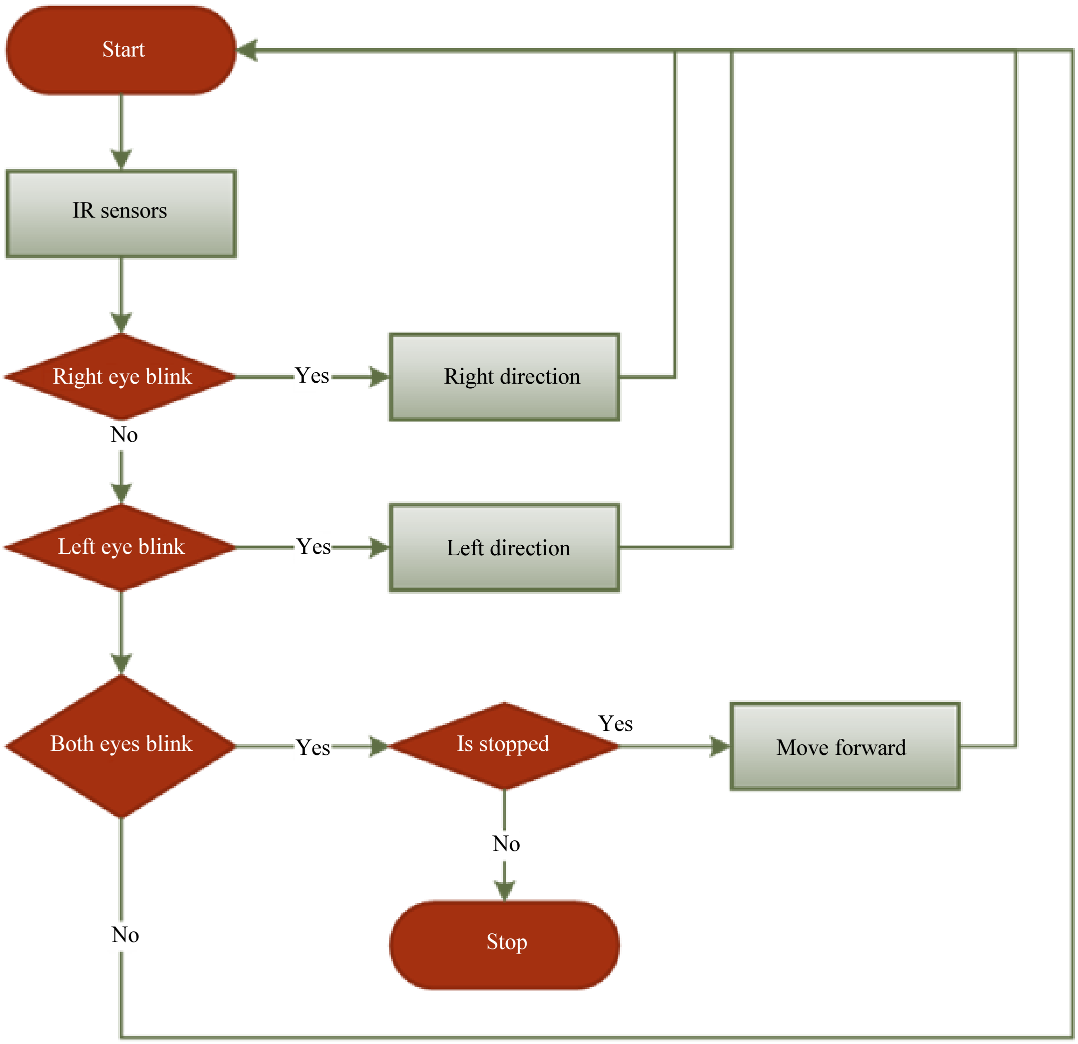

Fig. 2: Eye blink controller's flowchart

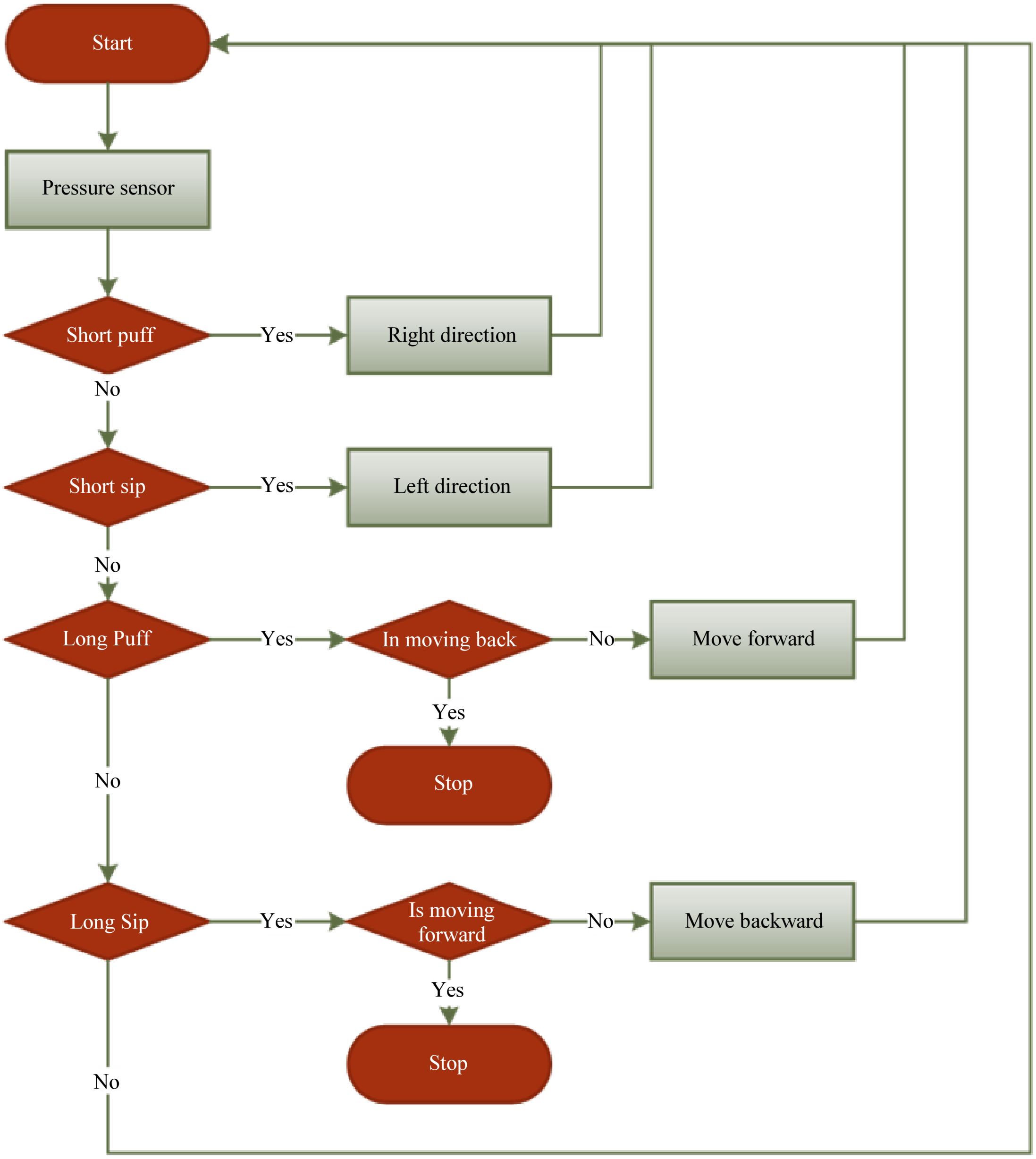

Fig. 3: Sip-and-puff controller's flowchart

Upon activating sip-and-puff controller, the wheelchair will be moved according to the user's sips and puffs on the tube connected to the pressure sensor. If the user makes a short puff, the wheelchair will turn in the right direction. If the user makes a short sip, the wheelchair will turn in the left direction. If the user makes a long puff while the wheelchair is moving backward, then it will stop. Otherwise, it will move forwards. Finally, if the user makes a long sip while the wheelchair is moving forward, then it will stop. Otherwise, it will move backward. The flowchart in Fig. 3 shows the whole process.

System Design

The system is divided into two main parts: The eye-blink controller and the sip-and-puff controller. The controllers are independent of each other, with each having its own circuit design. The detailed system design of each one of the controllers is explained below. A combined circuit will include both systems in addition to the selection of which one to be activated.

