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Design and Testing of a Marsupial/Companion Robot Prototype for a Powered Wheelchair

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Mechanical Engineering
Department of Mechanical Engineering
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University of South Florida

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Dedication

To my family

Acknowledgements

My first and foremost thanks go to Dr. Rajiv Dubey for providing me with the opportunity to pursue my graduate studies under his guidance. I deeply appreciate his patience and understanding and also for giving me the freedom to choose my research problem. I am indebted to Dr. Shuh-Jing Ying for being a constant source of support and helping me out of dilemmas. I am obliged to Dr. Autar Kaw for conceding to serve on my committee and encouraging me throughout my stay here. I thank Mr. Stephen Sundarrao for coming up with ideas for my thesis and lending a helping hand at every instance. I would also like to thank Dr. Daniel Hess for giving me an opportunity to work with him during my initial semesters.

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I thank my family for their unconditional love and support and for being my source of inspiration. I thank GOD for his blessings and for being the driving force in helping me realize my dreams.

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ABSTRACT

Individuals with disabilities yearn for an increased level of independence, seeking to supplement their missing function(s) and to carry on with their lives with minimal or no assistance from another person. A review of the existing assistive-care products has revealed that many of the defects in these devices, particularly in wheelchair-mounted robots, can be alleviated. Surveys have also identified tasks that users would like to perform by themselves, but are constrained from doing so by using currently available devices. An attempt has been made here to try to resolve these issues by developing a prototype of a marsupial robot that can dock into the powered wheelchair that is used for manipulation purposes. The primary function of this system is to assist the user in his/her daily tasks such as pick-up small objects and place them as per the user's commands, push to open/close doors and remove obstacles from the wheelchair path. It is with the objective of providing an enhanced quality of life to a person with impairment(s) that a proposal for a simple, safe and inexpensive approach to assist him/her in performing an activity is made here.

Chapter 1

Introduction

1.1 Motivation

1.1.1 What characterizes a disability?

The U.S. Census Bureau identifies “a person with a disability to have difficulty in performing functional tasks (seeing, hearing, talking, walking, lifting objects or climbing stairs, etc.), in activities of daily living (bathing, dressing, eating, etc.), or meets other criteria like a learning or developmental disability, or has difficulty with certain roles (working at a job or around the house, etc.).” “A person who cannot perform one or more activities, or who uses an assistive device to move around, or who needs the personal assistance of a care-taker for carrying out basic activities, is said to have a severe disability.” [49]

1.1.2 Main causes of disabilities and available statistical data

Stroke is the leading cause of permanent disability in the U.S., with over four million Americans suffering from disabilities and impairments as a result [10]. A third of the survivors from stroke are left with severe disabilities [19]. Approximately one born over 3000 in the world is affected with muscular dystrophy and genetic diseases and about 10 % of these cases are the most severe involving limb impairments [1]. The incidence of spinal cord injuries in the U.S. is also quite high with about 6,500 new injuries being added each year of which 60 % result in quadriplegia [42].

Highlights from the data collected in the Survey of Income and Program Participation (SIPP) during the period October 1994 -January 1995 [48] indicate that:

- Among the 237 million people 6 years old and over, an estimated 1.8 (+/- 0.2) million used a wheelchair and an additional 5.2 (+/- 0.3) million used a cane, crutches, or a walker, or had used such an aid for 6 months or longer.
- The number of people aged 6 and over who needed the assistance of a helper with one or more activities of daily living (ADL) was 4.1 (+/- 0.2) million of whom 2.2 (+/- 0.2) million were 65 years old or older.
- Among people 15 years old and over, 15.3 (+/-0.4) million were unable to perform one or more functional activities. 9.0 (+/-0.3) million needed a human assistant with one or more instrumental activities of daily living (IADL) of whom 4.9 (+/- 0.2) million were age 65 or older.

US Bureau of Census also points that osteoarthritis affects 1.2 million mobility device users, and besides stroke, it is one of the most prevalent conditions among wheelchair and scooter users, with about one-third of the mobility device users depending on another person in one or more Activities of Daily Living (ADL). In addition, Parkinson’s disease, multiple sclerosis and other neurological impairments also affect an individual’s abilities [5].

Trends reveal that by 2035, 20% of the population will be over 65 years of age, 55% will have a disability and this will increase to 75% for those over 75 years. The number of wheelchair users under 24 years of age is presently around 150, 000 and this would rise to 450, 000 for those over 74 years. For at least one-third of the users, wheelchairs, being the most commonly used assistive device, provide the only means for independent mobility [19, 34, 42].

1.1.3 What is rehabilitation and rehabilitation engineering?

James B. Reswick, founding president of RESNA defines rehabilitation engineering as “the application of science and technology to improve the quality of life of a person with disabilities. Rehabilitation Engineering activities include (but are not limited to): Invention, Research and Development, Evaluation, Production and Marketing, Technology Selection, Service Delivery, Instruction of Use, and Maintenance and Repair” [59]. Cooper loosely defines rehabilitation engineering as “the application of science and technology to the design and development of assistive (adaptive) technology and rehabilitation techniques” [36].

The focus of the rehabilitation engineer is the person with the disability and what has to be done to make his/her life better. In order for rehabilitation engineering to be a success, it is required to “[match] the appropriate technology with the proper techniques to the person with a disability to achieve the goals set forth by that person.” Rehabilitation can be considered to be the restoration of normal form and function after injury or illness, and rehabilitation engineering is dedicated to providing assistive equipment for the disabled [35]. The goal of rehabilitation engineering is to enhance the quality of life for people with disabilities [27].

1.1.4 Rehabilitation robotics is a good solution!

The statistics mentioned in the chapter earlier reveal that catering to the needs of people with disabilities is a key issue that needs to be addressed to facilitate their integration into the mainstream society in an effective way. The most common solution to overcome the limitations due to disabilities is to provide assistance through a personal attendant or a trained co-worker [26]. Another possible way to overcome the hurdle would be to use an assistive device and curtail the need of a human caretaker [20].

Though a robot can never be a replacement to a human being in terms of the emotional support and understanding a person with disability receives from a human attendant, the hardships involved in finding a human carer who can really look after the individual in consideration, in addition to the high medical costs, is an impetus to look for an alternative like a robotic device to assist in simple chores [35]. Based on their review of published statistics on the disability population that most likely pertained to severe manipulation deficits, Stanger and Cawley estimated that between 100,000 and 500,000 individuals in the United States could potentially benefit from robotic assistive devices [17, 20].

Under such circumstances, the area of assistive technology and rehabilitation engineering becomes all the more important, with greater responsibility resting on the shoulders of people who are involved in trying to merge the people with disabilities with the masses.

Rehabilitation robotics is an area where rehabilitation engineers have attempted to transfer technology designed for industrial automation to restore the abilities of people suffering from physical/mental ailments [13, 20]. Assistive technology is thus, an appropriate field to assist people who have lost certain abilities common to a majority of the population, and also to cater to individual needs depending on the nature of the disability [25, 30]. In order to be able to meet the growing demands of the future populace, who will be forced to maintain their mobility and manipulability, development of various kinds support technologies – be it simple manual wheelchairs or sophisticated robot systems, is an absolute necessity [33].

Research and surveys by various institutions and organizations have identified tasks like opening a door and picking up objects from the floor as the most difficult for an individual with a disability, which are made all the more difficult when using a powered wheelchair [18]. Mobile robotic devices, coupled with the advantages of a mobile base and a robot arm, lighten the burden on the user when carrying out such activities arm due to an increase in the workspace and manipulability [17].

1.2 Thesis objectives

The objective of rehabilitation service robots is to assist the physically challenged such as those with disabilities and the elderly in leading an independent livelihood. The person with a disability is the focal point and the goal is to design and test a prototype that can accept commands from the wheelchair driven by the individual and also dock into the wheelchair itself avoiding any additional discomfort and inconvenience to the user. This is expected to result in increased independence and ability of the users to take better care of themselves when using the wheelchair, whether at home or at work. The following are the thesis objectives:

- Identify chores that encumber the users in their daily lives.
- Assess the efficacy of existing products for performing the determined tasks and ascertain areas of improvement.
- Develop a marsupial robot prototype from commercially available components.
- Design an interface to control the robot using the wheelchair joystick.
- Conduct experiments to demonstrate the potency of the prototype in enhancing the quality of life of the user.
- Propound further research to justify the need for a similar end product.

