

# Engineering Better Electric-Powered Wheelchairs To Enhance Rehabilitative and Assistive Needs of Disabled and Aged Populations

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## 1. Introduction

All around the world, the age distribution of the world population is shifting towards older ages, causing an increase in the world population's mean or median age. The corresponding figures for the world population's mean age as a whole are 23.9 for 1950, 26.8 for 2000, and 37.8 for 2050 (United Nations, 2004). The growing trend of the world population's mean age is largely due to the decline in the fraction of the population composed of children (declining fertility) and the rise in the fraction of the population that is elderly (due to longer life expectancy). The impact of population ageing on developed countries with strong economy strongholds, such as United States of America (USA) and Japan, is even more severe. To a certain extent, Singapore, serving as a Southeast Asia's financial and high-tech hub, is also affected as well. Population ageing has major consequences and implications in all areas of our daily life as well as other important aspects such as economic growth, savings, investment and consumption, labour markets, pensions, property and care from one generation to another. Additionally, health and related care, family composition and life-style, housing and migration are also affected.

According to a published report titled "Singapore's population ageing" (CAI, 2006), it is found that the number of seniors will increase from 8.4% in 2005 to 18.7% in 2030 as illustrated in Chart.1. In absolute terms, seniors will increase from about 296,900 in June 2005 to 873,300 in 2030. The report continues to elaborate that "the first batch of post-war baby boomers will reach 65 years of age by 2012. Today, one out of every twelve Singaporeans is aged 65 or above. By 2030, this ratio will become one out of five". These figures indicate that our ageing population in Singapore is escalating at a fast rate. Other than the aged population issue, the numbers of disabled people with mobility difficulties are expected to increase over the years. Mr. Heng Chee How, Minister of State for National Development and Mayor of Central Singapore District, backs up this statement for Singapore context and he believes that the key driving forces behind this expected increase are, "the proportion of a growing population who use the wheelchair as a result of medical conditions and accidents and the rate of ageing of the population itself." Similarly, in

worldwide context, an estimated 100-130 million people with disabilities need wheelchairs. Experts predict that the number of people who need wheelchairs will increase by 22 percent over the next ten years (R.A. Cooper & R. Cooper, 2003). Due to the increasing population of mobility impaired people in the world, there is an overwhelming need for wheelchairs and the research and development required to make these wheelchairs safer, cheaper, more comfortable and effective and widely available.

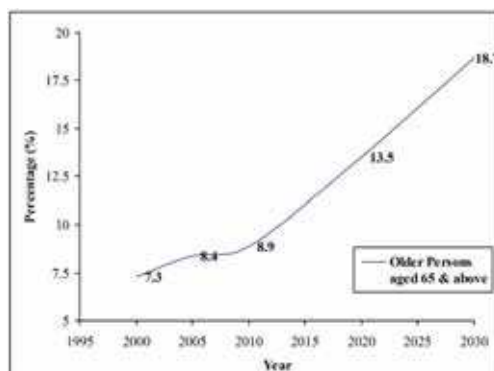


Fig. 1. Proportion of Resident Population Aged 65 & Over From 2000 – 2030

Source: Singapore Department of Statistics (DOS), 2005

Some advanced technologies can be explored for engineering better wheelchairs to enhance the rehabilitative and assistive needs of the disabled and aged populations. Assistive technology (AT) is defined as any technology that is developed to assist people with disability or old age to perform tasks that are too difficult for them to complete. It promotes greater independence for people with disabilities by enabling them to perform tasks that they are formerly unable to accomplish, or has great difficulty accomplishing, by providing enhancements to or changed methods of interacting with the technology needed to accomplish such tasks. By doing so, the daily needs of the disabled and aged populations can be better taken care of without any extra assistance. As mentioned earlier, the aged and disabled populations are rising at a fast pace, hence a lot of research efforts have been poured into the AT field. Many researchers are devoting their time and attention on AT research work so as to improve the lifestyle of the aged and disabled peoples (Cooper et al., 2008).

Wheelchair technology is one of the most favourable technologies to be investigated because the demand for electric powered wheelchairs has been increasing very rapidly due to ageing populations. The introduction of wheelchairs allows individuals to complete daily tasks with greater independence and to access school, work, and community environments. More individuals are able to benefit from the new options and sophisticated wheelchair-related technologies. For examples, Nanyang Technological University (NTU) in Singapore has developed a wheelchair with wheelchair gap enabler, which allows wheelchair users to board a bus faster and easier and also clear low steps, such as roadside curbs, with ease and efficiency. The iBOT developed in USA can engage four-wheel drive to maneuver rough terrain, go up slopes, or climb 4-inch curbs. These improvements have given great helps to the disabled people sitting in the wheelchairs to overcome many difficulties. Since

wheelchairs have been in use for several hundred years, it is going to continue to evolve in their design and use; much remains to be learned about optimum design and safe use of wheelchairs (Cooper et al., 2006).

Electric-powered wheelchairs (EPWs) have gained increasing popularity among the disabled as well as aged populations because they provide functional mobility for people with both lower and upper extremity impairments. They are becoming increasingly important as more users transition from manual mobility to powered mobility. This shift is especially true for individuals with progressive conditions and people with high levels of impairment (Cooper, 1998). Advances have been made in the design of EPWs over the past 20 years, yet there are some aspects in these wheelchairs which have not improved substantially since the early 1980s. These include adequate mobility and comfort with enhanced control methods (Ding & Cooper, 2005), proper leg and foot support (Lei et al., 2005), advanced maneuver and navigation techniques (Aissaoui et al., 2000).

