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Wireless Motion Control of an Intelligent Wheelchair Using Hand Gesture Recognition Technology

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Abstract:

A 'hand gesture' based easy to operate navigation mechanism using the wireless technology in the form of wheelchair control system is presented in this work. This work proposes an integrated approach for detection, tracking and recognition of hand gestures in real time. The approach uses acceleration technology to establish a reliable medium of human-machine interaction for the movement control of an intelligent wheelchair. The remote control facility up to 60 meters and obstacle avoidance technology provided for additional comfort during navigation task for elderly or disabled people. The wheelchair motion is controlled by employing Arduino microcontroller interfaces with MEMS accelerometer sensor, motor driver unit, proximity and edge detection sensors. The designed system was tested with five experiments consisting of 50 trials each by two participants independently. An average accuracy of 98 to 99% was found for all modules. Overall system performed well and result shows encouraging outcomes.

Keywords

Hand Gesture Recognition, Wheelchair control, Gesture controlled wheelchair, MEMS technology, intelligent wheelchair, Assistive Technology.

1. Introduction

Elderly, paralytic persons and physically disabled persons experiences difficulties for navigating in their habitat without any assistance. Wheelchair is the most common mean of locomotion after paralysis or physical disability. Manually it's difficult to drive a wheelchair in familiar habitat even for an able bodied and becomes more tedious for impaired people.

Navigational intelligence associated powered wheelchairs is an important step towards the service of these people. Someone's need for navigation often causes feeling of dependency and demoralization. With the present development in the robotics, assistive technology, embedded system and rehabilitation engineering, it is possible to address this problem.

Literature review reveals that the gestures are used for robot control applications to achieve man machine communication. Zhang et al proposed a wheelchair control system based on hand gesture recognition using machine vision technique he used Haar-like features and the AdaBoost learning algorithm for gesture detection [8]. Hand gesture recognition of digits and letters based on MCS and fast NN is proposed [5]. In a study conducted by Lu et al, A simulated MEMS based hand gesture control system is developed using an automatic gesture segmentation algorithm and the Hidden Markov Model (HMM) is used for the hand gesture model training [6]. A web cam and pressure sensor based hand gesture recognition and control system using Lab view has been proposed by Posada in his work, where wheelchair moves in according to the hand positions. However angle of contraction and light conditions affects the image captured by the webcam. The system tends to unstable if similar objects are detected [4]. A low cost, glove based gesture recognition system was prototyped and tested. This system was having two subsystem under it. The overall system efficiency for the gesture set was found to be 80.06% in IM and 93.16% in EIM mode [3]. In a study conducted by Kawarazaki, an image-recognition algorithm is used for the computation of the wheelchair steering signals. An arm positions decides the wheelchair direction. User need to hold any object in both hand and need to move it as per the intentions of movements. The system gave 90.6% of recognition rate [2]. In another study wheelchair control mechanism is developed using hand gesture vocabulary consisting of five hand gestures and three compound states [1]. Kuno et al proposed a robotic wheelchair with three control modes: an autonomous, a manual with face recognition and a remote control mode. Autonomous mode is just like other autonomous wheelchair, In manual mode the wheel chair is controlled by head movement, or face movement and with remote control user can move the wheelchair near or away from him [7].

Though remarkable progress has been made, still the present day systems suffers from several limitations. Web cams, vision cameras employed increases the bulkiness of the systems. Further some systems required computer for processing the signals. Some of the studies are performed in simulated environment and their testing and validation in real environment in real time was not performed. The system designed by Natesh et al gave 80% accuracy which cannot be considered safe for navigation system. The continuous use of both hands causes the feeling of tiredness to the user as in case of [5]. In the system proposed by kuno et al, the movement of face is considered as a command input, a natural movement in this case may leads to undesired movement of wheel chair, and thus this limits the navigation flexibility of system. In order to overcome these limitations a cost effective working model demonstrating the successful use of hand gesture for controlling a wheelchair has been developed. The proposed navigation systems can be wirelessly controlled without muscular forces as well as without help of attendee. The wheelchair can be operated by simple hand gestures in required directions. The capability to understand movements of hand will improve communication efficiency, which will enable the user to interact with robot bypassing the tedious sets of detailed instructions.