To summarize, the goal is to create a small “marsupial/companion” robot to ride on a wheelchair, and then, get off to assist with ADL tasks such as opening doors and picking up dropped items. The emphasis is on developing a system to control the wheelchair and robot motion from a wheelchair joystick. This device would be particularly useful to individuals with reduced mobility as a navigational tool and also as an assistive device for the execution of simple tasks.

1.3 Thesis outline

An overview of the research performed in the area of rehabilitation robotics focusing on mobile robots, along with the drawbacks in wheelchair-mounted manipulators, is provided in chapter 2 to establish the purpose of this project. A brief introduction to the concept of marsupial robots is also made in this chapter. It also contains the results of various surveys carried out with respect to tasks identified by users as the most important in everyday life, problems faced while using existing assistive devices and also improvements suggested by them. Chapter 3 addresses the problem presented in this current work by describing the need for such an assistive device and illustrates the basic design concept of the robot prototype with regards to task execution. The actuators used in the device are also included at the end of this chapter. Chapter 4 explains the different components of the control system architecture of the robot in detail. The data obtained from the controllers upon executing the program to drive the system is presented in chapter 5 along with the results of the preliminary experiments performed. The conclusions arrived at after analysis of the observations made from the tests and future recommendations made in order to fabricate a fully functional model are provided in chapter 6.

Chapter 2

Background

2.1 Prior research

Research has been going on in the area of rehabilitation robotics for a couple of decades now. Quite a number of significant results have been achieved as an outcome of the devoted efforts put in by various educational and research institutions. An impressive array of assistive devices has come up to make things possible and easier for people with impairments like cerebral palsy, stroke, or spasticity, etc [14, 35]. These rehabilitation robots have been classified into three groups namely: fixed workstation systems, wheelchair-mounted robots and mobile robots. A brief description of a few products is given below:

2.1.1 Fixed work-station systems

1. The RAID (Robot for Assisting the Integration of the Disabled) workstation was primarily designed for users with little or no upper limb function, in office environments. It could open racks, pick up selected documents, etc. as per the directions of the user [13, 30].

2. DeVAR (Desktop Vocational Assistive Robot) is a robotic workstation for quadriplegics that uses a voice-controlled robotic arm. It was developed for office-use for printing purposes and other computer-related tasks, etc. [43-44]

3. ProVAR, built upon the results from DeVAR, aims at easier control, better functionality and greater economic feasibility [44].

4. Robotic Assistive Device is another workstation-based robot designed for assisting severely disabled users in performing manual tasks like handling objects, etc. [56]

5. Afmaster is a remotely controlled manipulator commanded through a joystick, etc. to assist the user at home or work [47].

6. Wolfson robotic manipulator, a desktop-mounted workstation system, was developed at the Bath Institute of Medical Engineering, but, was found impractical by users for everyday use as it restricted the person to a particular room [21-22].

7. Neater-Eater is another recognized product allowing the user to dine independently without requiring the help of another person [55].

2.1.2 Robotic wheelchairs

These service robots are semi/fully automated and carry the users around with almost no assistance. e.g. NavChair, Bremen, Vahm, Maid, etc. [2-3, 5, 29].

2.1.3 Wheelchair-mounted robots

1. The ARM (Assistive Robot service Manipulator) or the MANUS is one of the most popular wheelchair-mounted robot systems designed to assist people with disabilities. This general-purpose manipulator aims to assist heavily handicapped persons who have lost the ability to use their arms in object manipulation tasks such as drinking, gripping objects, etc. A complicated control system provides the user with the capability

of operating the device through different types of user-inputs. Modifications have been made for use in various projects to perform many tasks ranging from opening a door and picking an object to feeding and leisure activities [1, 9].

2. RAPTOR permits persons with severe disabilities to manipulate objects in their personal environments, hit switches and even for feeding tasks, thus establishing a greater measure of functional independence [31].

3. KARES is a wheelchair-mounted robot system performing autonomous tasks like handling an object and manipulating a switch on a wall. Manual control was made possible through SPACEBALL 2003, an auxiliary 3D device [39-40].

4. Weston robotic arm was designed to extend the functionality of the trolley-mounted Wessex arm. The arm is driven in a vertical plane on two parallel vertical tracks and can be swung around when required [21-23].

5. Asimov is a modular, lightweight robot designed to compensate for handicaps in the upper limbs [60].

2.1.4 Mobile robots

1. MoVAR (Mobile Vocational Assistant Robot) is a three-wheeled omni-directional robot with a PUMA mounted on it. A touch sensor was mounted on the base and a force sensor and proximity sensor were mounted on the wrist and gripper respectively. Command input was through keyboard, voice and head-input, with a camera system displaying the robot’s movements and its surroundings. Although it had achieved its functional goal of feasibility, it was not very reliable as each subsystem was crucial for

the performance of every single task. It was difficult to use and the aberrant behavior was also considered dangerous to the surroundings [43].

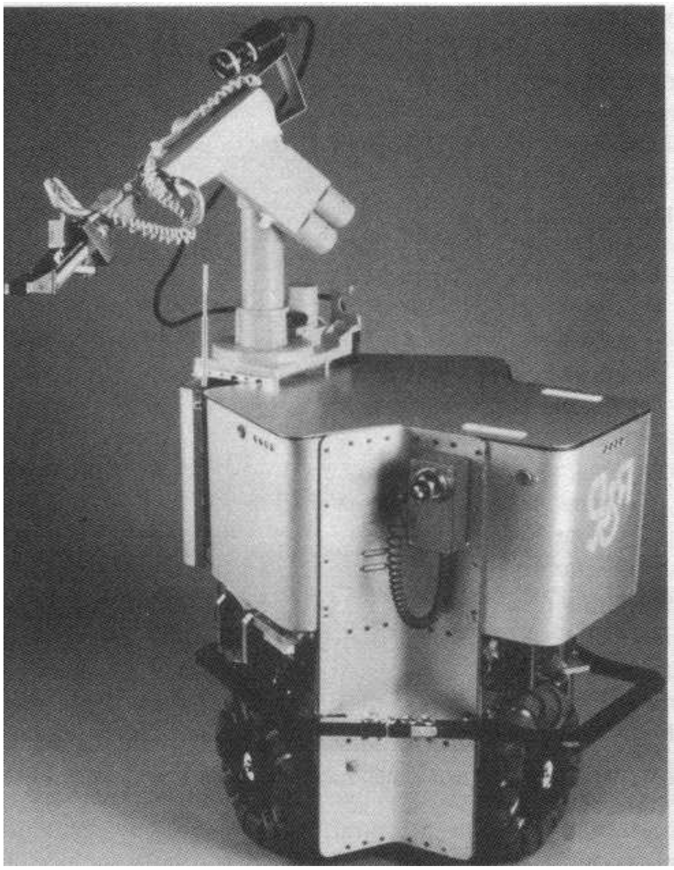


Figure 2.1 MoVAR

2. The French Atomic Energy Commission (CEA) has developed the mobile robot, MOVAID, as a part of the TIDE Project, to essentially carry out transportation tasks (ferry out food, medicines, etc.) in a home environment. It has a docking capability at various fixed workstations for data exchange and power supply [13, 25].

Figure 2.2 MOVAID

3. As a development of the MOVAID Project, another small multi-functional mobile robot, PARTNER, has been developed to carry out safe navigation in the presence of unpredictable obstacles. This is a small multi-functional mobile robot designed to carry out autonomous tasks like transporting food, drugs, etc. It integrates a wireless infrared link with a low-cost local building automation network [13].

Figure 2.3 PARTNER

4. URMAD (Unita' Robotica Mobile per Ausilio ai Disabili) project was aimed at demonstrating a robot prototype to assist persons with disabilities in carrying out certain tasks in a semi-autonomous manner [53].

Figure 2.4 URMAD

5. WALKY is a mobile robot system developed for people with disabilities in lab environments. The mobile base is equipped with ultrasonic sensors and has an on-board computer for performing calculations for carrying out the designated tasks. The user can move it in either manual or automatic modes. It is hoped that this would increase employment opportunities for people with limited motor functions [50].

