Head Movement Based Control System for Quadriplegia Patients

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***Abstract*— A driving aid system, which utilizes only a person head movements, is designed and implemented on a small DC-Motor vehicle prototype. The system is configured to accept a pre-assigned driver's head tilts for the speed and steering control actions. The head tilts are recorded using an accelerometer, which is mounted on a head-band that fits the driver head. The head tilts collected data are transmitted via a Bluetooth transmitter after being interpreted using a Fuzzy Logic based interpreter. Once the data is received by the vehicle's on-board Bluetooth module, it passes to the steering and speed servo-controllers. Both Fuzzy Logic controller and a conventional PID controller are used to carry out the transmitted commands. The driving aid system is first implemented on microcontroller Platform and is verified for proper operation using software. Furthermore, the complete integrated system is tested for functionality and performance.**

Keywords— Arduino, ADXL345 Accelerometer, Quadriplegia, Fuzzy Logic, PID controller, Bluetooth.

I. Introduction

Previously, people suffering from hand or leg or both disabilities, that is known as Quadriplegia (a condition that occurs when part of the spinal cord inside the neck has been injured, this injury causes loss of feeling and movement in the arms, legs, and trunk, were deprived from the right of driving a car. They have to rely on friends, family and public transportation to get out for daily basics. Remote controlled cars by head movements opens up a new wealth of possibilities.

In 2007 the Ministry of Social Development, the Supreme Council for the Affairs of Persons with Disabilities, the Committee on the National Register and the Ministry of Health conducted a survey of disability in Jordan with the exception of the capital city, the survey data indicated that the number of people with disabilities reached (25,143) cases, a rate of 0.5 % of the population in 2007. Upon Arab Countries people with hand or leg or both disabilities in Sudan rated 5% of the total population, thus topping the list of Arab countries, followed by Palestine with 4% of the total population, followed by Oman with 3% of its total population, then The Hashemite Kingdom of Jordan with 2% of its population, while the figure was 0.5% in Qatar. From the mentioned statistics, it's obvious that this project will be very helpful to this category in the local and global society [1].

The idea started in Anna University Chennai, India [1]. The main idea was so simple just to enable the disabled person to move his wheelchair in a fixed speed not taken into account how to control it completely. In this work a new system is developed based on the same idea, however, it enables the disabled person to be fully trusted on himself to move and control a vehicle with an instinctive movement.

This paper describes the basic concepts that is basically to capture a pre-assigned special head tilts, which interpreted using a Fuzzy Logic (FL) controller into speed and steering commands. As easy as it might sound, it also poses challenges in distinguishing the target control signals from personal reflexes. Hence, the use of the Fuzzy Logic controller to interpret these preassigned head movements. A Gyro Accelerometer system connected to the person's head is used to record the head tilts and to pass it to the FL interpreter. These tiny Micro Electronics Mechanical (MEMs) inertial devices provides fix axes information: rotational angles and acceleration measurements. Their small size, low power requirement, and simple interface make them good candidates for the selected task.

Once the head movements are identified, as speed and steering commands, they are to be the vehicle on board controllers should provide the necessary control actions to perform the user's intended tasks transmitted to vehicle on board controllers in order to maneuver the vehicle accordingly. FL controllers on the vehicle's side will be used to regulate the speed and the steering (i.e. gas pedal and the steering wheel).

FL based controllers is used to control position and regulate the vehicle speed and breaking system. Also it is used to interpret the head movements and generate the corresponding appropriate car desired movements and speed. The Gyro Accelerometer "i.e. head movement" is connected to a Bluetooth communication system.

In this paper section II provides the conceptual design of the system. Section III sheds more light on the methodology used in designing the head piece and the car's system. Section IV illustrates the system implementations. Section V highlights the results and testing done on the speed subsystem and the steering subsystem. Finally, section VI presents the paper's conclusion and suggests future recommendations.

