Chapter 9  Summary and Conclusions

9.1 Summary and Conclusion

The research work proposed is to ease the lives of those among us who are unfortunate enough to have lost the ability to move their limbs due to stroke, significant amount of paralysis in the regions below their neck (SCI - Spinal Cord Injury), old age and other disabilities. Such physically challenged find extremely difficult for locomotion, so they depend upon various assistive aids. The most common choice for them is the use of seated wheeled navigation systems for indoor navigation. Although today various types of wheeled navigation systems, particularly powered wheelchairs, are available in the industry, there is a limit in the number of designs with features that suits for people who fall in the above category. As such they lack specific features and control methods to be used in the rehabilitation process of these people. In this research work, an integrated platform of Multi-Modal Control in Automatic/Semi-Automatic Navigation System for Rehabilitation of People with Mobility Issues including a Patient Monitoring System is investigated and analyzed which can provide mobility to users and assist in their rehabilitation process.

In chapter 2, a review of mobility aids and rehabilitation of people with mobility issues is presented. It presents facts on how rapid is the growth of the oldest groups among the older population in the world. It also mentions about 'mobility' issues as called one of the "four giants" of geriatrics (memory loss, urinary incontinence, depression and falls/immobility). It shows how people with mobility issues are isolated from the society. Whether their condition is physical, emotional or mental, all met the same attitudes. They were kept off from social gatherings because they needed special attention or people to take care of them. Assistive aids are often required for them to facilitate mobility, communication, self-care or domestic activities. Also these people find it tough to even navigate inside the home without external aids. It also explains how due to industrialization, especially in developing nations, elders and physically challenged are left alone at home to take care of themselves. In a typical Indian family both the parents go to work and the children go to school. The elders are alone at home taking care of the house. The situation is same even if they are very old or even if they require medical attention as it is very expensive to hire a personal nurse or to admit them in private old age homes. In developed
nations like US it is common that the adult children and the parents live separately even if the parents are very old and need external aid.

It also highlights the fact that a physical barrier to basic mobility is one of the three factors that result in the exclusion of many people with SCI from full participation in society. For improving care and overcoming health, social and economic barriers of people with SCI, WHO suggests to use appropriate assistive devices that would help people to perform everyday activities. It presents the fact that each year, about 15 million people worldwide are affected by stroke and 80% of the people affected by stroke are having mobility issues. The assistive devices in the market are very generic in nature and very few of them available are too costly for the people of developing and underdeveloped nations. Nuclear families which enveloped the western nations have found its way into many developing nations and the need for such assistive devices have increased manifold in these low income countries.

A survey conducted at the at the Physical Medicine and Rehabilitation Department of Amrita Institute of Medical Sciences, Amrita Vishwa Vidyapeetham University, Cochin, Kerala, India about the hand gesture based wheelchair supported and encourage this research work. A questionnaire was provided to the doctors and the summary of the answers is provided. The wheelchair is suggested to at least three patients daily who visit this department which puts total number of patients for whom wheelchair is suggested, at 1095 every year. While prescribing the wheelchair the doctors consider primary diagnosis, co-morbiditis, functional status, goal, socio-economic status and potential for return to work as the primary factors. The doctors suggest the patients what type of wheelchair is best for them. The prevailing wheelchairs (joystick based) are unsatisfactory for the population (stroke patients and SCI patients) that the doctors treat. For patients with severe quadriplegia it takes time to recover some motor control in their hands. Mudra can be used only by those patients who are able to move their hands back and forth to a certain extent without external help. There might be heat produced because of the battery underneath the seat which might cause damage to the skin of the user who are seated. As the existing powered wheelchairs with joystick control are not suitable for the patients whom the doctors treat, they suggest to buy only a manual wheelchair. They rarely suggest to change the wheelchairs. The answers only point to the fact that the existing joystick based control
mechanism is not suitable for stroke patients and SCI patients and that which is suitable for them is not available in India.