Figure 2.5 WALKY

6. Project ARPH (Assistance Robotics to Handicapped Person) belongs to the mobile robot system category and has a manipulator arm mounted on a mobile robot. The objective was to carry and manipulate an object in a partially known environment such as a flat [8].

Figure 2.6 ARPH

7. HERO 2000 is a mobile manipulator that has an optional multi-jointed gripper with a sense of touch. It can lift a pound in any direction, pull upto 26 pounds and even dock into its charger when running low on battery. It is composed of commercially available components, 1 main and 6 slave processors, is programmed in BASIC and is considered the smartest, most versatile and most easy robot around to use. Yet, it was not able to make the expected impact due to safety concerns [30].

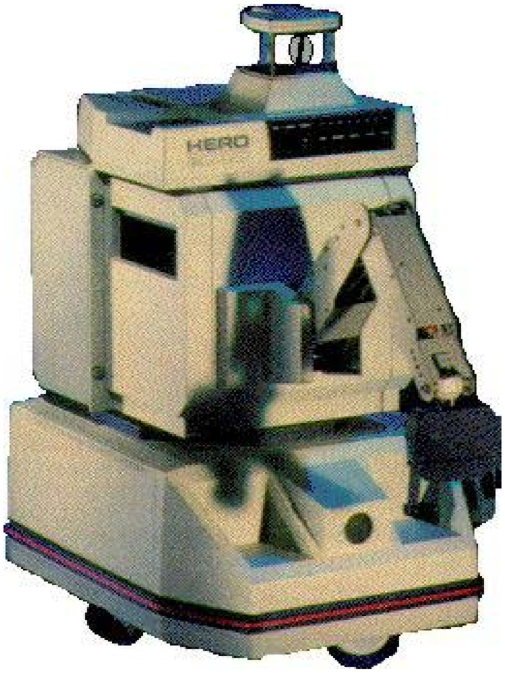


Figure 2.7 HERO 2000

8. HANDY is a low-cost manipulator that was first designed to help a child have his meal without assistance from a helper using a single switch. Later modifications have resulted in a set-up to assist people in applying make-up, shaving and also taking care of their dental hygiene, giving them an opportunity to perform these tasks by themselves, thereby increasing their quality of life. Its main drawback is that it is constrained to a fixed environment [24].

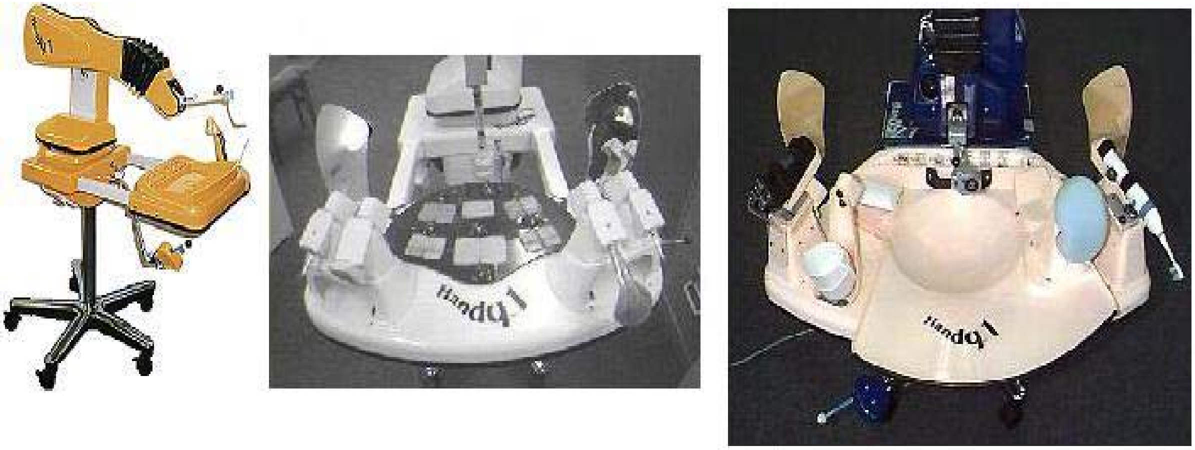


Figure 2.8 HANDY - for eating food, applying make-up and, brushing and shaving

9. A manipulator mounted on a small mobile trolley (Wessex) was taken up to design a low-cost, stand-alone, multi-functional, mobile assistive device. It was developed to overcome the defects in the Wolfson workstation manipulator. But, this required a carer to push the trolley on which the manipulator was mounted from place-to-place [23].

Figure 2.9 Wessex robot

10. HelpMate is a trackless robotic courier designed to navigate autonomously in hospitals and other medical facilities transporting pharmaceuticals, laboratory specimens, equipment and supplies, meals, medical records, and radiology films back and forth between support departments and nursing floors [58].

Figure 2.10 Helpmate

11. GOBOT was designed to provide children affected with severe physical disabilities the ability to explore and interact with their environments. It consists of an adjustable positioning frame attached to a battery-powered base that can be driven with a joystick or switches. Children can be positioned in standing, semi-standing or seated positions [30].

Figure 2.11 GOBOT

12. AMOS (Assistive Mobile Robot System) was developed to assist the physically challenged persons by picking and transporting objects of daily use, and placing them in designated indoor locations semi-autonomously. The user interacts with it through a web-browser connected to a computer network allowing for communication from anywhere, by anyone and anytime [35].

2.2 Survey results and user feedback

A survey among practicing clinicians regarding their opinion about the possible benefits of new power wheelchair technology has indicated that 9 to 10 percent of the patients find it extremely difficult or nearly impossible to use the wheelchair for ADLs.

Conclusions from the survey also indicated that the users did not accept sophisticated technology either because they felt that such devices were ineffective or difficult to use or that such complexities were redundant and existing controls were adequate [41].

Pre-developmental surveys conducted by institutions across England and North America have indicated that performing tasks such as picking up things from the floor or off a shelf and tasks associated with eating, personal hygiene and leisure activities on their own through the use of assistive devices rather than seek the assistance of another person rated highly [4].

Results from a survey conducted by the Bath Institute of Medical Engineering (BIME) indicate that tasks requiring stretching, gripping and reaching to the floor all rated highly on the "not able to do" list and also figured on the list of the top five tasks under "most like to do but cannot" list. Participants in that survey also suggested without any prompting that a mobile device would be of far greater use. In another survey conducted by Middlesex University mostly involving people with spinal cord injuries, 22 out of 50 individuals considered reaching, stretching and gripping to be a top-priority task with 12 also including reaching to the floor among their priorities.

From a survey in Queen Alexandra Center, Canada, the top responses from the 36 individuals who took part in the questionnaire included picking up an item from the floor, opening/closing a door. From a powered upper-limb orthosis survey conducted in 1991 at the University of British Columbia, Canada, out of 11 users who were asked to identify "most like to do but cannot" tasks, 9 wanted reaching/picking up objects. Results indicate that reaching, gripping, and picking up objects from a shelf/floor, fetching, turning appliances and opening drawers are all important tasks.

Table 2.1 Results of pre-development surveys

	BIME[1]	Middlesex[2]	Queen Alexandra[2]	University of British Columbia[2]
Total number of subjects	42	50	36	11
Reaching, stretching, gripping, picking up objects	-	22	18	9
Reach or pick-up from floor	4	12	4	-
Cooking, fixing food, drinks	18	10	9	2
Eating, drinking	4	9	-	6
Personal hygiene	2	3	11	7
Dressing		6	3	4
Gardening, hobbies and crafts, leisure	1	13	8	7

[1] Survey question: “What would you like to use a manipulator for?”

[2] Survey question: “What five tasks would you like to do, but cannot?”

Table 2.2 User task priorities

Priority	Task
High	Picking up objects, esp. from floor or shelf, carrying objects

Table 2.2 User task priorities (contd.)

Moderate to high	Eating/Drinking

Individuals have always been emphasizing on the need for simplicity, reliability, minimum mass and low cost [6]. In addition to the general reaching tasks, mobility related tasks like opening doors and windows, and operating door-opening switches and elevator buttons have also been suggested by users [5, 26].

2.3 Limitations in existing devices, esp. wheelchair-mounted robots

In the case of the trolley-mounted robot, users sought greater functionality and also suggested mounting the robot on the wheelchair or having a remote-controlled powered trolley [21, 23]. MANUS evaluation users indicated that having too many commands for a small adjustment and too many functions to keep in mind at the beginning were the most difficult things when using rehabilitation robots [5, 15, 39]. They also found the MANUS to be useful, but not useful enough to gain totally independent lifestyles to justify the high costs [11]. One of the most commented issues was the physical size of the Manus arm, preventing the user from driving the wheelchair close to a table or maneuvering the wheelchair through narrow passages [15].