Eye-Blink Controller

As shown in the following Fig. 4, the eye-blink controller system design is composed of the following parts. The system gets the input from two infra-red (IR) sensors, one for each user's eye. This input enters a Pic microcontroller circuit, which in turn translates the signal into digital output sent to a small Raspberry Pi computer. The Raspberry Pi interprets the signal values and sends commands to the wheelchair controller that directly controls the wheelchair motors.

This system works in parallel with the conventional joystick controller which can act on the wheelchair as well.

Sip-and-Puff Controller

As shown in the Fig. 5, the sip-and-puff controller system design is composed of the following parts. The system gets the input from pressure sensor through a tube from user's mouth. This input enters an Arduino microcontroller circuit, which in turn translates the signal into a digital output sent to a small Raspberry Pi computer. The Raspberry Pi interprets the signal values and sends commands to the wheelchair controller that directly controls the wheelchair motors. The conventional joystick controller can also act on the wheelchair as needed.

Combined Controller

As shown in Fig. 6, the combined controller system design is composed of both eye-blink and sip-and-puff controllers. A single Raspberry Pi computer can be used. The RaspBerry Pi takes input from both controllers, but filters only the selected one, the choice coming from the chin push button.

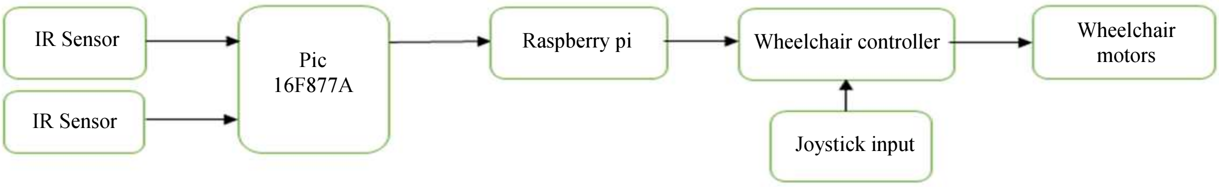

Fig. 4: Eye blink controller's system design

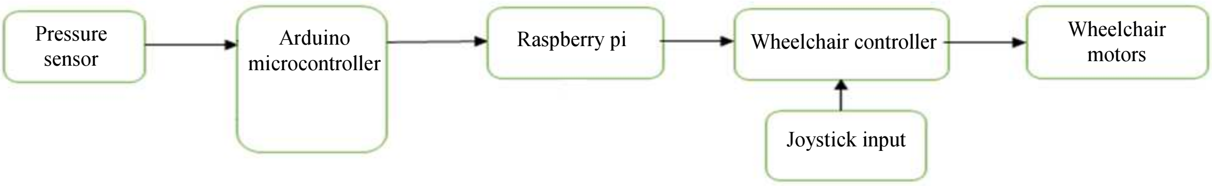

Fig. 5: Sip-and-puff controller's system design

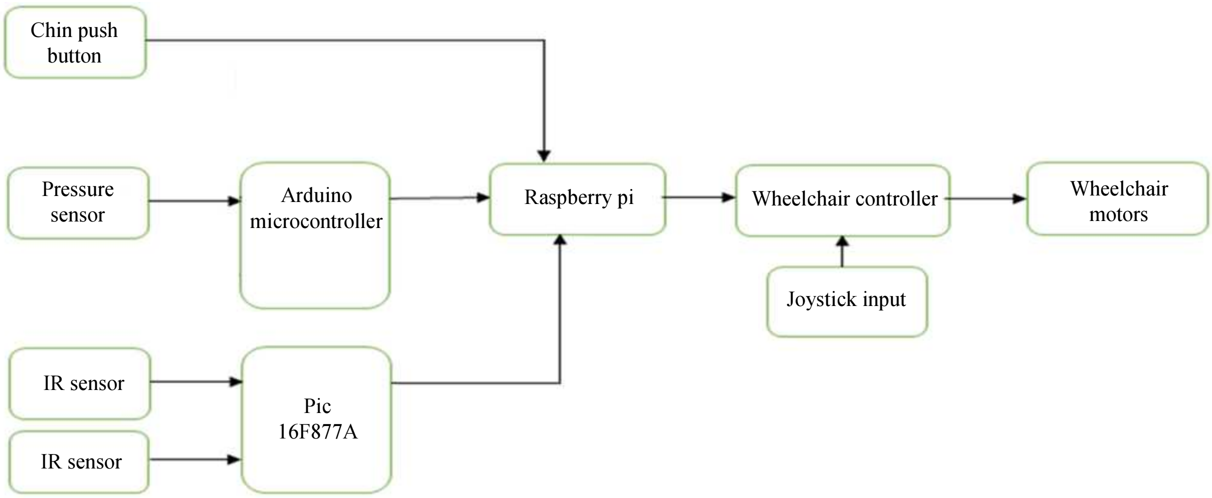

Fig. 6: Overall system design

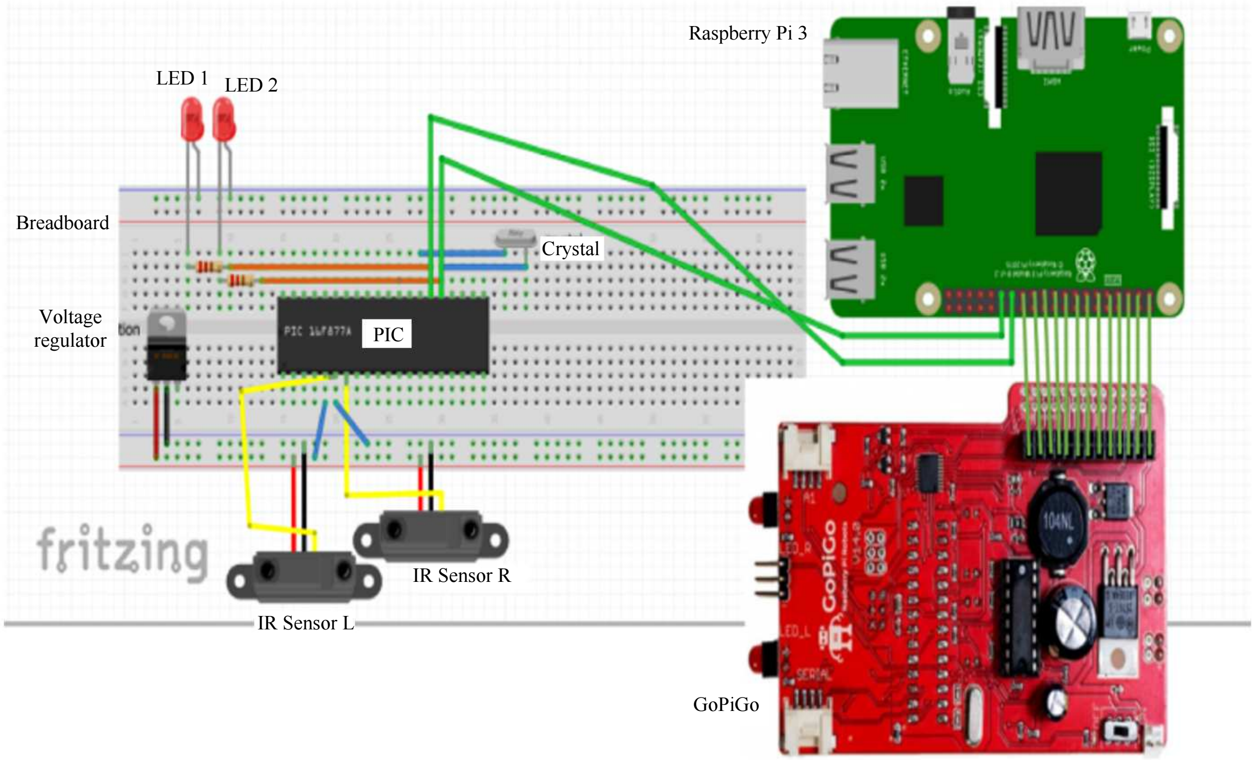

Fig. 7: Eye-blink hardware connections

Implementation

The prototype is still not implemented for the overall system. However, the individual prototypes for both eye-blink controller and sip-and-puff controller were implemented and tested on two GoPiGo robots. Preliminary tests were also done.

Eye-Blink Controller

The Fig. 7 shows the detailed connections. The green board on the right is the Raspberry PI. The red board is the GoPiGo controller. The black chip is the PIC microcontroller. The two similar components down are the IR sensors (for left and right eyes).

First, the Infrared Radiation (IR) sensors are used to detect the eye-blinking and then they send the signals for PIC 16F877A microcontroller. The PIC microcontroller interprets the received signals and sends the output to specific pins on Raspberry PI board. Te raspberry pi is connected to the Go-Pi-Go red controller board to move the motors forward, right, left and stop.