II. PRELIMINARY APPROACH

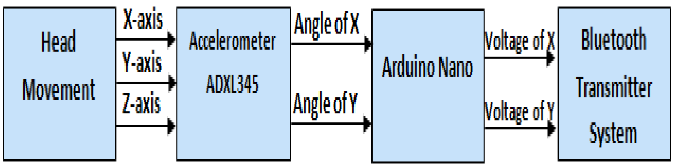
The engineering conceptual design based on the person's head tilts captured and interpreted into car speed signals and steering signals. The basic idea relies on using a pre-assigned head tilts to replace the hands and legs actions that persons typically use emerged challenges from replacing two body parts with only a signal member is clear and evident. However, the motivation and the rewords generated by such a system is overwhelming. Head movements were classified into vertical and rotational movements, both movements were chosen so the disabled person catch up with the road.

The main challenge was to create a capture mechanism (i.e: Cruise) that distinguishes between the target controls signals from personal reflexes.

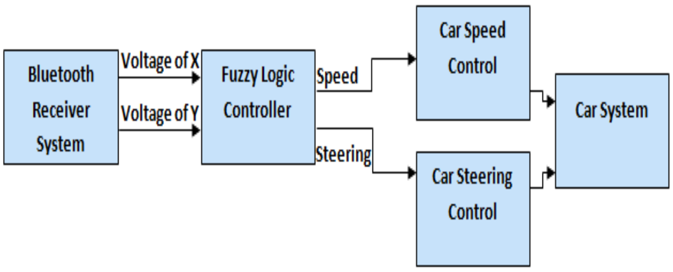
III. METHODOLOGY OF THE PROPOSED SYSTEM

The overall system as shown in Figure 1 consists of two parts; the head piece and the vehicle's system. These two systems are connected wirelessly through Bluetooth modules.

The head piece is designed and implemented using Arduino, because the ADXL345 has a built in library on it, while the vehicle system is implemented using MATLAB, an interface between the head piece and the car's system is then created.



A. *Head Piece.*



B. *Vehicle's System*

Fig. 1. Overall System Design.

A. *Head Piece*

The head piece block diagram shown in Figure 1, A; consists of an accelerometer and an Arduino Nano in order to collect different angels of head's tilts. Collected data then transmitted through Bluetooth HC-05 to car's controller.

The most important reason for using Arduino Nano was to map the voltages from the ADXL345 to angles, it's also light which is needed for the head piece.

As shown in Figure 2, A; rotating around the z-axis is the side to side movement as in looking left and right, B; Rotating around the x-axis would be the motion when you look up or down, and C; Rotating around the y-axis is tilting the head side to side.

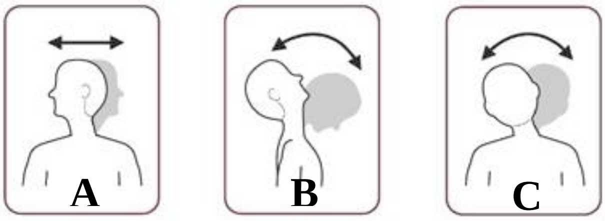


Fig.2. The Motion Axes, A. rotating around the z-axis represents the user's feedback, B. Rotating around the x-axis represents the speed and breaking signal , C. Rotating around the y-axis represents the steering signal.

The ADXL345 accelerometer sensor module is used in order to capture the vertical movements (i.e., speed and breaking signals) and the rotational movements (i.e., steering signals).

B. *Vechial's System*

The complete car's system is illustrated in figure 1, B, where the data is received by Bluetooth HC-06. The microcontroller is used as an on-board controller where it is used to control the two DC Motors (i.e. speed and steering System) distributed to the differential and then to the wheels.

Typically, the output of a FL controller is derived from the rule base using the system's fuzzified inputs. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior final step, defuzzification. The process itself consists of four stages, which is illustrated in Figure 3 [3][4][5].

FL based controller is used to interpret the head movements and generate corresponding appropriate car desired actions. We took a reference with respect to the head movements as: moving it forward represents a positive value and moving it backward represents a negative value.