The view from the wheelchair was limited with the Manus mounted, and this is even more so the case with the Manus folded out. Also, right-handed users found it awkward to have the Manus arm mounted on the left side of the wheelchair. The foldout and fold-in procedures required too much space and the reach to the floor was found to be too short [15].

Users desired independence but, at the same time, they did not want their capabilities to be curtailed due to the difficulties in use, poor reliability, and high costs of existing applications [17].

2.4 Marsupial robots

Shape shifting, marsupial robots have been used in Urban Search And Rescue (USAR) operations to aid rescue workers in locating victims of a disaster, etc. The marsupial team essentially consists of a large robot that can carry a number of smaller robots similar to a kangaroo carrying its little ones in its pouch, hence the term marsupial. The mother robot can navigate into a certain hazardous location unfit and unsuitable for human entry and when the terrain becomes too much for the large robot to move about freely, the smaller baby robots are released. These gain their power from the larger robot and communicate with it using the sensory data acquired [32].

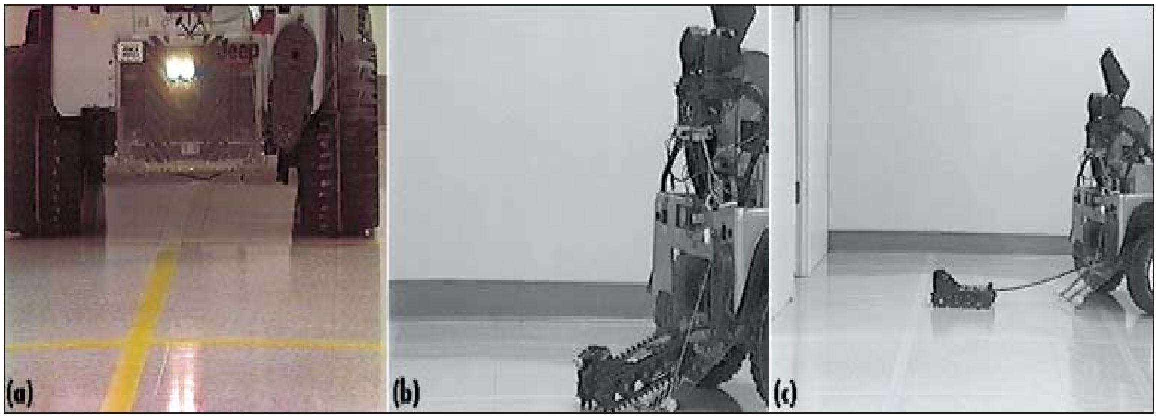


Figure 2.12 Microrover Bujold deployed from inside the Silver Bullet

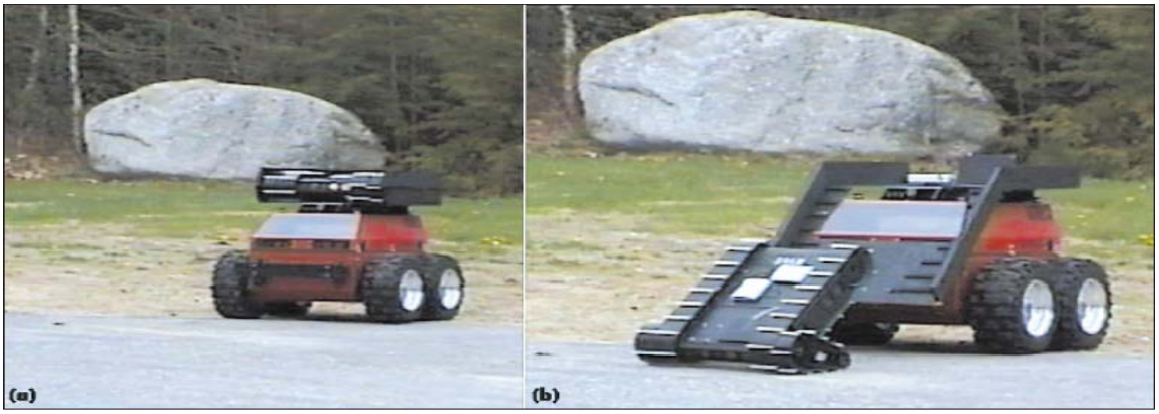


Figure 2.13 The RWI/ISR marsupial team

The possibility of using a mobile robot in tandem with a powered wheelchair to form a marsupial team is experimented here, since one does not always have need for a robot. A robotic arm mounted to a wheelchair can be a hindrance to the user, but, a mobile robot can perform its assigned task when required [25] and disappear from the scene once it performs its function. The wheelchair can be considered to be the docking station for the mobile robot providing the power and control mechanisms for the robot.

Chapter 3

Problem Description and Concept Formulation

An assistive/rehabilitation robotic device is something that should be able to perform the designated tasks in a minimally structured setting to enable people with disabilities to function more independently. Most of the tested devices have not received the anticipated success due to their complexity and high costs [38]. Simple ways have to be developed to make devices more user-friendly and give them a feeling of safety and freedom [41]. Our goal is to achieve good mobility and manipulability functions and facilitate in a better quality of life building morale and assist in integrating the affected person into the society. The objective is to enhance inadequate human input, through the use of a device to translate the impaired motions and use them to perform the required task independently [4].

3.1 System problem description

Research and surveys by various institutions and organizations have identified the following tasks as the most difficult for an individual with a disability, made all the more difficult when using a powered wheelchair:

- Mobility, covering activities associated with getting around, such as opening doors, operating light switches or lift buttons
- General reaching and moving, such as reaching down to pick up an item off the floor or reaching up to get an item off a shelf

In the presence of a multitude of devices, the currently proposed concept has to be justified. A marsupial with a powered wheelchair as its docking station has many advantages over a wheelchair-mounted robotic arm. There would be no restriction on the workspace of the arm with respect to the individual in the sense that the arm would not prove to be an obstacle. The user need not go through a multitude of complex operations to get the arm to the required position and the workspace of the arm as an independent entity is constrained only by the nature of the task to be performed. It would save an individual with a disability using a powered wheelchair both time and effort to move about freely through doorways and to move small objects around him/her.

One place where such a device would really come in handy would be in narrow pathways/corridors where a person on a wheelchair is trying to negotiate a turn and at the same time, is trying to enter a room or turn into another corridor. There have been a few instances when people were stuck in the doorways while trying to perform the above-mentioned maneuver. It might seem just another turn to make or another doorway to go through, but, it is definitely time-consuming and a strain on the user. A small miscalculation on part of the user and there is no easy way out once the user is grounded. A wheelchair-mounted arm may also not be able to assist the user under such circumstances depending on its dimensions and its position on the wheelchair. A mobile robot on the other hand can push the door and hold it open while the user passes through.

3.2 Design criteria

The aim of rehabilitation technology is to effectively utilize and at the same time, improve the residual functions of persons with disabilities. In order to develop a system to be able to appease the user, it is desirable that individual requirements are met rather than merely providing a high-tech aid and then hoping that it would assist the user [23]. When attempting to incorporate an assistive device like a robotic arm onto another assistive device like a wheelchair, the merger should be such that the end product should not impose additional hindrances on either the user or the system and the result should be something that is not less efficient and less functional than either of the individual components [37].

A number of factors need to be taken into consideration when working on a rehabilitation device [21]:

1. No compromise on wheelchair control: It is vital that the presence of the robot does not compromise the safe control of the wheelchair. This requirement covers a number of areas such as stability of wheelchair, steering, control, maneuverability of wheelchair and the user’s vision.
2. No compromise on usability of wheelchair: For electric wheelchair users, their wheelchair is their immediate requirement. The presence of the robot must not compromise such aspects as seat adjustment and transfer into or out of the wheelchair. In addition, the robot must be mounted so as to enable easy removal when not required.