Here, in the presented interface, we used Micro Electro Mechanical Sensor (MEMS) sensor to recognize hand gestures. MEMS is a sensitive device having capability to detect even the small tilt of hand. Use of ZigBee wireless technology makes it to be controlled remotely from near about 60 to 70 meters of a distance. So a person laying on a bed can operate it to call near or away by simple hand movements. The designed wheelchair will autonomously detect and avoid the obstacles in its path. Thus people can operate wheelchair even in smaller spaces without collision.

2. Methodology

2.1. System Architecture

Architecture for wireless motion control of an intelligent wheelchair using hand gesture recognition technology is shown in Fig. 1. MEMS accelerometer sensor is used to control the wheelchair as per the movement of the hand. The accelerometer sensor senses the accelerating force and convert the hand position into 3-Dimensional Output in the form of a particular voltage for the x, y and z coordinate orientation. Crystal oscillator is used here to generate the clock pulse & to support the RF module with its frequency. It is provided in both the transmitter and the receiver section. RF transmitter transmits the data signals with its carrier wave which can be accepted only by the receiver of the same frequency. The signals from accelerometer sensors that are received in analog form has to be converted in to digital form. This is done by employing AD converter and the digital values are fed to Arduino microcontroller. On receipt of these digital values, programmed controller controls the direction of motors through motor control unit.

Depending on the direction of the MEMS, wheelchair directions like front, right, left and back are controlled. Arduino also receives input from proximity sensor and edge detection sensor. A real time working model is implemented with a wheelchair and DC motors operating on 12V rechargeable battery. In this system we are implementing it with Arduino AT mega 328 microcontroller at transmitter and receiver sections. Proposed system designed to be work on 12V DC power supply.

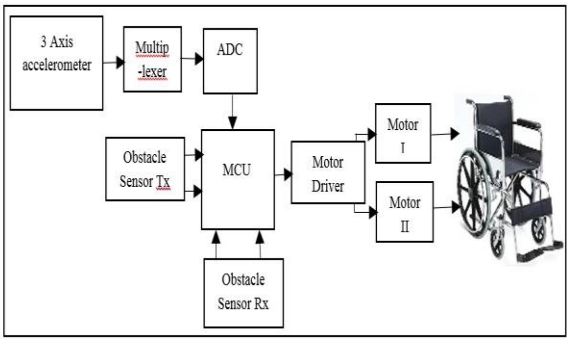

Figure 1. General Architecture of hand gesture based wheelchair control system.

2.2. Components

2.2.1. Hand gesture module

The gesture detection module is designed by using a three axis ADXL 335 accelerometer sensor. This is a very handy device for measuring object's relative orientation with the earth. The sensor measures change of speed of anything on which it's mounted and thus gives a particular value of voltage for orientation along three coordinate and provides information in detecting the hand gestures. The threshold values for X, Y and Z co-ordinates are determined with the help of accelerometer readings for different hand orientations. The values obtained are thus observed in digital form through the serial port of MCU on the computer's monitor as shown in Fig. 7. It provides the basis for sorting of the hand gestures. The following block diagram explains working of an accelerometer.

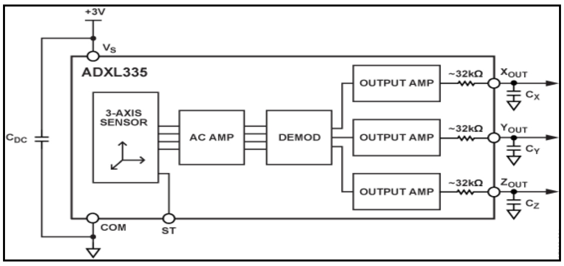

Figure 2. General Architecture of hand gesture based wheelchair control system.

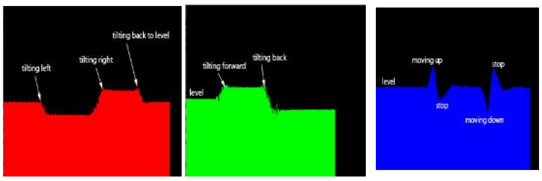

Figure 3. Accelerometer levels in X, Y and Z directions.