In this chapter, the three main features to be incorporated onto electric-powered wheelchair are discussed. These features include 1) voice-activated control and closed-loop current control for electric-powered wheelchair, 2) personal navigation system based on wireless sensor network and 3) motorized foot rest which give a way of mobility for handicapped and elderly people to move around in indoor condition easily and to perform rehabilitative excercises without being dependent on someone else.

## 2. Existing Electric-Powered Wheelchair Technology

Electric-powered wheelchairs available in the market provide much functionality for the user and are composed of many different sub-systems. Each of these sub-systems and their functions can be tailor made for catering to a specific target user group.

The basic system of a wheelchair is the drive system which usually consists of a two wheel drive type or a four wheel drive type. The mid wheel drive power wheelchair is maneuverable in small spaces and provides for a tighter turning radius but the wheelchair may get stuck on uneven terrain. The front wheel drive system is very stable for uneven terrain and for inclined mobility but they are slower as compared to the rear wheel drive system. The most common type is the rear-wheel drive wheelchairs. The chair is stable and can achieve high speeds. The only drawback of this system is the large turning radius of the wheelchair (Ding & Cooper, 2005). External all-terrain wheelchairs typically use the four wheel drive system as they are easier to maneuver and control. Wheelchairs with special functions such as stair climbing or dynamically balance function use a wheel-cluster system (Ding & Cooper, 2005). Stair climbing is done by balancing the centre of gravity of the chair between the front and the rear wheels at all times. Dynamically balancing the wheelchair on two wheels, mimicking the human balance model, enables the user to move around at eye level. Our system uses a rear wheel drive system as the stability of the wheelchair is an important criterion when designing for elderly users or for users with limb disabilities.

Portable power is an important aspect of the wheelchair. The study by Beno et al. (2002) explores the feasibility of flywheel batteries for vehicles in general. Another study by Cooper & Tai (1998) discusses the feasibility of flywheel batteries for electric-powered wheelchairs and explores the safety issues such as fragmentation failure or touch-down failures of the flywheel. Typically, electric powered wheelchairs use chemical batteries as their energy source but it makes the wheelchair bulkier and difficult to transport.

There are many ways for the user to input information into the wheelchair control system. The joystick is the most commonly used mode of input for the wheelchair. Cooper et al. (2000) have designed an isometric joystick and compared its performance standards to a position sensing joystick while Diciano et al. (2007) developed a digital isometric joystick and studied the force applied by the user on an isometric joystick and motion sensing joystick. Jones et al. (1998) studied the performance of wheelchairs using a performance sensing joystick and a force sensing joystick. Oskoei & Hu (2008) propose a myoelectric based virtual joystick, which utilizes myoelectric signals from the forearm of the user to navigate the wheelchair. The advantage of this methodology is that users with severe motor disabilities find it easier to maneuver the wheelchair. Another mode of input for such users is voice recognition. The user trains the system to recognize simple commands such as "GO" or "STOP" and uses them for navigating the wheelchair. Pacnik et al. (2005) and Stanton et al. (1990) have both devised intelligent wheelchairs with voice recognition control. A combination of joystick input and voice recognition input is utilized in the wheelchair designed by us to help users with motor disabilities and to navigate in close-spaced environments.

A navigation system for wheelchairs would require the user not to worry about the path taken and concentrate only on commanding the wheelchair. The Brunel Navigation System for the Blind (BNSB) (Cecelja et al., 2006) is developed by integrating three main technologies: Global Positioning System (GPS), Geographical Information System (GIS) and Mobile Communication System (MCS). The BNSB uses GPS as the main navigational systems which operates in assisted GPS (AGPS) mode and fixes the users' position. The same system can be used for wheelchair users as well but implementing it in indoor environment may not be efficient. Wheelchair users in a fixed indoor environment like a shopping centre or the user's house would benefit much with an indoor navigation system. The Power-Line Positioning (PLP) Indoor Location System (Patel et al., 2006) uses the residential powerline for finding the location of the user. The PLP uses fingerprinting of tone detectors in different parts of the house and the room to localize them and find their location. Use of Wireless Sensor Networks for navigation has been done by (Lei et al., 2005) who have designed a wireless assisted pedestrian system using magnetic compass and accelerometers. Jirawimut et al. (2003) propose a method for dead reckoning correction in pedestrian navigation system while Usui et al. (2005) evaluate the position accuracy of pedestrian navigation systems using 3-dimensional maps in lieu of 2-dimensional maps. For us, wireless sensor network is used for the wheelchair navigation system in known indoor environments along with a digital compass for direction mapping.

Commercial foot rests available for wheelchairs are manual and they have very bare minimal functionalities. These conventional foot rests are manually adjustable to some preset heights and positions which are then locked at that position by an external locking mechanism. The problem with such conventional foot rest is that the old age or disabled user who is normally quite weak needs a lot of strength to lift up his/her legs onto the resting pad of foot rest. Another alternative is to ask someone besides the user to provide the assistance. Additionally, prolong sitting on the wheelchair causes a set of problems to the user as mentioned by Aissaoui et al. (2000). At present, there is next to negligible literature regarding the motorized foot rest and therefore the related work is presented in this chapter.