3. Security: The user being located within the workspace of the manipulator, its construction must rule out the possibility of any harm to the user.
4. Functionality: User-oriented functionality should enable every user to perform common tasks of his/her life.
5. Flexibility: Configuration and control need to be enumerated to the meet the needs as well as the physical and mental abilities of the user.
6. Mobility: Low weight and low energy consumption are critical issues for mobile systems in general.
7. Other: The size of the mobile base has to be small enough to move around in a normal house, etc. Safety, non-interference with the use, accessibility and mobility of the wheelchair, strength, cost and aesthetics and the ability to perform simple tasks which an individual wants to go about unaided are some of the other factors which have to be taken into consideration [40].

3.2.1 System requirements

The device must be able to:

- Exert enough force to push open a door gradually
- Reach to the floor level to be able to pick up small objects
- Allow for simple and easy control
- Task execution should be fast enough in order not to frustrate the user
- Be able to get onto and off the wheelchair as and when required easily

3.2.2 ADA requirements

The Americans with Disability Act of 1990 stipulated that certain requirements be met as per the ADA Accessibility Guidelines for Buildings and Facilities (ADAAG) to enable easy access to people with disabilities to all facilities both at work and home [46].

3.2.2.1 Forward reach

The maximum high and the minimum low forward reaches should be 48 in (1220 mm) and 15 in (380 mm) respectively in the case when the clear floor space only allows forward approach to an object. When the high forward reach is over an obstruction, reach and clearances shall be as shown in Figure 3.2.

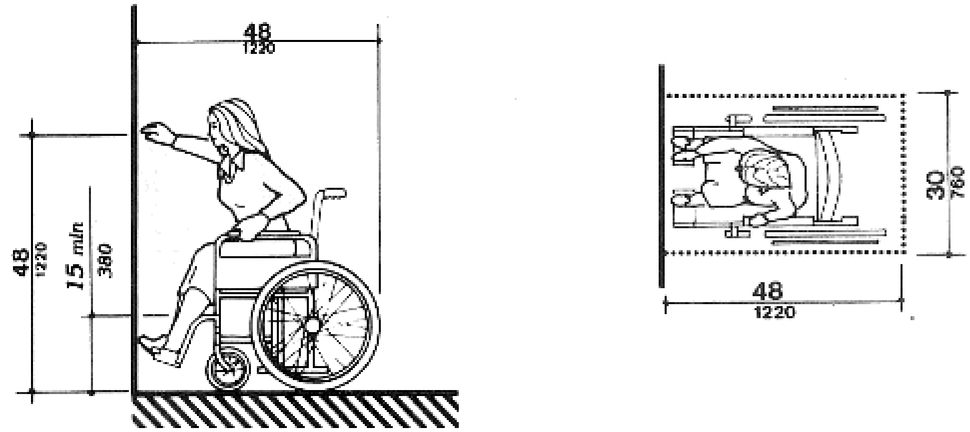
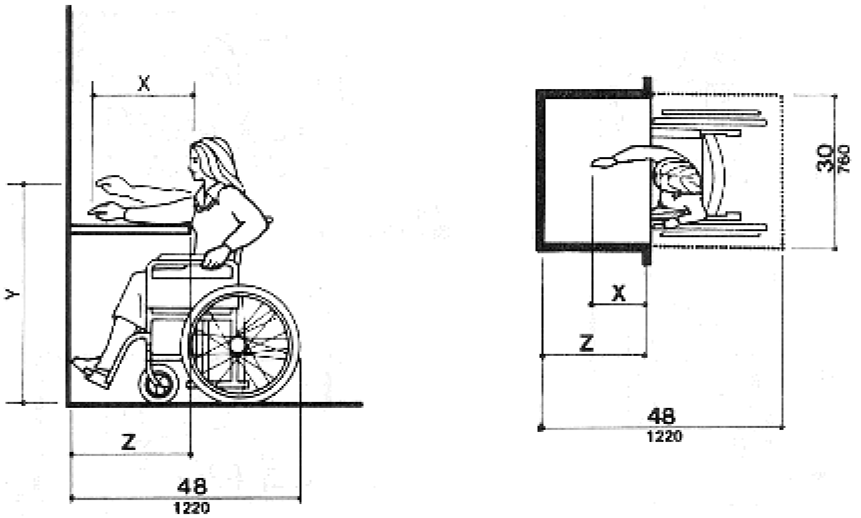


Figure 3.1 High forward reach limit



NOTE: x shall be ≤ 25 in (635 mm); z shall be ≥ x. When x < 20 in (510 mm), then y shall be 48 in (1220 mm) maximum. When x is 20 to 25 in (510 to 635 mm), then y shall be 44 in (1120 mm) maximum.

Figure 3.2 Maximum forward reach over an obstruction

3.2.2.2 Side reach

The maximum high and the minimum low side reaches should be 54 in (1370 mm) and not less than 9 in (230 mm) respectively when the clear floor space allows parallel approach by a person in a wheelchair (Figures 3.3 and 3.4). If the side reach is over an obstruction, the reach and clearances shall be as shown in Figure 3.5.

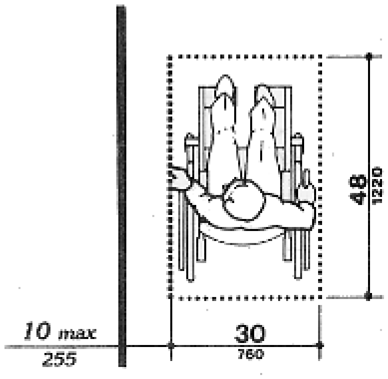


Figure 3.3 Clear floor space - parallel approach

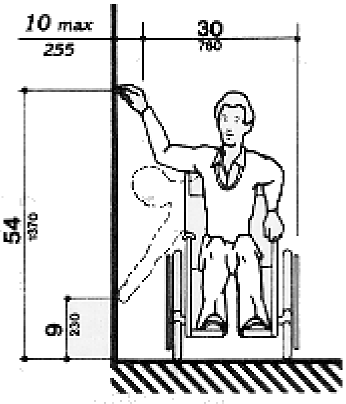


Figure 3.4 High and low – side reach limits

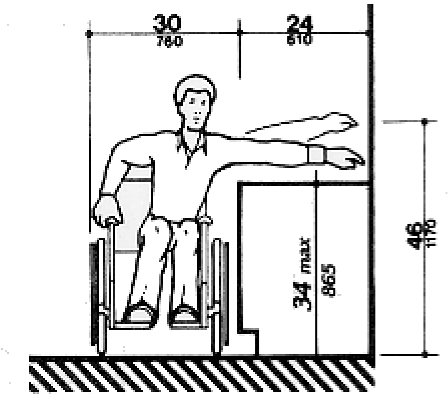


Figure 3.5 Maximum side reach over an obstruction

3.2.3.3 Door opening force

Although most people with disabilities can exert at least 5 lbf (22.2N), both pushing and pulling from a stationary position, a few people with severe disabilities cannot exert 3 lbf (13.13N). Although some people cannot manage the allowable forces in this guideline and many others have difficulty, door closers must have certain minimum closing forces to close doors satisfactorily.

Forces for pushing or pulling doors open are measured with a push-pull scale under the following conditions:

1. Hinged doors: Force is applied perpendicular to the door at the door opener or 30 in (760 mm) from the hinged side, whichever is farther from the hinge.
2. Sliding or folding doors: Force is applied parallel to the door at the door pull or latch.
3. Application of force: Force is applied gradually so that it does not exceed the resistance of the door.

The maximum force for pushing or pulling open a door shall be as follows:

1. Fire doors shall have the minimum opening force allowable by the appropriate administrative authority.
2. Other doors:
    a. exterior hinged doors: (Reserved)
    b. interior hinged doors: 5 lbf (22.2N)
    c. sliding or folding doors: 5 lbf (22.2N)

These values do not apply to the forces required to retract latch bolts or disengage other devices that may hold the door in a closed position.

3.3 Concept development

Bending and picking an object on the floor is a tough call for wheelchair users with spinal-cord injury or weak limbs, though it is one of the tasks more frequently encountered. Similarly, opening/closing a door gives users the flexibility to navigate around on their own. Utilizing the user's latent abilities as much as possible is important, and the device should only provide assistance to the extent of the user's deficiency. Thus, the user needs to be capable of maneuvering the assistive device. In this aspect, the present device is different from other devices in that mobile robots in general have always tended to be either autonomous or semi-autonomous.