Some of the various powered wheelchair control methods are presented in the third chapter. Joystick Based Navigation Control, Touch Screen Based Navigation Control, Human Eye Controlled Navigation Control and Non-invasive Brain Signal Interface Control are some of the existing methods detailed in this chapter. Even though there are many control methods available, only joystick based control method is a commonly, commercially available one. All other control methods are only at research level and yet to be commercialized. Even those very few companies which make customized control options are only in Western countries and people of developing and underdeveloped nations cannot afford them.

Design, Implementation and Analysis of Multimode Navigation Control is explained in Chapter 7. The need for various control methods is investigated and elaborated in this chapter. In order to ensure a safe and comfort navigation for people with mobility issues a multimodal automatic/semi-automatic navigation system which ensures less user interaction is proposed. This is done by three different control methods: a) Even though most of the motor and sensory functions are damaged in SCI Patients with severe disabilities (C1-C4) eye control is not lost. The proposed system uses EOG based control method in such cases. b) For stroke patients, elders and SCI patients of categories C5-C6 who have lost finer control of their hands, but who can still move their hands, hand-gesture based control method can be used. C) For the remaining categories of SCI patients and other users, either voice based control method or hand-gesture based control method can be used. The two different control methods, Voice based navigation control and Integrated EOG Based Control and Patient Monitoring Systems (ECPMS) are discussed in detail.

The voice based navigation control can be regarded as a very user-friendly system. It has some special features integrated into it like the personal security module and the obstacle avoidance techniques. This method is best for certain categories of SCI patients and other users who cannot use their limbs for navigation control. The design, development, implementation and testing are presented and investigated as part of various modes of wheelchair control. ECPMS system has been designed and integrated on to the wheelchair. Investigation was carried out to measure various body parameters of the users with and have been processed and analyzed. The
communication system was tested by simulating the case in which various parameters exceed the threshold level by observing if a contact to the caretaker was made successfully via smartphone. The EOG-based navigation control was tested with the user.

In Chapter 5, IR camera-based hand gestured controlled wheelchair system demonstrates the feasibility of simple hand gesture control for navigation in powered wheelchairs. A gesture capture module with IR Camera and sensors is designed and a simple correlation-based image processing algorithm is used to realize gesture identification to control the wheelchair. GUI-based program was developed for easy system customization, to store the comfortable gestures in the database and use it for gesture identification. The experiments from the GCM and GRM show that gesture-based control system is feasible. The success rate in gesture identification is very promising and the response time of the IR camera-based hand gestured controlled wheelchair is comparable to that of joystick-controlled wheelchair available in the market. The evaluation of the IR camera-based hand gestured controlled wheelchair by two groups of users—one experienced users and the other, new users is a pointer that our prototype can be accepted by the users of wheelchairs. Only few hand gestures - forward, reverse, right and left which are intuitive, the control method is easy to learn. As even tiny movements of hand can be recognized by the GRM we can see that IR camera-based hand gestured controlled wheelchair can be used by a wider range of people - not only elders but certain category of quadriplegia who are able to move their upper limbs to certain extent but cannot exert force to move joystick. Even though the leg gestures are not captured and tested, the hand gesture success rate indicates that the GCM box can be fitted at the foot plate position in the wheelchair, for certain category of users who can use only their legs.

A comparison of various features of powered wheelchairs available in the market with joystick was presented. The comparison clearly states the fact that wheelchair manufacturers have come up with various wheelchair designs and models with tons of features but the control method is prevalently joystick-based. Many wheelchair users are being left out without option to use joystick control for powered wheelchairs and some of them can't use such control at all. Our survey also points to that, that wheelchair users are looking for a change in control method. With the turning radius of 24 inches, weight of 120 pounds, maximum speed of 4 miles/hour, weight of person carried 220 pounds, range of travel 9.3 miles/charge, motor power of 320 watts,
and at a price in the range of joystick controlled wheelchair, IR camera based hand gestured controlled wheelchair meets the technical specifications of the joystick control powered wheelchairs.