The actual happening within the sensor part during movement of MEMS is shown in Fig. 3. a) in X axis movement, level at start then left tilting then the right tilt and finally level again. Fig. 3 b) Orientation in Y axis, level at start, forward tilt, back tilt then level finally. Fig. 3 c) Z axis. First level, quickly raised up, then quickly lowered. Up movement generates drastic increase in force followed by a sudden decrease at stop, finally the voltage levels out again. Opposite effect is seen during down movement.

2.2.2. Transmitter & Receiver module

Hand gesture recognized by the MEMS sensor transmitted to the controller in digital output by RF transmitter after encoding. Fig. 4 a) & b) shows the block diagram. The transmitted data signals are received by RF receiver which operates in the same frequency as the receiver. The encoded data signals are separated by the decoder

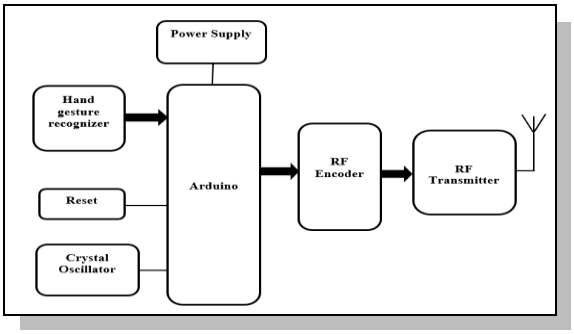

Figure 4. a) Block diagram of transmission section.

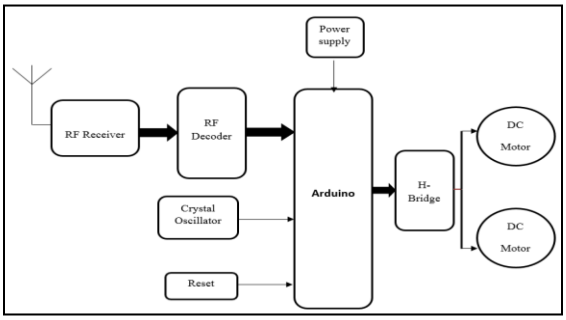

Figure 4 b) Block diagram of receiver section.

2.2.3. Control module

Microcontroller

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ATmega328P based Arduino microcontroller has 14 digital I/O pins (6 PWM pins), 6 analog inputs. The microcontroller, the motor driver unit, proximity and edge detection module together forms the control module for designed system. Sensor is interfaced with controller. Specific values of accelerometer are analog inputs which are converted to digital using ADC so that it can be understood to controller. The data of various hand positions obtained from the accelerometer gives the readings for deciding the threshold value for x, y and z coordinates.

Motor driver unit

For the desired motion of the wheelchair high torque geared DC motors were used. L293D IC is used to control the motors. This is bi-directional IC and enable to change the direction of rotation by simply reversing the polarity. The motor driver is controlled by the microcontroller. For smooth turning operation of the wheelchair Pulse Width Modulation (PWM) is used .The PWM allows the power to be sent in small packets over higher frequency through the microcontroller to the motor driver. The constant ON and OFF states helps for smoothly conduction of turning motion.

H-Bridge has four switching elements as shown in the Fig. 5 a & b.The switches are turned on in pairs, either high left and lower right, or lower left and high right, but never both switches on the same "side" of the bridge.

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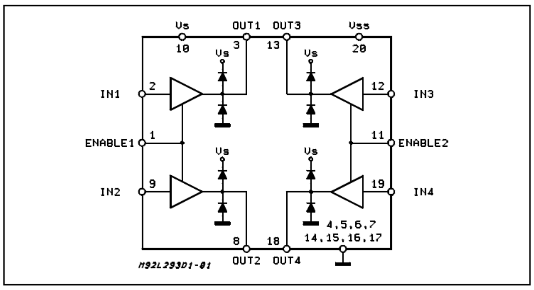

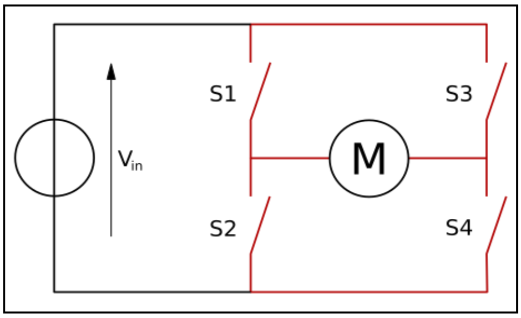

Figure 5a. H-bridge circuit diagram.