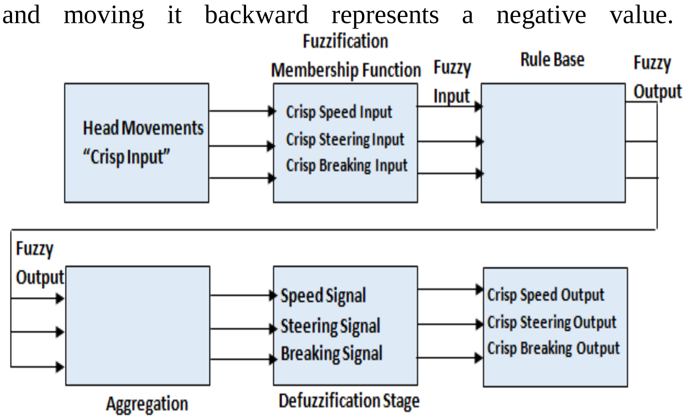


Fig. 3. Fuzzy Logic Interpret scheme

FL controller used to provide variable speed and steering angles, by mapping different voltages values into angles through almost 25 membership function.

In order to differentiate between natural head movements and intended head movement's, a capture mechanism is used as the car's cruise, these movements are then interpreted using a FL controller into speed and steering commands.

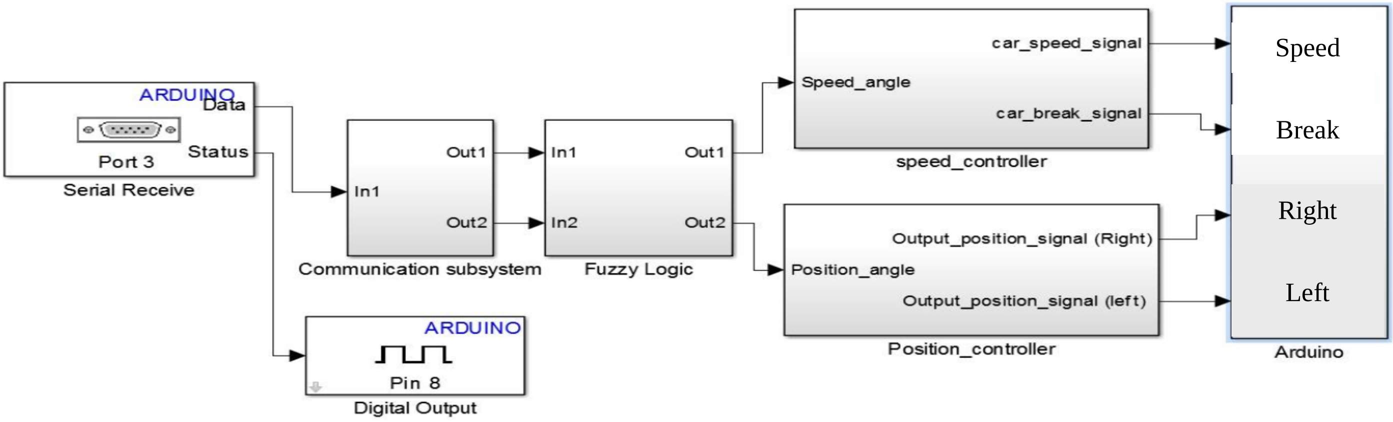


Fig. 4. Simulink Car's System.

The capture mechanism which differentiate between natural head movements and action movements by calculating the head angle's derivative, if the head speed is high it will set at a certain speed (i.e.: it holds the last head's speed control signal). This will allow the user to move freely. Any negative angle represents the de-capture which enables the user to control the car's speed again. The same for the steering signal; the head angle's derivative is calculated, if the derivative is high, the control signal will be eliminated.

Since FL controller depends on user knowledge rather than system's classifications this feature makes the system design applicable on any other applications (e.g., Wheelchair) [3][4].

The control signal comes out of the fuzzy logic controller enters the L289N H-bridge to drive the positon control signal (i.e., steering system which consist of the DC Motor with the feedback potentiometer) and the speed control signal (i.e., DC Motor speed regulation).