The overall robot with controller is shown in Fig. 8.

Sip-and-Puff Controller

According to the low-level design (Fig. 9), the design starts with the Absolute Air Pressure sensor where the user will sip or puff through it with the help of a tube. The sensor measures the air pressure and sends it to the Arduino mini pro as an analogue signal. The Arduino will take the analogue signal and convert it into 8 bit resolution of digital signal. The connection between the Arduino and the pressure sensor is made with three wires, which are VCC (Red), GND (black) and A0 (green) as analogue port.

In order to transfer the digital signals of the Arduino mini pro to the Raspberry Pi 3 model B, two XBee 1mw wire antennas are used to allow the Raspberry Pi and the Arduino communicate using RF signals (2.4 Mhz). One of the antennas is connected with the Arduino mini using six pins (Fig. 9) while the other one is connected serially to the Go-PiGo controller in the serial port as shown in the figure. The communication is done using 4 wires from the XBee Explorer which are the GND (black), 5V (red), DOUT (green) and DIN (yellow) connecting them to the pins of the Robot controller which are GND, 5V, RX and TX. The serial communication of the robot allows transferring the data with a speed of 9600 bps. It's important to know that the software for both Raspberry Pi and Arduino is programmed according to this configuration (9600 bps). Then the Raspberry Pi is connected to the Go-PiGo controller (Dexter).