Figure 5b. H-bridge switch diagram.

Proximity detection module

To determine closeness of objects or the walls with wheelchair during motion an ultrasonic sensor, HC-SR04 is used as part of the proximity detection module. The sensor sends the analog voltage values to controller which is converted into centimeters and thus the distance is calculated. Thus the collision with the obstacles or walls during motion is successfully averted.

Edge detection module

The edge detection sensors mounted on the wheelchair at its backside. Sensors are positioned at digital low state constantly on the plain surfaces, but during backward motion at sharp slope or height if any it sends a digital high signal to the controller.

2.3. Control mechanism

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MEMS chip has piezo resistive material, which is suspended by four beams doped with piezo resistive material. On accelerated motion of sensor, in any direction, the beams are deformed during mass movement and thus the resistance of the piezo material changes. Change in resistance causes the sensor to detect the accelerated motion. MEMS sensor has a Tilt register in it. Any change in the direction causes the change in values of the tilt register. These digital inputs are given to the Arduino controller. Then the Arduino produces the output which instructs the driver circuit to close or open the switches in it. Depending on the switches closed it produces either positive or negative output and motor rotates accordingly. Microcontroller is programmed in such a way that, whenever MEMS sensor detects the extension of hand it will rotate both motors in anticlockwise directions and wheelchair will move in forward direction. Similarly for flexion of hand backward movement is assigned. Right side tilt of hand and left side tilt are assigned to right and left turn respectively.

The different hand gestures and their corresponding control commands are depicted in Fig 6. On the basis of tilt of the MEMS, microcontroller controls the wheelchair in front, right, left, back directions. Additional safety feature called "panic button" is provided. On pressing, it wheelchair stops immediately. Further the proximity sensor and edge detection sensors are used to detect the obstacles near wheelchair and accordingly microcontroller will control the movement of wheelchair for avoiding these obstacles.

3. Experimentation

Experiments were conducted to test the validity of proposed model. Two subjects have controlled the wheelchair with our designed interface. The experiments were repeated for five times with 50 trials of commands in each experiment to test conformity of operability of designed system. The gestures employed for different motions and their threshold values in x, y and z coordinates are outlined in Fig. 6.

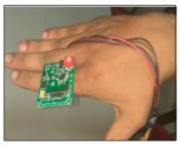
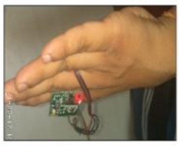
	Forward	$X >= 250\ Y <= 250$ $Z <= 210\ \&\ Z>=275$
	Backward	$X <= 250\ Y <= 250$ $Z <= 210\ \&\ Z>=275$
	Left	$X <= 250\ Y >= 250$ $Z <= 210\ \&\ Z>=275$
	Right	$X <= 250\ Y <= 250$ $Z <= 210$
	Stop	$X <= 250\ Y <= 250$ $Z>=275$

Figure 6. Hand gestures and corresponding control commands.

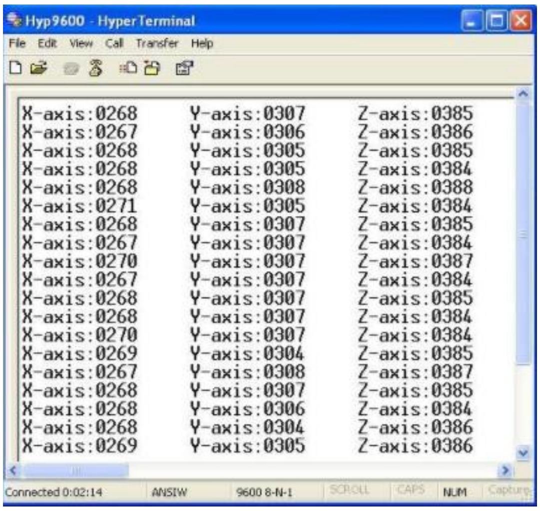


Figure 7. X, Y, Z coordinate values of accelerometer sensor.

