Chapter 1  Introduction

1.1 Motivation and Objective

Majority of the current systems that are used for indoor navigation, are powered wheelchairs that are designed for people with mobility issues like elders and physically challenged who have lost their limbs in accidents. These powered wheelchairs have joystick control as the most commonly used control methods. The users have to continuously use the navigation control system (Joystick), for moving from one room (source) to another room (destination) in case of indoor navigation. As such they may be used by only certain category of quadriplegics (C7-C6) and elders who have finer control of their hands and fingers. The problem is that even for elders and quadriplegics of C7-C6 categories have to exert considerable amount of force to use the Joystick and navigate. Majority of the stroke patients and SCI patients are dependent on caretakers for their mobility and hence the rehabilitation of such people is often unsuccessful as they consider themselves to be burden for their families and friends. The proposed research work is aimed at providing freedom of navigation for stroke patients and quadriplegics and can prove to be a great source in their rehabilitation process. It can also provide a suitable platform for reclining of the user which is very much required in case of skin pressure sores.

Most of the commonly available electric wheelchairs are controlled by the human machine interface which uses joystick controller. However this kind of controlling mechanism is not suitable for physically challenged like SCI patients/quadriplegics, who suffer from paralysis of arms, hands, legs and pelvic organs, caused by the spinal cord injury and stroke patients. As such they cannot be used in the rehabilitation process. In order to ensure a safe and comfort navigation for such persons 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. In case of semi-automatic
navigation, the user is expected to use the control method continuously to reach the destination. In automatic case, the user is going to use the control mechanism only once to specify the destination. They need not use the control method continuously to navigate to the destination. The safety mechanism inbuilt in the system makes sure that the mental comfort, intelligence and freedom alone is not the intended purpose. Safety of the system is given a high priority in case an obstacle is encountered while automatically navigating or the system malfunctions.

In this work the existing solutions to address mobility issues of the stroke patients, SCI patients, aged elders and physically challenged are analyzed and a suitable electronic control system is developed, that has multiple ways (gesture based, EOG based, voice based) of command input techniques, helping in mobility of patient’s indoor navigation from point (source) to point (destination). The main focus being a novel hand gesture based control method (patent pending). In addition an embedded system based control for autonomous navigation is developed using the Location Aware and Remembering Navigation (LARN) algorithm, to calculate the shortest path to a set of predefined locations inside the house based on grids without the need to use wireless sensors or devices. In this process the success rate in hand gesture recognition is analyzed and the response timings and confusion matrices, lab testing, field testing with stroke patients, SCI patients, elders and physically challenged, is evaluated. Safety of this integrated platform is evaluated based on ramp test as per American with Disability Act - ADA standard, obstacle detection test and angle of rotation test. Further a suitable platform for rehabilitation of the stroke patients, SCI patients, aged elders and physically challenged with high degree of freedom of navigation is investigated.

1.2 Contributions

The goal of this research work is to use the current technology to provide a suitable in-house platform for the quadriplegics to help in their rehabilitation process. As such the platform would be a mobile one which can automatically take the quadriplegics anywhere within the house without the need to navigate continuously using conventional control (joystick) methods. A cost efficient, end-product oriented is the approach taken here. The control method and the entire platform should be comfortable for them to use. As there are currently no specific platform (such as powered wheelchair) available in the market for the exclusive use of Stroke, SCI patients,
Elders and Physically Challenged (SSEP) group of people, the investigation, the realization methods and the realization of hardware will serve as a morale boost for such users.

**Objective 1:** Develop an electronic control system that has multiple ways of command input techniques helping in rehabilitation in quadriplegic patient’s indoor automatic navigation from point (source) to point (destination).

To be able to design an electronically controlled and manipulated system design which is configured with various sensor systems (EOG, hand gesture and voice) and able to understand the commands from the SSEP group of users with various degree of disabilities, in indoor automatic / semi-automactic navigation. For the patients whose degree of disability is very high belonging to category C1-C4 who have less or almost no muscular activity the EOG technique is a suitable control method where only the activity of eye is necessary. For those who are not suffering from severe cases of quadriplegia i.e. of category C5-C6 have activity above cervical spinal nerves (above neck portion), generally they are able to speak so there is a necessary easier way for control mechanism which is going to be voice operated. Finally for rest of the patients belongs to lower category of quadriplegia are able to move their upper limbs to certain extent, but they cannot rely on existing technologies like joystick operated control system for reliable navigation where they are needed to exert at least certain pressure for operating joy stick. So such people can use the hand gesture capture control method for pleasant navigation. The overall wearable system is completely customizable for various degrees of disability and user friendliness.