The steering system is controlled using PID Controller [6][7][8][9]. The reason why the speed of the DC motor in the steering system must be controlled that in many cases the desired results cannot be obtained as wanted, and as calculated in theoretical terms, also decreasing the steady state error of the system and increase the response speed which will enhance the system performance.

IV. System Implementation

MATLAB software is used in designing and implementing the car's speed and steering. The reasons for using this software comes from the fact that MATLAB is a very powerful engineering tool, it's the industry standard computing platform, and it is used for high powered scientific computing and algorithm testing. The most important reason; the need for using FL toolbox. FL toolbox was used to control position and regulate the car speed and breaking systems. In addition, it was used to interpret the head movements and generate corresponding appropriate car desired actions[10].

Arduino Software was also used, it's a nice platform with simple tools for developing interactive objects[11]. Arduino was used in designing and implementing the head piece, which contains the Arduino Nano, HC-05 and the ADXL345[12].

A. MATLAB Implementation

Complete car's control system was designed and implemented in MATLAB/Simulink. Figure 4 shows the developed and tested three sub systems. These systems consist of: the positon control, the speed control and the communication subsystem (i.e., the serially received signal consist of two signals; speed and steering, they're divided through communication subsystem).

V. Results and Discussion

This work allowed variable speed and steering commands that provides flexibility upon others work.

A. Capture Mechniasm Results.

Figure 5 shows the degree of the head motion for 80 seconds with the speed of the car. Head motion started from 0° and raised to 20° at normal speed, the speed of the car started to grow reaching 52 km/h, rapid motion of the head at the 15th second led to Cruise on the same speed before the rapid motion (60 km/h), after capturing the speed of the car at the 30th second there were different degrees of head motion without any change in the speed. At the 30th second there were a reversed motion in the upward direction of the head (break) led the head motion control the speed once again and lasted until the 40th second, which led the speed of the car turning to zero, at the 40th second the head appeared to move from 0° to 10° in a downward direction, which led to increase the speed of the car to 30km/h. At 60th second the speed was captured again by a quick motion of the head.

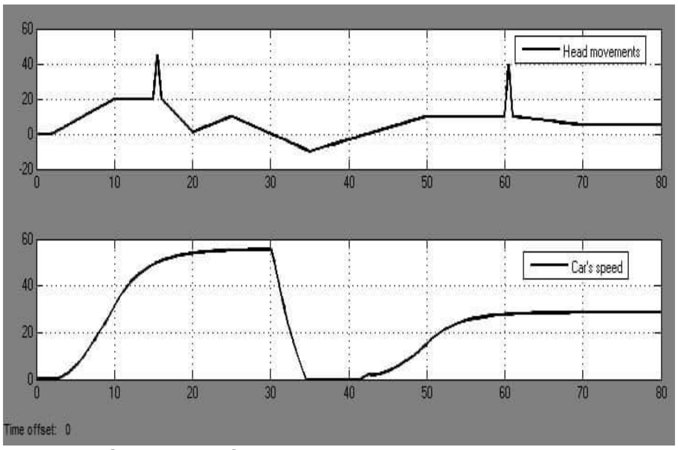


Fig. 5. Speed Capture Mechanism.

Figure 6 shows Degrees of the head rotation with the degrees of car's wheels rotation for 50 seconds, where the movement of the head and the wheels to the right represents by positive values. And the motion to the left represents by negative values. At the 10th second the head moves at high speed to the right and then at a moderate speed to the left, it is noticed that the wheels fast rotation to the right is negligible by the system due to the high speed, while the moderate rotation to left will be accepted so the wheels will rotate to the left with the head movements. In the same manner at the 15th second and the 25th second, there was a quick movement of the head but the system was not influenced by that move.