The response time of IR camera based hand gestured controlled wheelchair is comparable to that of commercially available powered wheelchairs. IR camera based hand gestured controlled wheelchair response time is anywhere in the range of 450 ms to 750 ms. The results during the safety evaluation are also very encouraging. IR camera based hand gestured controlled wheelchair has obstacle detection mechanism which can find any obstacle in one meter distance and also passed the ramp test as per the ADA standard. The overall cost should be as comparable as possible to the existing powered wheelchairs so that it can be affordable even by the people of developing nations like India. It is not claimed that IR camera based hand gestured controlled wheelchair is the cheapest one, but its price is anywhere in the low cost range of powered wheelchairs. This aspect also opens up scope for future work on IR camera based hand gestured controlled wheelchair which can consider alternatives to costly hardware without compromising in performance. The gesture recognition method provides flexibility to the user to define the simple gestures in most convenient way for them. IR camera based hand gestured controlled wheelchair will reach the intended users and be used in their daily life for convenience and better user experience at an affordable price.

In yet another hand gesture based navigation control, a novel IR sensor based 'Mudra' is investigated, evaluated and presented in Chapter 4. 'Mudra' is a Sanskrit word which means Gesture in English. As this gpaD mechanism is based on gesture, this powered wheelchair system was named as Mudra. This system indicates the feasibility of simple hand gesture control for navigation in powered wheelchairs for patients with mobility issues. A pad which has a smooth glossy surface called gpaD was designed to identify the hand gestures of users who can move their hands only to a certain extent including stroke patients and patients with spinal cord injury, as against hand movements of healthy person. As gpaD is designed with IR sensors and detectors and an MCU along with few other simple electronic components the cost is very less, less and 70 USD.

The success rate in identifying the correct gestures as shown in Table 4.1 is very much assuring. Overall success rate in recognizing the gestures is 99.25% which is extremely
encouraging. In many cases we see that the success rate is 100%. The response timings of Mudra as listed in Tables VII to XI and in the Figure 4.7 show that it is well within the range of 0.3 seconds to 0.8 seconds. For any gesture change to Reverse gesture, the response time is around one second. The response timings of a commercially available joystick based wheelchair is given in the Table XII along with Mudra response timings. Mudra's performance is similar or better in many cases and not bad in few other cases where the response timings are close to one second.

The evaluation of the Mudra by two groups of volunteers - one experienced users and the other, new users, as given in Tables XIII and XIV is a pointer that Mudra can be accepted by the users of wheelchairs. Only with five hand gestures - forward, reverse, right, left and brake which are intuitive, the gesture based control method using gpaD is simple for anyone to master. This evaluation by the joystick based powered wheelchair users who who are elders and/or physically challenged indicates that Mudra can be used even by others who are not stroke patients or SCI patients. Five out of seven of these volunteers would prefer to use Mudra over joystick based wheelchairs.

Five patients including three stroke patients, one patient with issue in spinal cord and one patient with injury in legs volunteered to test Mudra. These patients were part of Rehabilitation Department of Amrita Institute of Medical Sciences, Kerala, India and Amrita Kripa Charity Hospital of Mata Amritanandamayi Math, Kerala India. The feedback and evaluation by these patients are very promising that three of them rated Mudra as 'Best' and one as 'Moderate' and other as 'Unsatisfactory' when they were asked to rate Mudra based on their experience. These ratings point to the fact that Mudra can succeed as a commercial product too, apart from providing a mobility aid to stroke patients and SCI patients for whom a commercially available powered wheelchair is not available to them in their countries or is very costly for a customized wheelchair in countries which are available with few wheelchair manufacturers.