### 3. Microcontroller Based Voice-Activated Powered Wheelchair Control

This part of the chapter describes the design of a microcontroller based voice-activated powered wheelchair supplementary with joystick control. Most of the conventional electric powered wheelchairs use a joystick as a user input mode of control to maneuver the powered wheelchairs (Nisbet, 1996). The major drawback of joystick control is that users with upper limb disability would find it difficult to maneuver the wheelchair. Moreover, elderly users with weak and jerky hands would be more comfortable giving verbal instructions than navigating the wheelchair using a joystick. The proposed voice-activated powered wheelchair supplementary with joystick control would allow users with weak and disabled upper limb to maneuver the wheelchair easily without the need to use hands. Referring to Fig. 2, the electric powered wheelchair consists of three main building blocks viz. the user interface, the control system and the drive system.

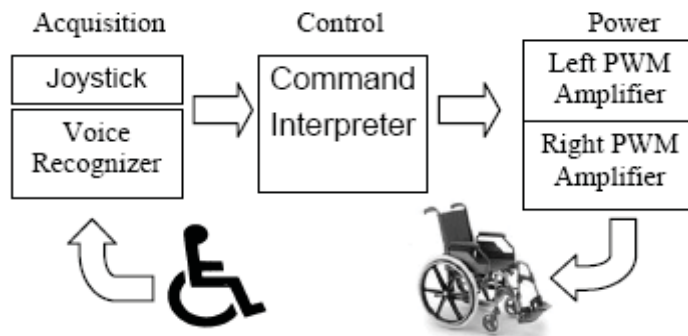


Fig. 2. Block Diagram of an Electric Powered Wheelchair

#### 3.1 User Interface (Acquisition)

This electric-powered wheelchair is targeted for elderly users and users with disability hence, both joystick and voice recognition are used as user interface for acquisition. The supplementary joystick gives a better control of speed for better manoeuvring in confined areas. During the research work, a standard HFX magnetic joystick is used for joystick control. The joystick utilises Hall Effect Sensors to measure the physical movement of the joystick's handle. When the handle is moved, magnets attached to the shaft of the joystick (one for each axis) link the Hall Effect sensors causing a fluctuation in the magnetic field. This causes a voltage change that is interpreted by the integrated microcontroller. Both X and Y axes sensors are placed in series with a resistor and a fixed bias of 5 V is used to power the sensors, and the centre voltage output is 2.5V. The output voltage of the joystick can't be 0V or 5V due to additional resistance, but varies between 0.8V and 4.6V.

The voice processing module, as shown in Fig. 3, consists of a HM2007 voice recognition chip which processes the input voice signals fed through a microphone. The microphone is capable of noise cancellation and voice amplification. The voice recognition chip uses a supervised training method for classification. The voice chip is initially trained by the user. Once the system is programmed with the required commands, the chip operates in the hearing mode i.e. the chip listens continuously and tries to match the words spoken by the

user to the words programmed earlier. If there is a match, it sends an output corresponding to the match; otherwise the module continuously waits and keeps listening. The words recorded by the system are recognized by their frequencies, and different people speak may the same words at different frequencies. Hence, only the user's voice must be used for training the module. The accuracy rate and the ability to work even in noisy environment are very important for the safety and the ease of use of the wheelchair.

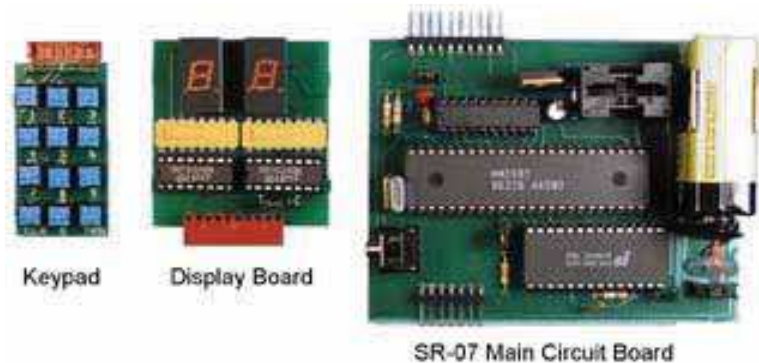


Fig. 3. Components of the SR-07 Voice Recognition Module

The user trains the chip using the included keypad. One of the keys is pressed and the voice command is spoken into the microphone clearly. For example, pressing the number of "01" would train the word number 01 and assign the voice command spoken to it. The LED in the main circuit board blinks off momentarily, signalling the successful acceptance of the word and the number used for this command is displayed. Further commands can be programmed in a similar way.

### 3.2 Control System

The microcontroller chosen for the implementation of the control system is an Infineon XC886 high performance 8-bit Microcontroller with on-chip flash memory for enhanced motor control. It has automatic code generation provided by the software DavE , and can be programmed using C programming language with Keil compiler and debugger. The microcontroller has several peripheral features required by the control of the power wheelchair, such as Capture/Compare Unit (CCU6) with two independent 16-bit timers dedicated for PWM generation for AC and DC motor control, providing 4 compare channels with 7 outputs, and 8-bit ADC with high accuracy, providing 8 channels, to convert the analog input signals to digital signals respectively.

There are two modes of control possible for the drive system viz. the open loop control and closed loop control. In open loop control as there is no feedback from the motor, the microcontroller will not be able to detect any increase or decrease in speed and take corrective action. This may result in a jerk effect that may cause discomfort to the wheelchair user. Providing a closed loop current control using a PI controller, as shown in Fig. 4, would ensure that any abrupt change in the load torque would not result in an abrupt change in the motor torque resulting in close to zero acceleration and negligible jerks during wheelchair operation.