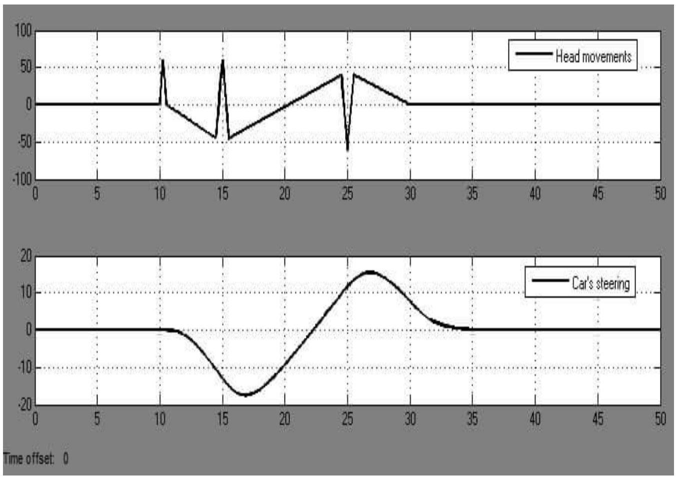


Fig. 6. Steering Capture Mechanism.

B. Speed System Results

The testing was done using Potentiometer as the input, a mapping was done to change the input to (-90 to 90) degrees. Input voltages were calculated form pin 3 and the output voltages were calculated before and after the H-Bridge the corresponding results are shown in TableI.

TABLEI. SPEED SYSTEM TESTING

Angle	Output Voltage	Speed Output Control Signal	
		Speed	Break
Any negative angle	4.88V	4.88V	4.88V
0 deg	0V	0V	0V
10 deg	0.66V	1.17V	0V
30 deg	1.79V	2.81V	0V
50 deg	2.9V	4.48V	0V
80 deg	4.57V	7.33V	0V
90 deg	4.89V	7.8V	0V

As the angle is increasing, the output voltage is increasing as well, hence the corresponding speed will increase. 'Break' represents the output of the breaking system, if breaking is applied the output will be 4.88V else it will be zero.

C. Steering System Results

The testing was done using a potentiometer as the input, a mapping was done to change the input to (-90 to 90) degrees, but the output range of the steering system only (-45 to 45). Voltages were calculated for the output voltage, the results are provided in Table II.

TABLEII. STEERING SYSTEM TESTING

Input Angle	Input Voltage	Feedback Voltage	Output Voltage	Steering Output Control Signal	
				Left	Right
-45 deg	1.5V	2.5V	2V	0V	3.14V
-40 deg	1.62V	2.5V	1.76V	0V	2.71V
-35 deg	1.74V	2.5V	1.52V	0V	2.69V
-20 deg	2.1V	2.5V	0.8V	0V	1.41V
0 deg	2.5V	2.5V	0V	0V	0V
25 deg	3.1V	2.5V	1.2V	2.13V	0V
35 deg	3.26V	2.5V	1.52V	2.69V	0V
40 deg	3.38V	2.5V	1.76V	2.71V	0V
45 deg	3.5V	2.5V	2V	3.14V	0V

When ‘Left’ is zero, ‘Right’ will make the DC motor moves in the same direction, but when ‘Right’ is zero the direction of speed will be reversed.

VI. Conclusions

A driving aid system for the unfortunate person was presented. The proposed design pre-assigned head movements to replace car acceleration pedal actions and steering wheel maneuvering motions. The selected head movements were carefully selected to enable easiness of usage and conform to natural head movements. A Fuzzy Logic base head motion interpreter was successfully designed and implemented. It resulted in outstanding performance and it successfully distinguished natural head movements from the pre-assigned control actions.

The head piece operated fully extracting head motion data and passing it to the on-board FL interpreter. Then the screened data was sent through an on-board Bluetooth module, which will be translated later into control actions on the car’s side. The head piece performed well; carrying out the user’s commands that generated by the head movements. Micro devices were used to build the head piece, which possess no weigh problems for the user.

A fully operational vehicle on-board controller was successfully designed, implemented and tested. The head movements that pertains to the speed were successfully transmitted, then received by the car’s FL speed controller. This enable the user to speed up or to slow down accordingly.

A capture mechanism (i.e. like a cruise control) was included to enable the car driver to engaged/disengage natural head movements from command based movements. This capture subsystem performed well in testing.

All the systems were integrated together and verified for operation and the overall system performance turned out to be good and functional.

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