3.3.1 Basic design features

The maximum reach of the arm is 30 in above the ground, which is sufficient enough for a person in a wheelchair to collect an object from the end-effector obviating the need for bending forward. This is in agreement with the ADA stipulations as far as the minimum reach is concerned. The actuators for the base are two 12 V DC gear motors that drive the rear wheels and generate enough torque to push a regular door gradually to open/close it. Two independent caster wheels that are free to rotate are fixed at the front and they provide the necessary support for the mobile base. The manipulator is not powerful enough to harm anyone and is able to carry a load of up to 0.5 lbs.

The manipulator can operate in the vertical plane with motion in the horizontal plane being provided by the mobile base. The components of the system are two fiberglass links of 11.75 in and 10 in length representing the mock-up of the robot arm, with a 12 V DC geared motor and servos mounted at the ends to drive the links and open/close the gripper, a box to encompass the electronic circuitry for operating the manipulator and the base, and wheels hooked to motors at the bottom. The arm is a two-degree-of-freedom RR manipulator with a two-fingered gripper functioning as the end-effector to lift/grab small objects. The gripper, also made of fiberglass, is modeled on similar lines as the Armitron and the gripper on the Lynxarm by LynxMotion [52]. It is two-fingered, parallel-jawed, provides pinch grip and is able to grasp small objects. The mobile base has dimensions 10 in x 10 in x 4in and the whole system weighs 25 lbs.

No major modifications need to be made to the wheelchair other than adding an extension underneath the footrests for the robot to climb back into the wheelchair after performing the designated task. By using the manually driven scheme, the robotic system can be designed to be of low cost, small size, and lightweight.

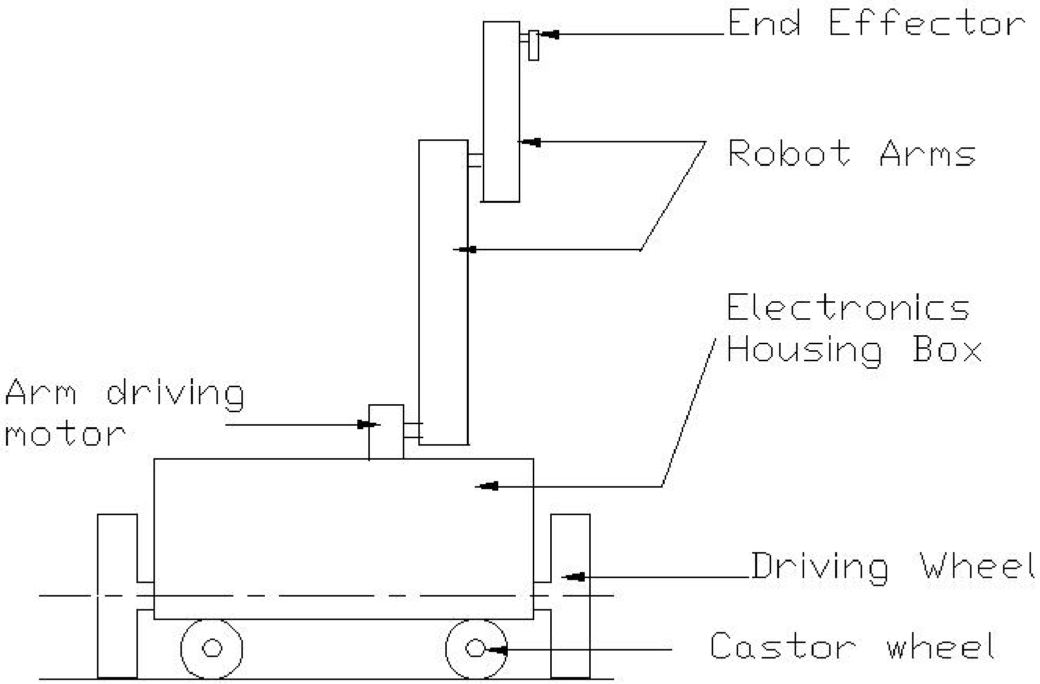


Figure 3.6 Basic design concept

3.3.2 Torque calculations

Having decided upon the link lengths, the payload of the end-effector and knowing the amount of force required to push a regular door, free-body diagrams are drawn for each of the links, the base and the system as a whole, to determine the joint actuator torques and also the motor torques for driving the base wheels. These values are verified by experiment by demonstrating the task execution.

Motor torques were calculated using the following values:

Base height = 8.75 in

Link 1 = 11.75 in

Link 2 = 10 in

End effector = 3 in

Net weight of the system = 25 lb

Safety factor = 1.5

Pay-load = 0.5-1 lb

Coefficient of friction = 0.5

Net force exerted by the base = 5 lbf

The following abbreviations were used in determining motor/servo torques:

Mi – Torque at Motor/Servo i

Fix, Fiy – Reaction Forces in the x and y directions respectively

Fw, Fc – Friction forces at driving wheel and caster wheel respectively

Nw, Nc – Normal reactions at driving wheel and caster wheel respectively

We solve for F2x, F2y and M2 at link 2, F1x, F1y and M1 at link 1 and Mw at the base using the dynamic equations of motion:

$\Sigma F_x = m.a_x$

$\Sigma F_y = m.a_y$

$\Sigma \tau = I.\alpha$

Thereafter, using a safety of factor of 1.5, we determine the optimal joint torques and the motors/servos required for manipulating the arm and driving the wheels are selected.