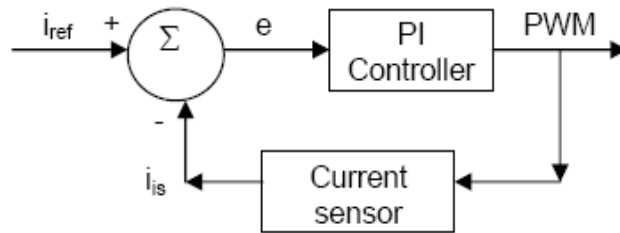


Fig. 4. Closed-Loop Feedback Current Control

The motor torque,  $T_{em}$ , is proportional to the armature current,  $I$ , across the motor.

$$T_{em} = k\phi I \quad (1)$$

$$T_{em} = T_l + J \frac{d\omega}{dt} \quad (2)$$

$$V = iR + k\phi\omega \quad (3)$$

If the current is controlled such that there are no sudden changes, then the motor torque,  $T_{em}$ , would also not have any sudden changes. The acceleration,  $d\omega/dt$ , of the motor is dependent on the difference between the motor torque,  $T_{em}$ , and the load torque,  $T_l$ . Since there is no abrupt change in the motor torque, the wheelchair moves at a constant speed with zero acceleration, hence there is no jerk at all. Hence a good control of current can lead to a much better performance of wheelchair. Furthermore, with the use of current sensor HXS 50-NP/SP2, it is possible to determine if the load current exceeds the current limit. With over current protection implemented, problems like overheating or damage of the motor are limited.

The microcontroller receives analog signals from the joystick, converts them to digital format and interprets and processes them. The voice recognition system processes the voice commands and sends the digitized signal to the microcontroller. The feedback from the current sensors is compared with the reference current and the speed of the motor is determined according to the error between the signals received from user interface and current sensors feedback. The microcontroller outputs the corresponding PWM signals to the motor drive circuit to drive the DC motor. The joystick control and the voice recognition control are further discussed below.

### 3.2.1 Joystick Control

The motion of wheelchair depends on the position of joystick. The duty cycle of PWM signals is generated according to the analog inputs from joystick, and the PWM signals determine the speed of the motors. The frequency of PWM operation is 20 kHz. The analog signal acquired from joystick is converted into digital format in the microcontroller which is used as the reference current signal for the closed-loop current control. X-axis and Y-axis of the joystick are used to describe the position of joystick knob. Different reference currents are assigned to each position. As shown in Fig. 5, the numbers (0 – 10) represent the strength of the reference current signal. The number on the left hand side indicates the left motor whereas the number on the right hand side indicates the right motor. If the reference



number is larger than 5, the motor rotates forward; when the given reference current number is less than 5 (0-4), the motor rotates in the reverse direction.

					10,10					
				9,10	9,9	10,9				
			8,10	8,9	8,8	9,8	10,8			
		7,10	7,9	7,8	7,7	8,7	9,7	10,7		
	6,10	6,9	6,8	6,7	6,6	7,6	8,6	9,6	10,6	
5,10	5,9	5,8	5,7	5,6	5,5	6,5	7,5	8,5	9,5	10,5
	4,8	4,7	4,6	4,5	4,4	5,4	6,4	7,4	8,4	
		3,6	3,5	3,4	3,3	4,3	5,3	6,3		
			2,4	2,3	2,2	3,2	4,2			
				1,2	1,1	2,1				
					0,0					

Fig. 5. Left and Right Motor Current Reference ( $I_{ref}$ ) Distribution over Joystick

**3.2.2 Voice Recognition Control**

The control signal flow diagram of the voice recognition circuit is illustrated in Fig.6. The voice recognition circuit is continually listening. When repeating a trained word into the microphone, the number of the word is displayed. For instance if the word "GO" was trained as word number 01, when saying the word "GO" into the microphone, the number 01 would be displayed. This number is sent to the microcontroller and logic corresponding to it would generate the appropriate duty cycle for PWM generation.

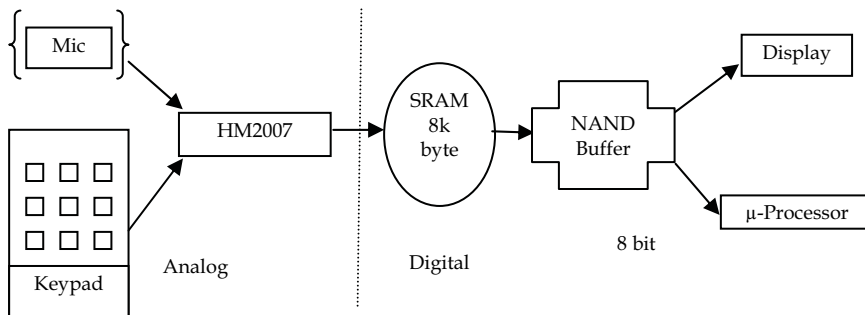


Fig. 6. Signal Flow Diagram of the Voice Recognition Control

The current sensor feedback signal corresponding to the load current drawn by the motor is first checked to see if it is larger than the preset current limit. This is the over-current protection feature. If the load current is within the normal operating range, the feedback current is compared with reference current, generating an error signal. The error signal is then injected into the PI controller to generate the output PWM control signals.



### 3.3 Drive System

The wheelchair has 2 DC motors attached to each of the left and right wheels. By controlling the individual speeds of both motors, the motion, i.e. the speed and direction of the wheelchair can be controlled. For example, the wheelchair turns left if the right wheel rotates faster than the left wheel and vice versa. A DC chopper not only allows adjustable speed control, but it also eliminates discontinuous conduction mode and allows bi-directional rotation. It consists of an H-bridge circuit which allows the direction and speed of the motor to be controlled by the power semiconductor switches. The switches are required to withstand a high current drawn by the motor under load conditions. The PWM outputs to adjacent switches are complimentary to ensure that there is no shoot-through effect resulting in a short circuit of the power supply.