Such a navigational system can be used in the rehabilitation process of the SSEP group of users which can give freedom and mental comfort with being able to move around by themselves to a greater extent. The system can also reduce the burden of labor or caretaker which is a compulsory requirement in severe cases of quadriplegics

**Objective 2:** Develop an embedded system based control for autonomous navigation. The Location Aware and Remembering Navigation (LARN) algorithm, to calculate the shortest path to a set of predefined locations inside the house based on grids without the need to use wireless sensors or devices.
To add intelligence to the proposed system, the system can find shortest path from one room (source) to another room (destination) so that the user need not have to navigate continuously. To dynamically recalculate a path to destination in case an obstacle is encountered on the way. It is proposed to implement an embedded system which can add intelligence to automate indoor navigation. This controller can act as central intelligence for safe autonomous indoor navigation with minimum inputs as user’s commands. The system receives user’s command from the destination control unit with different mechanisms as EOG, hand-gesture or voice, which defines the destination for the navigation. The controller finds the shortest path from the one room (source) to another room (destination) using the Location Awareness and Recognition Technique (LART) which uses a smart algorithm such as Dijkstra’s algorithm, Greedy breadth first algorithm or A star algorithm. The floor plan of the house (which is virtually divided into grids) is preloaded into the system controller with the entire static objects marked including walls. While navigating, the controller with help of obstacle detector identifies new static and dynamic obstacles which are not represented in the preloaded floor plan and recalculate the path to destination by considering the current location as source. Digital compass is used by the controller to gather information about the direction in the system is moving. With the help of rotation encoder the controller also keeps track of the grids (virtual) travelled by wheelchair. This knowledge helps the system to locate itself in a particular grid at any time inside the house.

This system with intelligence in navigation reduces the effort requirements for certain categories of SSEP group of people, to drive to different destinations. Quadriplegics who cannot otherwise move independently are able to move without the help of external aid. Implementing an intelligent controller for autonomous navigation would resolve the need of using laptops and notebook PCs in these kinds of autonomous robots. Replacing laptops or notebook PCs with an embedded controller would considerably reduce the overall cost of the system.

**Objective 3:** Analyze the success rate in hand gesture recognition, evaluate response timings and confusion matrices, lab testing, field testing with stroke patients, SCI patients, elders and physically challenged. Safety evaluation based on ramp test as per American with Disability Act - ADA standard, obstacle detection test and angle of rotation test. The integrated Patient Monitoring System helps in the safety of the SSEP group of users who require continuous monitoring of their vital health parameters.
**Objective 4:** Develop a simulator to simulate various scenarios the wheelchair can undergo in real time including dynamic obstacles, rotation encoder sensor error to keep track of the distance travelled, wheel alignment error, error correction mechanism etc. Provide flexibility to the user to simulate various house floor plan layouts of any shape and sizes. The aim is to simulate various behavioral patterns of a fully automated intelligent wheelchair with constrained specifications for testing and analysis purpose of the wheelchair. To carry out the performance analysis based on navigation time and simulation time obtained by simulating within the defined scope. Finally the study using the simulator is to help in verifying several theoretical facts that we have consider for the development of a real-time intelligent wheelchair system without having the actual system.

**1.3 Organization of Thesis**

Investigation of the existing mobility aids for the users with mobility issues which would also help in their rehabilitation process is presented in Chapter 2. The mobility issues in general are discussed first followed by the discussion on mobility issues with elders, stroke patients and SCI patients. The literature survey and related works in the field of navigation and control methods is the primary aim of this chapter. Various existing control methods related to wheelchair control are investigated and reviewed.

The system architecture is detailed in Chapter 3. A brief introduction to various control methods including hand gesture control methods - IR Camera based and IR sensor based, Automatic control and LARN algorithm, voice and EOG control methods and hardware setup is presented in this chapter.

Chapter 4 provides the details on the novel IR sensor based hand gesture recognition, identification, and navigation control (Patent Pending) method. The architecture, design, and implementation details are explained elaborately. The success rate in gesture recognition, the response timings, testing with patients and analysis of the results are also presented.

The analysis and evaluation of IR camera based hand gesture recognition, identification and navigation control is detailed in Chapter 5. It starts with the discussion on background and review of existing methods, followed by the design details, experimental setup and evaluation.
An exclusive discussion topic is provided to investigate the performance and analysis of the results.

Chapter 6 presents study and analysis of autonomous navigation system based on digital compass. Conventional auto navigation methods use wireless devices for positioning and complex algorithms for analysis. A simple LARN algorithm is used and the positioning information is identified with the help of a digital compass.

Two different control methods - voice based and EOG based are detailed in Chapter 7. It also includes the work on patient monitoring system which can be integrated with the wheelchair navigation for stroke patients and SCI patients who require continuous monitoring of their vital health parameters. These parameters include temperature, heart rate, and ECG. The implementation, testing, and evaluation of such a system are discussed in detail in this chapter.

Chapter 8 describes the Intelligent Wheelchair Simulator that is developed to simulate the real time scenario of a wheelchair in indoor automatic navigation. The simulator design, algorithm, simulations including error handling and correction and evaluation are presented in detail in this chapter.

Chapter 9 summarizes the results. A discussion based on the survey, evaluation, user feedback, and doctor feedback are provided. Analysis of the results leading to the possibility of this system succeeding in providing efficient mobility aid to the users and helping them in their rehabilitation process is reported.