The doctors' advice and help was sought many times even from the beginning of the design and making of gesture based Mudra. One of the doctors visited three different times the Humanitarian Technology Lab where Mudra was being developed to give feedback about design. The doctors indicated that such a gesture based wheelchair control would provide mobility to all those stroke and SCI patients who are psychologically affected severely as those who were carrying out day-to-day life as every other healthy person in this world, suddenly feel
hopeless after the stroke attack or SCI. To some extent they also think themselves they have become burden to their near and dear ones, as a full time caretaker is needed to attend to them for all mobility related issues. Mudra would be a boon to such people and would serve as a booster to their mental strength and give confidence to them. The doctors (who also tested Mudra themselves) and the authors hope that Mudra will greatly help in their rehabilitation process and rebuild their lives.

With the turning radius of 22 inches, maximum speed of 3.8 miles/hour, weight of 120 pounds, range of travel 9.3 miles/charge, weight of the person seated 220 pounds, motor power of 320 watts, Mudra meets the technical specifications of a commercially available joystick control powered wheelchairs. There are various powered wheelchair models available in the market with various features by many wheelchair manufacturers: Collapsible for Transport, Joystick Mount Adjustable, Armrest Position Adjustable, Seat to Floor Height Adjustable, Head Rest Available, Head Rest Adjustable, Tilt Adjustable, Footplate Height Adjustable, Backrest Position Adjustable, Spring Suspension Available etc. All these features can be incorporated in Mudra too as it is part of the wheelchair design. Even though there are so many different features which are part of wheelchair, the control method used in all these models is only joystick control. But this control method is not suitable for all people with mobility issues and they users of these wheelchairs are left without any option when it comes to the control method. Seven experienced wheelchair users, ten volunteers who never used any kind of wheelchairs, four doctors, two physiotherapists and five patients volunteered to test gesture based Mudra and evaluated it. Based on their feedback and with the price tag at less than 1000 USD, it is our sincere hope that the gesture based Mudra would serve as an alternative to the existing control method, help all people with mobility issues and be a catalyst in the rehabilitation of stroke and SCI patients.

In Chapter 6, a novel Location Aware and Remembering Navigation (LARN) algorithm is used to take the wheelchair automatically to any room inside the house. The system makes use of LARN Algorithm to navigate automatically inside a house. Location Aware and Remembering Navigation (LARN) algorithm, allows a wheelchair based device to pinpoint its location inside a house without the need for any wireless sensors or devices. The method is cost efficient and less complex compared to existing methods. The LARN Algorithm maps the floor space of the house into a number of grids by considering it as a polygon and assigns a specific coordinate to each of
These grids. The wheelchair keeps track of its current grid position and updates its location as it navigates. The accuracy of this algorithm is determined by the size of the grid, the angle in which the wheelchair moves and the ability to remember the coordinates of the grid it is traversing.

The voice based and EOG based wheelchair navigation control is presented in chapter 7. An automated voice based navigation system is investigated, which can be used by anyone who requires the help of others for their day to day locomotion. The voice based control takes input from the user as voice commands, recognizes it and takes the user to the intended destination. The EOG based command requires the user to give commands through movement of eye balls - left, right, up or down and mapped to four different directions - left, right, forward and reverse. EOG based control is very useful for users who are severely paralyzed but could use their eyes. Investigation was carried out to measure various body parameters of the users with and have been processed and analyzed. The communication system was tested by simulating the case in which various parameters exceed the threshold level by observing if a contact to the caretaker was made successfully via smart phone.

The detailed study on development of the intelligent wheelchair simulator to simulate various behavioral patterns of a fully automated intelligent wheelchair with constrained specifications for testing and analysis purpose of the intelligent wheelchair is presented in Chapter 8. As the intelligent wheelchair simulator does not use any algorithm for optimal path calculation, the time taken for path calculation is zero. Theoretically the navigation time and simulation time should be equal in the best case which implies stable performance of the simulator. The result obtained from sample simulation setup shows a small amount of variation in some cases due to the delay in stopping timer due to the sequential nature of the program or overload in hardware of the device in which the simulator operates or host operating system delays.