4. Results & discussions

In all 100 trials (5 experiments x 10 trials by each subject) of experiments were conducted by two participants separately. The proposed navigation system was found to be working flawlessly as per the given gesture commands. The number of successful recognition of detection of gesture, obstacle and edge are noted against total number of trials in each experiment. The ratio of successful trial to the total number of trial gave the accuracy of system. Results of experiments for both the participants are shown in Table No. 1 and their corresponding graphs are depicted in Fig. 8 a) and b)

Table 1. Experimental results (for 100 trials)

Expt. No.	Gesture Recognition		Obstacle Avoidance		Edge detection	
Sub	S-1	S-2	S-1	S-2	S-1	S-2
1	98	96	98	98	100	98
2	100	100	100	98	100	100
3	100	98	96	100	98	98
4	98	96	100	98	96	100
5	100	100	100	100	100	100
Avg %	**99.2**	**98.0**	**98.8**	**98.8**	**98.8**	**99.2**

It is evident from the above results that, in all five experiments first participant shown an average accuracy of 99.2%, 98.8% and 98.8% in gesture, obstacle detection and edge detection respectively. Fig. 8 a) shows the graphs of performance quantifiers for first subject. First participant shown quite good performance in all three control modules. His performance in all experiments were in between 98% to 99%, which is quite promising.

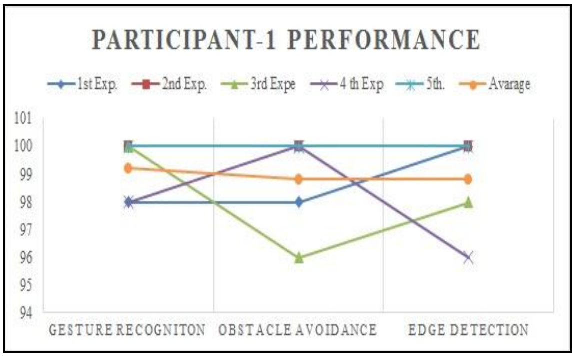


Figure 8a. Experimental performance Participant 1.

On the other hand second subject shown an accuracy of 98%, 98.8% and 99.2% in all three modules in the same order. This participant also shown consistent performance in all five experiments. Thus from these ten experiments and their consistent performance, it can be inferred that the designed system is performing quite well irrespective of the user. Both participant shown more than 98% accuracy with our designed system which is quite encouraging.

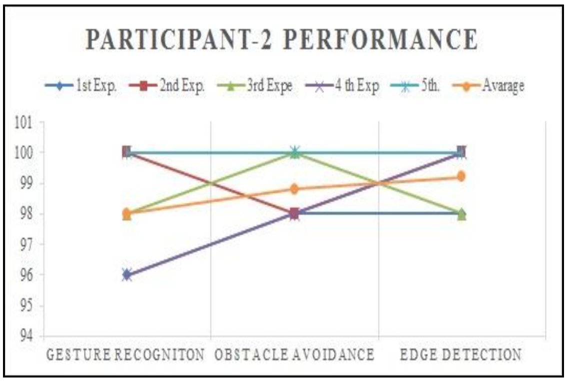


Figure 8b. Experimental performance Participant 2.

Range of communication for the employed wireless ZigBee module found to be well operable up to 60 meters in the indoor conditions. This facilitated the control of wheel chair remotely. The obstacle detection and avoidance is designed for distance of 15 cm from the wheelchair. If there is an obstacle detection, the wheelchair moves away from the obstacle till it is completely avoided. Proximity sensors found to be well operable for maximum angle of 200-250.

5. Conclusion & Future scope

This study successfully demonstrated wireless motion control of an intelligent wheelchair using hand gesture recognition technology. The five different gestures were tested to verify the correctness of transmitted control codes. The designed system was found to be very quick and responsive for gesture recognition and obstacle detection. Overall accuracy of the system is more than 98% for all three modules viz, gesture recognition, obstacle avoidance and age detection. Age detection and obstacle avoidance made it intelligent still a low cost affordable device. This wireless gesture based navigation technology provided an effective medium of locomotion for disabled. The system got positive feedback form the users.

As a part of further development, this assistive technology could be integrated with EEG or EOG interface mechanism, so that the wheelchair can be operated by brain signals of users, which will further improve its usability of ALS or tetraplegia patients. An autonomous navigation technology in indoor environment with fixed path can be implemented for ease of movement in familiar environment. An additional feature of mobile alert messaging system may be implemented in case of emergency with user.

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