The drive system is made up of two high current PN half bridge (BTS7970B) devices which amplify the input PWM signals to drive the DC motor. The designed PCB drive circuit board can provide a maximum driving current of 37.5A. The control system provides the PWM output signals to the drive system based on the command input signals from the user on the wheelchair. The output voltages are determined by the PWM signals. Fig. 7 shows the PCB layout of the H-bridge and its associated electronic circuit designed for the wheelchair.

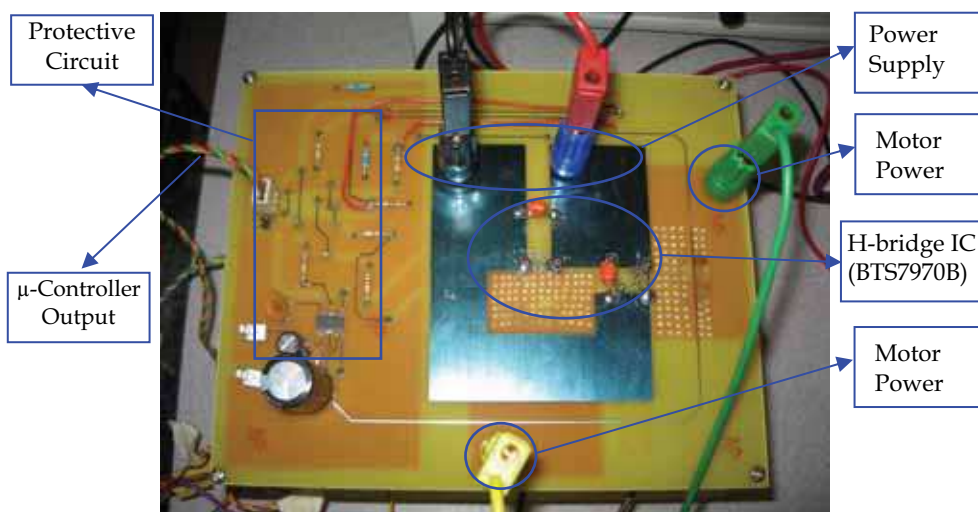


Fig. 7. PCB Layout of the H-bridge and its Associated Electronic Circuit

A 12V 36AH lead acid battery is used as the power supply for the electric-powered wheelchair. Lead acid battery is chosen over a flywheel battery as the wheelchair is designed for users with upper limb disability and elderly users and the risk of any damage due to the flywheel breaking or fragmenting is much higher (Cooper & Tai, 1998).

### 3.4 Prototype Wheelchair

Fig. 8 shows the schematic of the motor drive system and the control system of the prototype while Fig. 9 shows the prototype wheelchair.

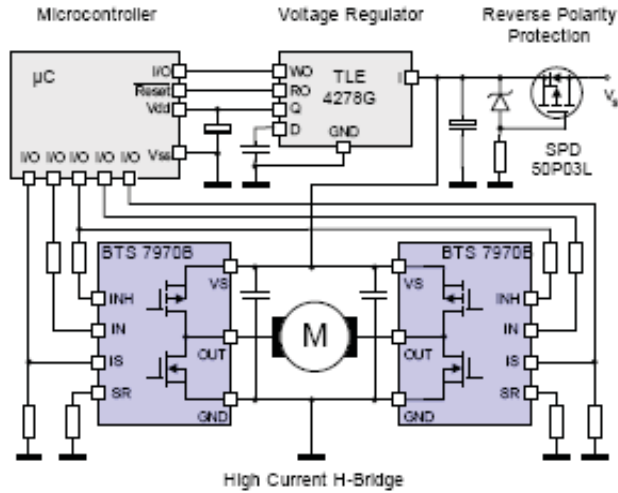


Fig. 8. Schematic Diagram of Prototype Motor Drives and Control System



Fig. 9. Prototype of Electric-Powered Wheelchair

The technical specifications of the wheelchair are given below:

Parameters	Value
Battery	12V , 36AH
Motor	24V DC
Charging Time	9 Hrs
Max. Driving Speed	Forward: 6.0Km/Hr Backward: 3.0Km/hr
Max. Weight Capacity	120 Kg
Total Weight of the Chair	77.29 Kg

Table 1. Technical Specifications of the Prototype

### 3.5 Experimental Results

The speed of the motor is determined by the voltage across the motor armature, as shown by equation (3), as the voltage drop across the armature resistance is negligible at steady state. To vary the voltage of the motor, a pulse width modulator (PWM) circuit is used. The PWM circuit varies the duty cycle of the output voltage and hence changes the average DC link voltage across the motor terminals.

The prototype electric-powered wheelchair has been tested with human load between 60 kg to 120 kg moving on a flat surface. The starting current of the DC motor is much higher than the rated full load current due to the negligible back emf across the motor armature. If the driver circuit is incapable of supporting the starting current it will fail, resulting in the breakdown of the whole system. The starting current drawn by the DC motor is observed to be about 20A. Our designed motor driver circuit board which can deliver up to 37.5A is able to meet this requirement. Fig. 10 shows the output voltage and the load current for a stationary wheelchair with a load of 100 kg. According to Fig. 5, the reference current for this joystick position is (5, 5) or a PWM duty cycle of 50% as evident from Fig. 10.