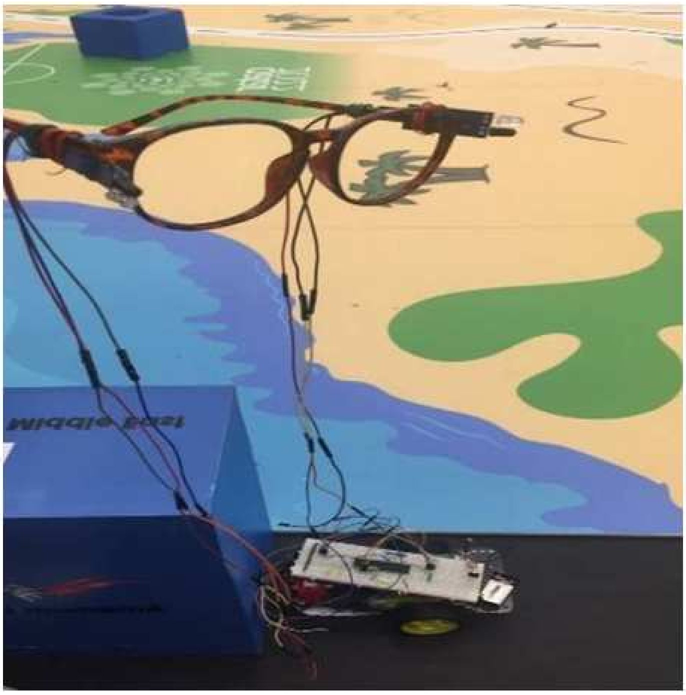

Fig. 8: Eye-blink controller on GoPiGo robot

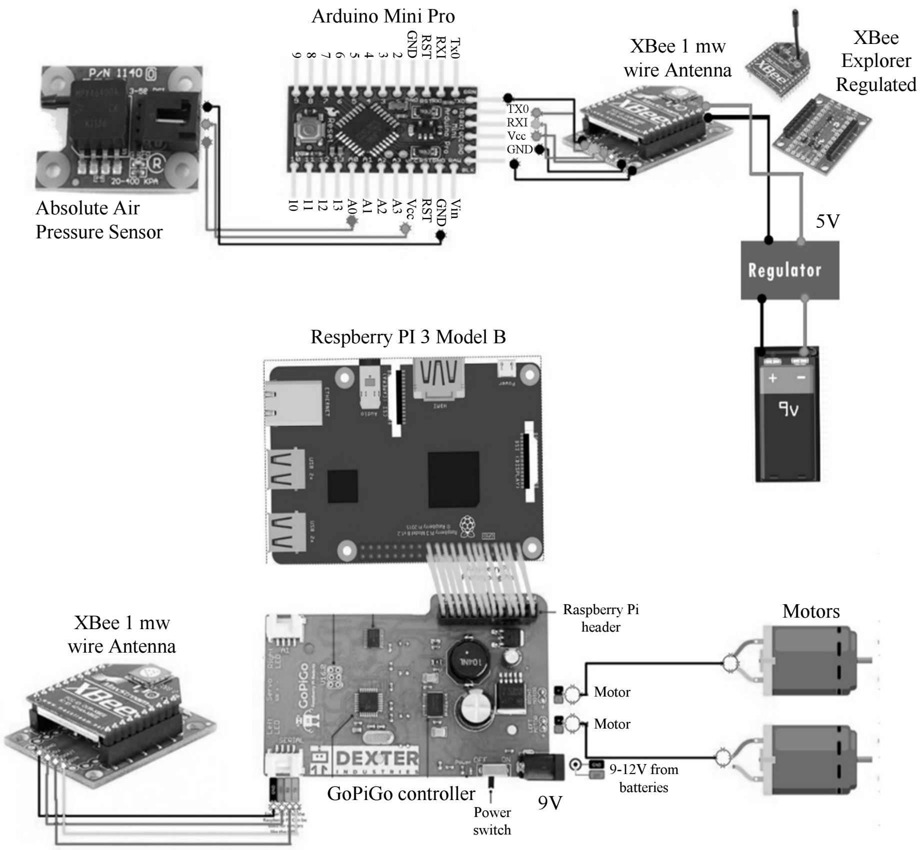

Fig. 9: Sip-and-puff controller's hardware connections

Due to this connection, the Raspberry Pi can receive the data as a packet from the Arduino and translate it into a command to send it to the Go-PiGo controller in order to move the motors to the desired directions. It is important to know that the first part of the design which is the Arduino mini, pressure sensor and XBee modules are required to have 5v power. Thus, a regulator is used to reduce the voltage from 9V. On the other hand, the second part of the design needs 9V power.

Preliminary Tests

As the overall prototype is yet to build, preliminary tests were done on the individual controllers and on GoPiGo robots instead of a wheelchair.

There are a wide range of experiments and testing methods that can be applied on the prototype in order to test its efficiency and its quality of performance. These experiments allow for a better understanding of the design. The preliminary results obtained after testing the robot with different experiments and the different type of paths are shown below. It is important to mention that the tests were done using:

- Standard control buttons for the robot
- Sip-and-puff controller
- Eye-blink controller

Then they were compared in a table. Figure 10 shows the first experiment for the standard electric wheelchair (with GoPoGo robot instead) with maze path that tests and implements different type of commands like forward, backward, left and right. This test can prove the speed of the wheelchair controller and its efficiency.

The second experiment was done on a straight path of 1.97 m length shown in Fig. 11. Two types of tests were done, the first one is going forward and the second one is going backward.

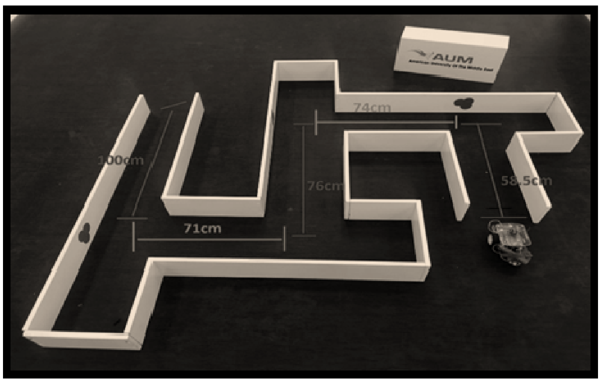

Fig. 10: Maze test path

The third experiment was done with obstacle ahead of the robot as it shown in Fig. 12. This experiment actually tests many commands, as well as it tests the response speed of the stop command, which is important for the safety requirements and needs.

Table 2 shows the obtained results in all the above three experiments: Using standard control buttons, eye-blink controller and sip-and-puff controllers. Although the standard buttons control is better in the majority of the tests, the other controllers seem to have acceptable results and even outperform the standard control in some cases.