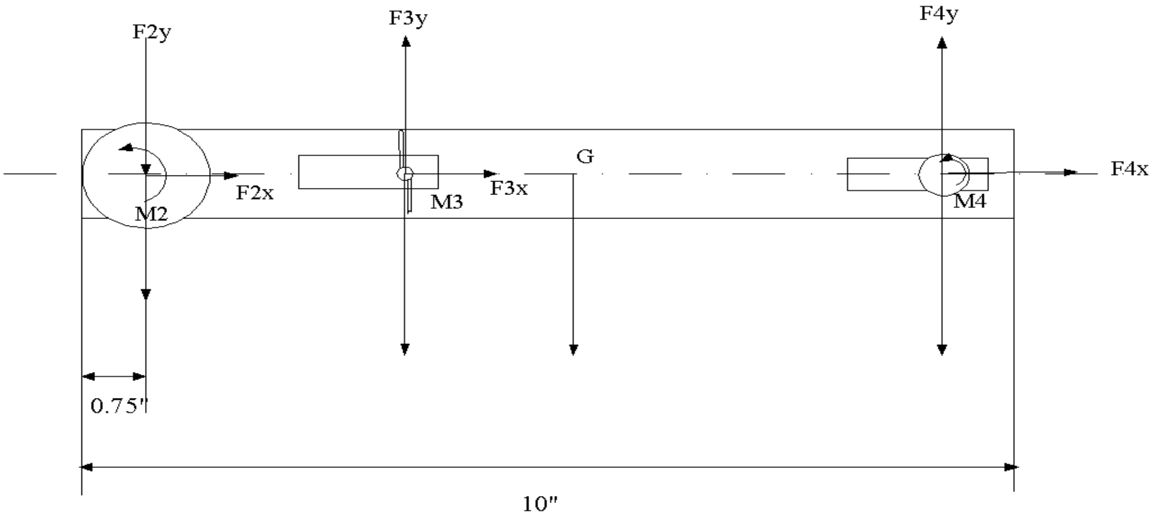


Figure 3.7 Free body diagram for link 2

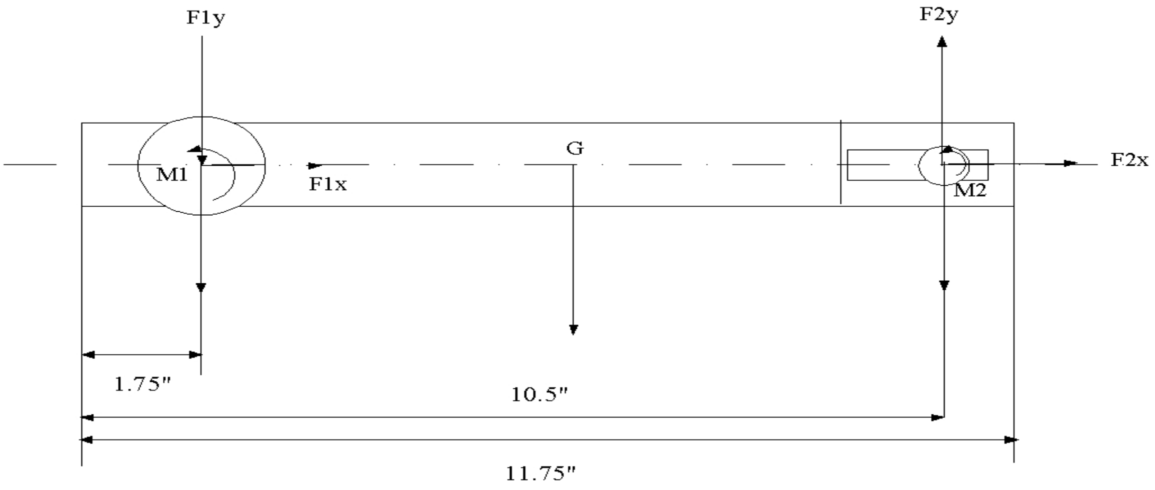


Figure 3.8 Free body diagram for link 1

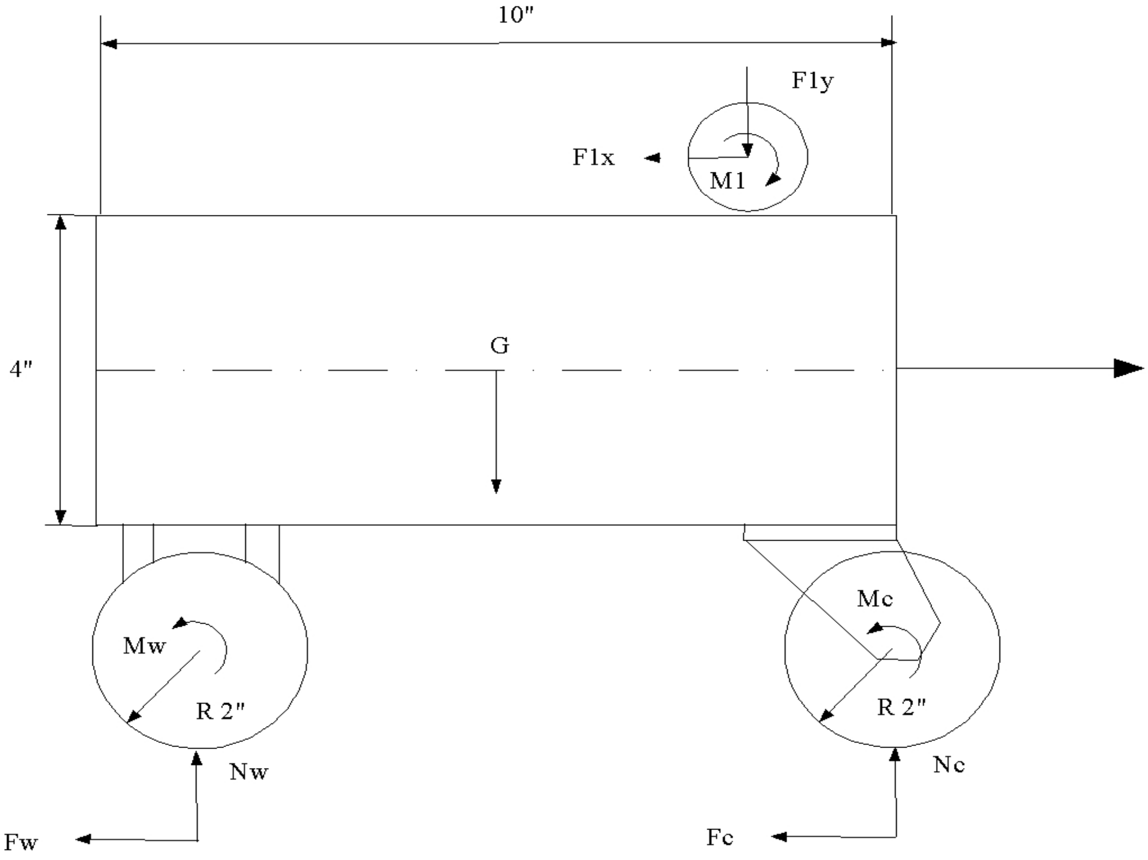


Figure 3.9 Free body diagram for base

Figure 3.10 Gripper

The end-effector is two-fingered gripper that is actuated by an aluminum push-rod connected to a servo at one end and soldered to the gripper at the other. The stiffness of the push-rod determines opening and closing of the fingers upon being driven by the servo when proper commands are issued by the user through the joystick. Another servo that is also controlled by the joystick is used at the wrist to hold the gripper in position and make minor adjustments to its orientation.

3.3.3 Actuators

The following actuators were used to drive the various components in our system:

3.3.3.1 Motors

A 4Z837 Dayton 12VDC Permanent Magnet Gear motor was used to drive the shoulder joint of the arm.

Figure 3.11 DC motor for arm

Table 3.1 Technical specifications of arm motor

Shaft Orientation	Parallel
Voltage Rating	12
Nameplate RPM	12

Table 3.1 Technical specifications of arm motor (contd.)

Input HP	1/90
Gear Ratio	192:1
Overhung Load (Lb.)	46
Full Load Torque (In.-Lbs.)	40
Full Load Amps	1.7
Rotation	Reversible
Mounting	All Position

Two1L478 Dayton 12VDC Permanent Magnet Gear motors fixed to the base were used to drive the complete system.

Figure 3.12 DC motor for base

Table 3.2 Technical specifications of base motor

Shaft Orientation	Parallel
Voltage Rating	12
Nameplate RPM	18
Input HP	1/30
Gear Ratio	161:1

Table 3.2 Technical specifications of base motor (contd.)

Overhung Load (Lb.)	50
Full Load Torque (In.-Lbs.)	50
Full Load Amps	3.0
Rotation	Reversible
Mounting	All Position

3.3.3.2 Servos

Two HS 422 servos were used for opening and closing the fingers of the gripper and also for holding the end effector in position at the wrist. The servo has a speed of 0.16 s/60° and its maximum torque output is 56.93 oz in.

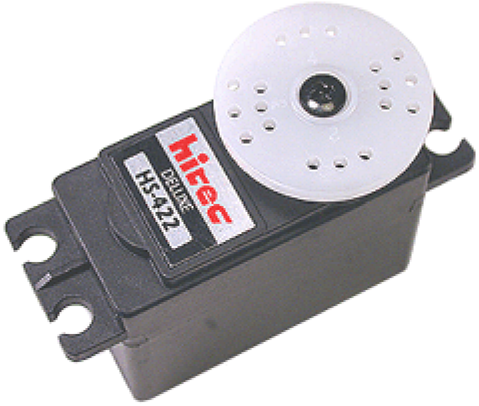


Figure 3.13 Servo for gripper and wrist

A HS815bb servo with a speed of 0.38 s/140° and maximum torque output of 343 oz in was used to drive the elbow joint of the arm.

Figure 3.14 Servo for link 1

Chapter 4

Control System Architecture

4.1 Overview

The performance by different persons in different environments when conducting different tasks dictates the control features to be implemented and procedures to be adopted when designing a control system. Posing minimal demands on the user in terms of cognitive abilities essential for operating the device and providing input signals to the system, providing a simplified and flexible control functionality with additional features like speeding-up process as and when required by the user to avoid irritation when time-consuming tasks are being carried out, are some of the criteria that govern the control environment design [1, 16, 27].

Our present interest in assistive technology is in mobility as well as manipulation. However, our focus here will be on devices that can be easily controlled and programmed by a human user with minimal effort, thereby making lower demands on the user's dexterity and mental load required to avoid unwanted movements [2].

Giving the users more control through a low-level control structure, rather than making them mere spectators while things are done autonomously, would give them a sense of achievement and satisfaction [3]. Our current device is a purely tele-operated manually controlled one in which the individual exerts direct control on the dynamic system. Such tasks have often been modeled as closed-loop negative-feedback systems in which the system is constantly trying to decrease the error (defined as the difference between the goal and the current state) by deriving feedback about its current state and then making appropriate control actions to compensate for this error. This kind of a human-in-the-loop control involves a display, a human, a controlled system, and a goal.