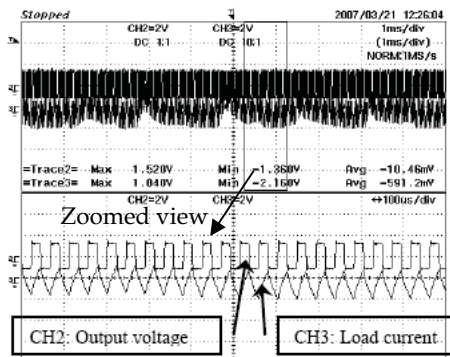


Fig. 10. Wheelchair in still position

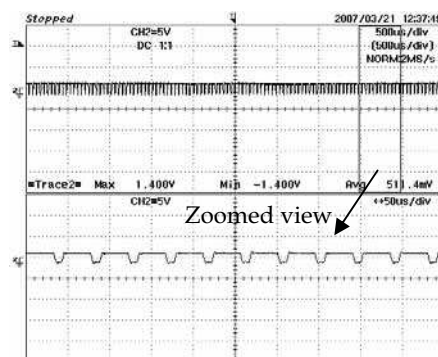


Fig. 11. Output Voltage in Steady State with Load for Forward Motion

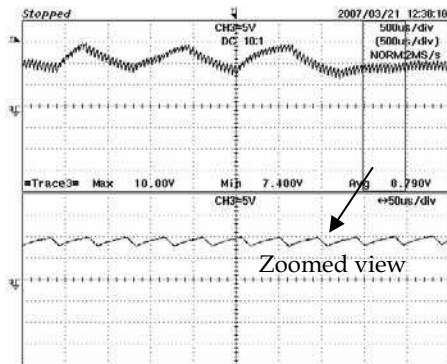


Fig. 12. Load Current in Steady State with Load for Forward Motion

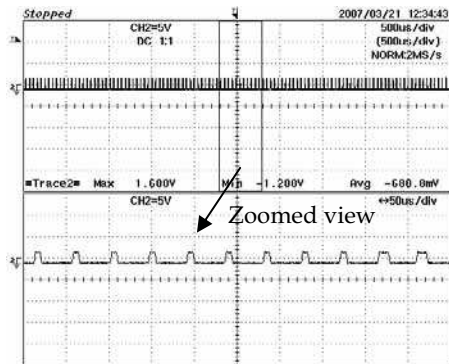


Fig. 13. Output Voltage in Steady State for Reverse Motion

From Fig. 12 it can be observed that the load current can be controlled to a certain level with stable performance. The fluctuating parts are due to the position change of the joystick, which is not fixed at one point due to manual control. Fig. 11 indicates the output voltage with a duty cycle of about 80% corresponding to a speed of 5 km/hr in the forward direction. Fig. 13 shows a PWM duty cycle of about 20% indicating reverse motion corresponding to a speed of 2.5 km/hr. The response time of the voice recognition system is calculated from Fig. 14 and Fig. 15 and is found out to be 672ms for the 'GO' command and 824ms for the 'STOP' command.

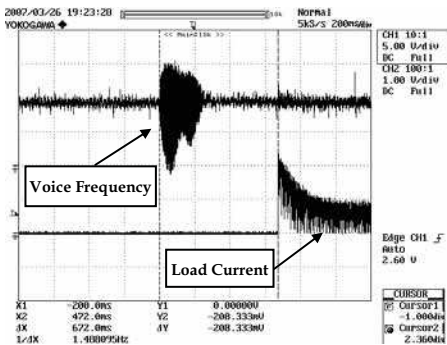


Fig. 14. Voice Frequency and Load Current with "GO" command

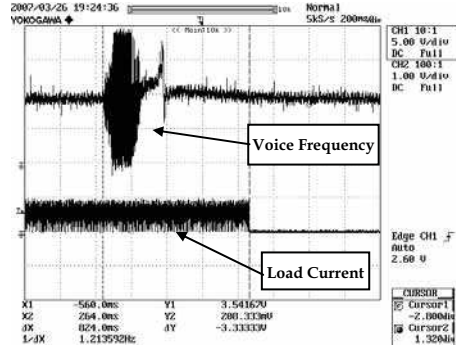


Fig. 15. Voice Frequency and Load Current with "STOP" command

This section of the chapter describes the design for a microcontroller based voice-activated powered wheelchair supplementary with joystick control. The voice recognition system helps the elderly users or users with upper limb disability in commanding the wheelchair. The next section deals with the design of a personal intelligent navigation system for known indoor environment using wireless sensor networks.

## 4. Personal Navigation System Based Wireless Sensor Network Technology

### 4.1 Introduction on Wireless Personal Navigation System

The objective of this section is to illustrate the development of a wireless indoor navigation system for the disabled and aged, particularly the wheelchair bounded, through the achievement of both location and direction determinations. A commonly used method of navigation for wheelchair patients in an indoor setting is the line tracking system, where light sensors are used to differentiate white and dark lines that are attached onto the ground surface. While this method has areas for further improvements (unsightly and inflexible navigation), hence a better wireless alternative is proposed in achieving the same motives. In recent years, the Global Positioning System (GPS) is widely used in many modern navigational applications. However, GPS technology is ineffective in indoor settings due to obstructions in buildings that hinder transmissions. Other possible location determining methods include using infrared, ultrasonic or radio signals and optical tracking systems.