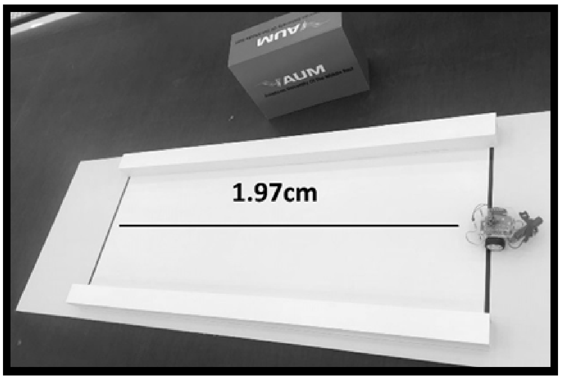

Fig. 11: Straight test path

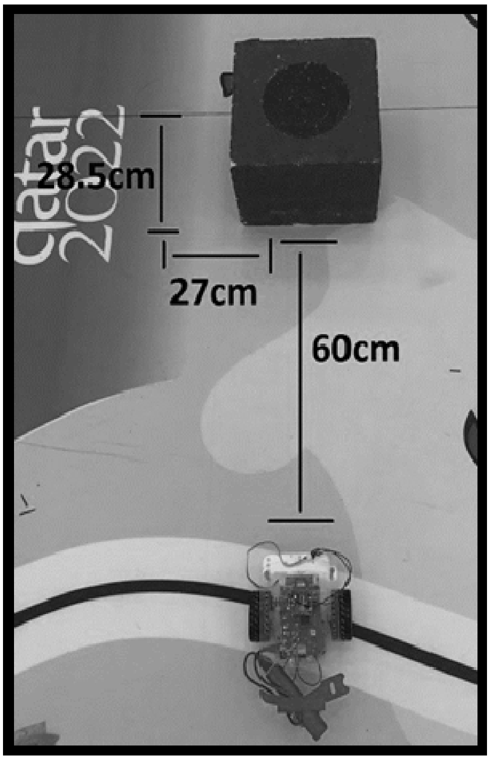

Fig. 12: Test path with obstacle avoidance

Table 2: Time comparison between standard, eye-blink and sip-and-puff controller

Path type	Standard	Eye-blink	Sip-and-puff	Largest difference
Maze	46.5s	56.5s	60.5s	60.5 - 46.5 = 14s
Straight (Forward)	18.9s	19.5s	17.5s	19.5 - 18.9 = 0.6s
Straight (Backward)	16.2s	16.8s	16.6s	16.8 - 16.2 = 0.6s
Obstacle ahead	20.3s	17.2s	16.9s	20.3 - 17.2 = 3.1s

Conclusion and Future Work

Helping physically disabled people to increase their mobility and depend on themselves is a main challenge. This challenge is increased when even the upper extremities are not functioning. In this case, an ordinary joystick controlled electric wheelchair is not sufficient to provide autonomous user movements.

Several solutions exist to overcome hand usage disability, such as chin control, voice control, tilt control, eye-blink and sip-and-puff control. Each of the mentioned solutions has its advantages and disadvantages, making it ideal for some situations and not acceptable for other cases. Furthermore, the user can get fatigue by using a method for a long time. Therefore, a genuine idea is to apply two solutions at the same time, whereby the user can switch between the two methods at any time as he pleases.

In our work, we designed an electrical wheelchair controlled by two methods in addition to the conventional joystick: Eye-blinking and sip-and-puff control. This is an innovative idea to solve the mentioned fatigue or situation problem. The user can select the method he wants by push button connected to his chin. If eye-blink control is selected, the user only needs to blink his right, left, or both eyes to drive the wheelchair without using any other part of his body. On the other hand, if the sip-and-puff control is selected, the user moves the wheelchair by simply sipping or puffing through a tube. Our system needed just a few sensors (IR and pressure), microcontrollers, small Raspberry Pi computers, a battery and a push button. This system will be of low cost due to the cheap components used.

As a future work, the system is to be built on an existing power wheelchair, connected in parallel to the joystick control cables. It will be then tested in different scenarios to produce outputs compared to a standard joystick control.

The design needs several enhancements, starting by a hardware redesign that can omit the microcontroller's part to reduce delay and cost. Another important enhancement is adding distance sensors that will detect obstacles on the wheelchair's way. This detection can be included in the software's design in order to avoid obstacles. This will be part of a smart wheelchair that can interpret the user commands and needs and then act upon them (Simpson, 2005). The smart wheelchair needs to be given a command such as going to somewhere and then it will try to apply this command, such as the autopilot mode in airplanes.

Further enhancements can include solar energy instead of a regular chemical battery. Also have a waterproof controller so that the chair can be used in outdoor environment. An emergency special code on a dedicated button can be added. This code will cause a GSM modem to send SMS message to an emergency number for help.

Ethics

This article is original. The author declares that there are no ethical issues that may arise after publication of this manuscript.

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