A literature study was conducted to understand some of the research papers that were published regarding wireless indoor navigation systems. For instance, the Brunel Navigation System (Cecelja et al., 2006) for the Blind (BNSB) is developed by integrating three main technologies: Global Positioning System (GPS), Geographical Information System (GIS) and Mobile Communication System (MCS). The functional components of the BNSB are accommodated into two remotely linked terminals: Mobile Navigation Unit located at the remote site of the visually impaired pedestrian and the Navigation Service Centre, which is the sighted guide. The Mobile Navigation Unit is a wearable terminal that includes a digital video camera, a GPS receiver and a mobile network interface. A dead reckoning system, used to position the user when the GPS is not available, is also placed in the unit. The Navigation Service Centre is a stationary computer terminal running a GIS database and a display system to visualize video image and the user's location on a digital map. Navigation information includes real time transmission of the video image, GPS or dead reckoning positioning data and voice communication between the user and the guide. Another research area for indoor navigation systems is the Mobile Ad Hoc Network (MANET). MANET (Latiff et al., 2005) is a collection of wireless mobile nodes that cooperatively form a network without specific user administration or configuration. All nodes contribute and maintain connectivity in the network since all of them can both communicate and also relay packets to other nodes. When nodes move, the topology of the network also changes and hence previously computed routes to a specific node has to be recomputed. Nodes can either determine location either by itself or rely on other nodes. The self-positioning system uses at least three signal strength measurements extracted from messages that are being broadcast by pre-determined nodes at intervals. These pre-determined nodes, also termed anchor nodes (AN), are stationed strategically in order to be received by all mobile nodes in the network. Distance of the mobile node (MN) to the ANs will be determined from the signal strength received based on a propagation path loss model of the environment. If the distance and location of these ANs are known, mobile nodes can triangulate its coordinates. The system to be developed will not require additional hardware since it uses the existing wireless communication hardware which is based on IEEE 802.11b standards. Another special feature of this self-positioning system is that it does not use signals from GPS.

A wireless pedestrian dead reckoning system (Lei et al., 2005) that combines inertial sensing and sensor network technology, called the NavMote is also in the research for indoor

positioning. The NavMote gathers information about pedestrian motion from an integrated magnetic compass and accelerometers. When the NavMote comes within range of a sensor network, it downloads the compressed data to the network. The network relays the data via a RelayMote to an information center where the data are processed into an estimate of the pedestrian trajectory based on a dead reckoning algorithm. Static and dynamic calibrations of the compass data are crucial to compensate the heading errors. The dead reckoning performance is further enhanced by wireless telemetry and map matching. It was also shown in research that indoor navigation is possible with the aid of augmented pictures (Merico et al., 2007), i.e. pictures with a very wide aspect-ratio that have been dynamically annotated with navigation information. Each picture is the result of automatically stitching together regular photos that have been taken under control of a "mapping" application. The mapping application starts from building plans in standard format and a list of points-of-interest and identifies where pictures should be taken from. The whole process is almost completely automatic and makes it possible to "map" a new building in a few days. Photos are processed in order to create a set of scrollable pictures that are augmented in real time with markers that indicate the direction to take and the position of "relevant locations" that can be used to recalibrate the dead-reckoning position.

Despite that many research works have already been carried on realizing the concept of wireless navigation system, local positioning system is still more favourable over GPS for indoor context. In similar approach as NavMote discussed by Lei et al., 2005, the target is for wheelchair-bounded aged and disabled people. In the implementation setup, radio frequencies of 433.98 MHz are used to set up a simple location determining network. As for direction determination, a 1490 digital compass sensor manufactured by Robson Company is being used. The sensor is a solid state Hall-effect device that is sensitive enough to detect the Earth's weak magnetic field and when rotated, outputs 4-bit digital signals that represent the compass' cardinal points to the microprocessor. Apart from the RF navigation system, a voice-activated powered module is also proposed to be incorporated with a joystick enabled wheelchair. The voice recognition system as described in the previous section recognizes voice commands and compares to those in the pre-stored memory; the respective coded digital signals would then be sent to the microcontroller which provides the relevant outputs to the wheelchair accordingly. With a voice-activated system, more convenience is hence brought to the disabled people. Additionally, a recent survey indicates that almost all of the people are not able to control the EPW by conventional methods and these users could benefit from the automated navigation system. Moreover, there are situations in which the user wants to travel from one location to another within a building either at home or at workplace repeatedly several times in a day (for example going to the toilet) (Pačnik et al., 2005). These users would benefit if a learning mechanism can be built into the wheelchair control system such that it would learn the path in an iterative manner and after few trials/iterations the controller would be able to take care of the navigation system making the user free to do something else or even relax. This is accomplished by integrating the Wireless Sensor Network (WSN) technology based on Zigbee protocol onto the EPW. The user first selects the destination he/she targets to go, through the WSN information; the indicator will guide the user on the EPW accordingly.



### 4.2 Navigation Methodology

Generally, in any navigation techniques, there are two possible ways widely used in directing a user from the starting point to the desired destination: The first method is to provide a general direction for the navigator to travel upon (unplanned routes) and the second method is to guide the user from one section to another (planned routes); Both techniques would eventually lead the user to his final destination. The illustrations and explanations of the navigation methodology are shown in the two figures in Figs. 16 and 17:

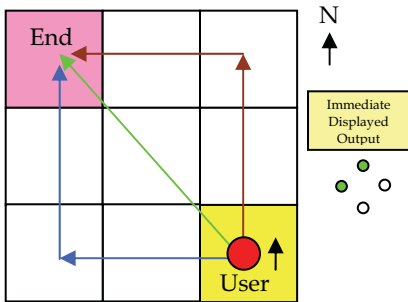


Fig. 16. Illustration on Unplanned Routing Methodology

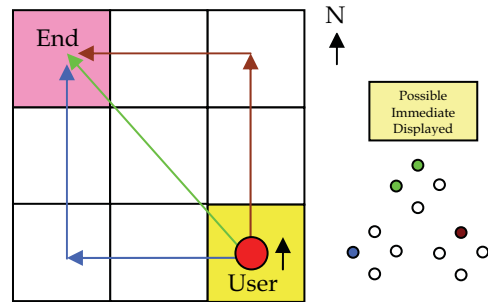


Fig. 17. Illustration on Planned Routing Methodology

Initially, the user starts from a random location, say the yellow grid, and he is facing the north direction as shown in Fig. 16. The final destination is to travel to a facility that is located in the pink grid. If the navigation system is programmed according to the unplanned routing methodology, the immediate displayed option would be as that shown in the diagram – directing him NorthWest with respect to where he/she is facing. This output direction indicates that his destination is somewhere along the NorthWest line, hence the user can choose to travel in the green line (fastest route), blue line, brown line or any other variations because all options would still lead him to his end point. In summary, the output directions given through the unplanned routing system always point the user DIRECTLY towards his destination. Consider the same scenario as seen in Fig. 17 but this time round, the output could be either the green, blue or brown route. This is dependent on how the route was planned beforehand and the user can make the choice out of the three options. In summary, the output directions given through the planned routing system need not always point to the destination directly. The user has to follow the navigation outputs accordingly to reach his destination, since he is not aware of where his endpoint lies.

Table.2 summarizes the comparisons between the two navigation methods. Based on the comparisons made between the unplanned and planned routing methodologies tabulated in Table.2, it can be concluded that adopting the planned routing method would be more appropriate for the aged and disabled people. The most important advantage of planned route over the unplanned route is that it can serve as an obstacle avoidance director. The scenario illustrated in Fig. 17 summarizes all the key benefits of planned routing methodology



	Unplanned routing	Planned routing
Output	Always point to end destination	Not necessarily point to end destination
Degree of freedom	High	Low
Distance traveled	Minimum	Varies
Time required	Varies	Varies
Ease of navigation	Low	High
Programming complexity	High	Low
Suitability for disabled	Low	High

Table 2. Comparison between the Unplanned and Planned Routing Methodologies

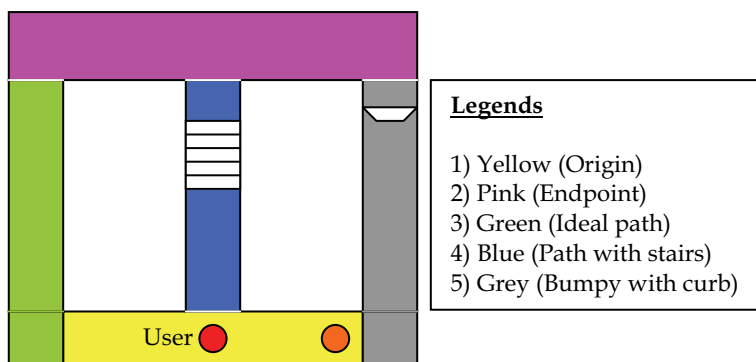


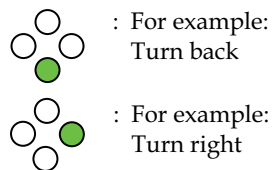
Fig. 18. Illustration to Show Key Benefits of Planned Routes Methodology

Consider a wheelchair user (red dot) who wishes to navigate to the pink region. There are three different paths for the user to choose of which the green path is the safest and easiest to cross. If the navigation system is adopting the unplanned routing method, the immediate output would be pointing the user straight ahead to the blue path, which is undesirable. However, if the planned routing method is to used, the output would direct the user to turn left instead, towards the green route away from the blue and grey paths, so as to avoid the obstacles along those routes. When the user is in the green region facing his destination point, the output would be simply move forward. Likewise, for the user at the orange dot, it would be his immediate instinct to choose the grey path since the unplanned routing system would simply tell him that his destination is 'somewhere' straight ahead. However, the planned routing system would instruct the orange user to take the extra mile towards the green path because the path is the safest possible way for the user. A set of software codes has been developed to compute the relevant directions that are used to guide the user to the intended destination. The corresponding true navigation charts, depicting the respective outputs at different locations and directions, have to be prepared beforehand as well.

**Function 1** (Current location = Yellow, Destination = pink)

Progress	A	B	C	D
*Current direction	N or NE	W or NW	S or SW	E or SE
Immediate output				

\* Possible directions faced by user at the instance in time



**Function 2** (Current location = Grey, Destination = pink)

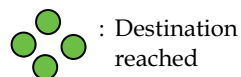
Progress	A	B	C	D
*Current direction	N or NE	W or NW	S or SW	E or SE
Immediate output				

**Function 3** (Current location = Blue, Destination = pink)

Progress	A	B	C	D
*Current direction	N or NE	W or NW	S or SW	E or SE
Immediate output				

**Function 4** (Current location = Green, Destination = pink)

Progress	A	B	C	D
*Current direction	N or NE	W or NW	S or SW	E or SE
Immediate output				



The 4 functions demonstrated as shown above aim to navigate the user residing in any of the locations to the pink destination region. Using the four functions, the sequences of the routing paths can be planned as the followings: -

Function 1 to 4 or Function 2 to 1 to 4 or Function 3 to 1 to 4

where Function 4 is the last function in all the 3 sequences, which is termed as the end function of the whole sequence. In the programming terms, regardless of the user's current location, the ultimate aim is to direct him to the end function eventually. In bigger and more complex layouts, there can be multiple end functions that lead the user to the same destination.

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