In the present case, the robot is the system, the visual about the state of the system is the display and the goal is to carry out the task whether it is pushing a door or picking an object. The user exerts a change in control by operating the joystick. The robot's travel direction and speed or the arm’s position i.e. the output, changes in response to this control input. This new system output is now visualized by the user who changes the inputs, and the cycle continues till the task is accomplished.

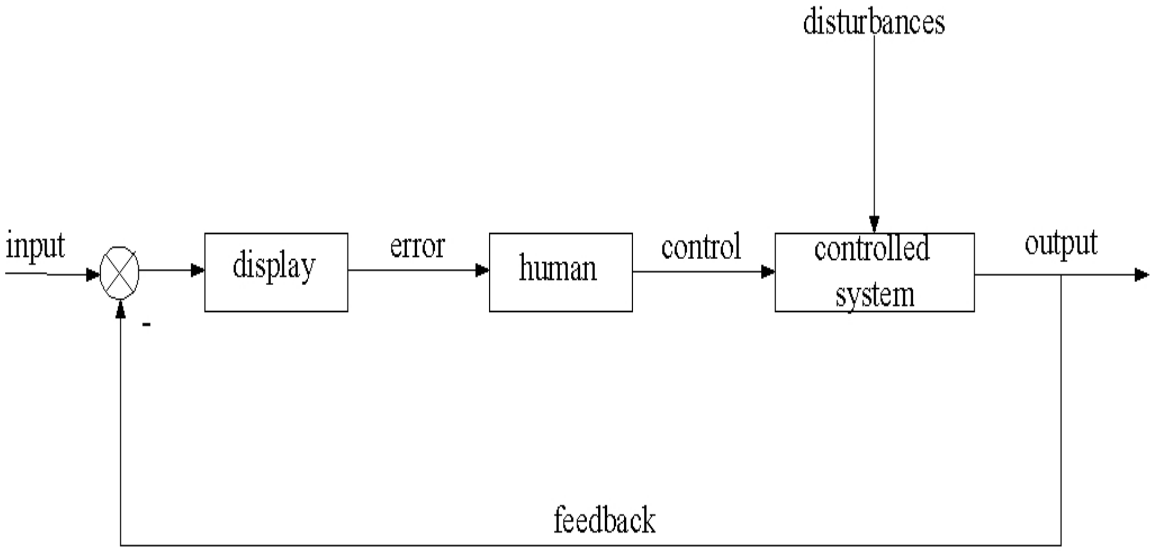


Figure 4.1 A simple closed-loop negative-feedback system as a model of manual control

4.2 Signal flow

A brief description of the signal flow from the joystick to the wheels or the arm is shown in figure 4.2 below.

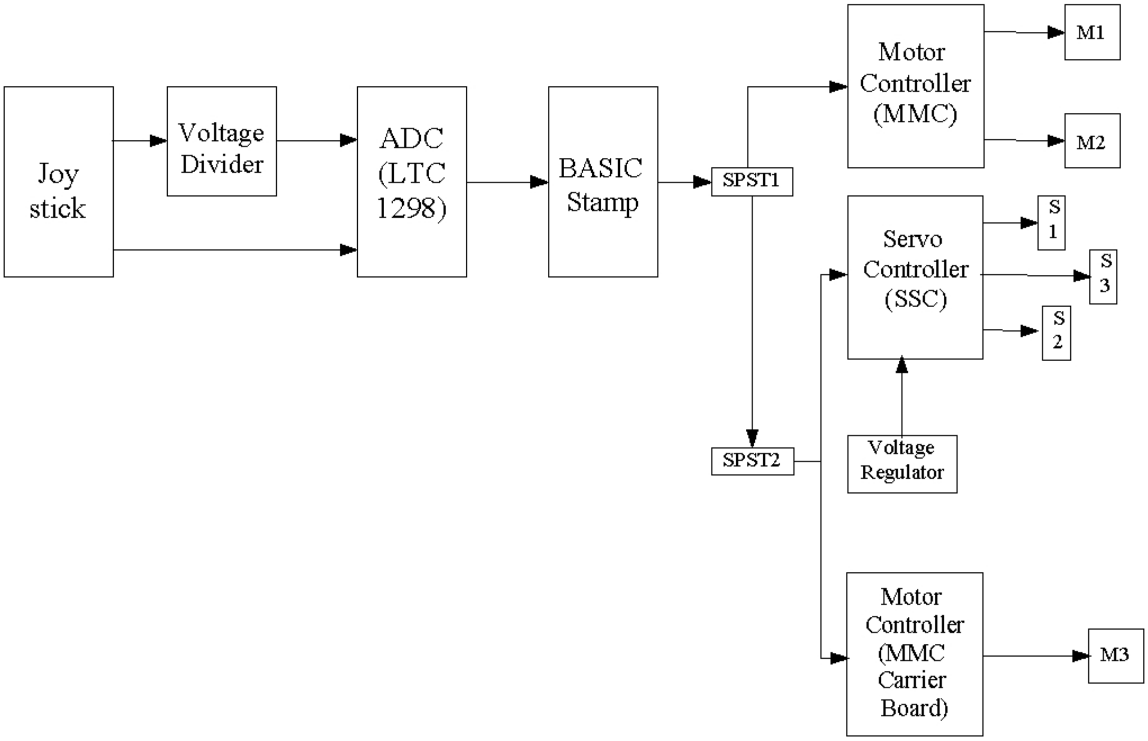


Figure 4.2 Signal flow diagram

Programs interlinking the various drives and their controllers can be downloaded onto the Stamp via an RS232 interface. Once this is done, the system can behave as an independent entity without the need for a computer to control the device. The user gives input signals from the joystick which has two channels – each representing speed and direction respectively. One of the channels is connected to the voltage divider and the resulting output is fed into one of the input channels of the A-to-D Converter, the other channel being connected directly to the second input of the ADC. The digital values coming out are sent to the BASIC Stamp, the brain of the system, which in turn transmits these signals to either of the Motor Controllers (MMC) or the Servo Controller (SSC) which act as slaves, depending on the state of the switches. Based upon the A-to-D values, the motors drive the base in either forward or reverse direction or take left or right turn. Likewise, the motor and the servos move the links up or down .

4.3 Joystick

A standard dynamic type wheelchair joystick is used in order to make the control process easy for the user of a powered wheelchair to handle the robot. The joystick is powered by the BASIC Stamp through a cable connected to one of the Vdd pins that provides 5V and another cable from the joystick is grounded by hooking it to the one of the Vss pins on the Stamp. A sketch of the joystick denoting the connection terminals and their purpose is shown below:

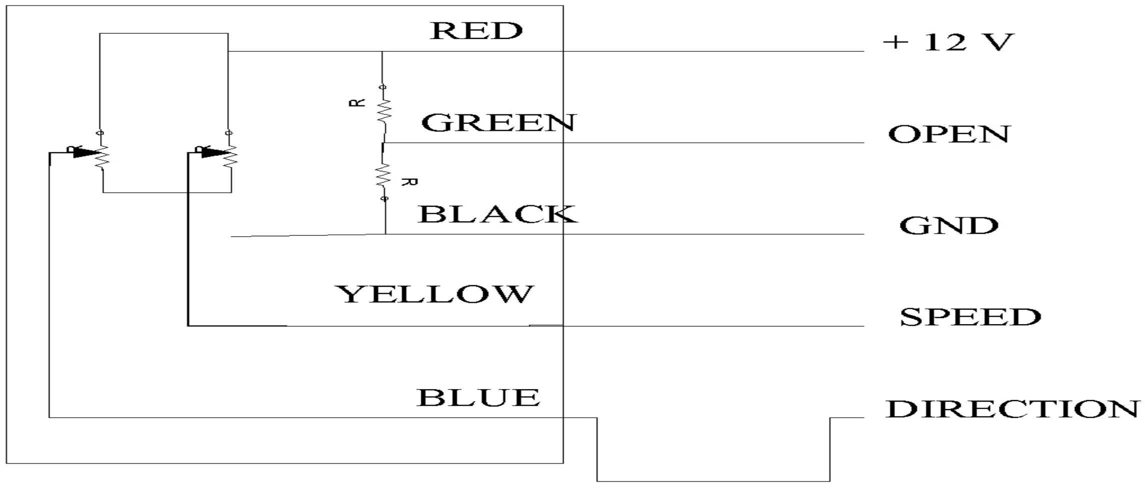


Figure 4.3 Joystick connections

4.4 Voltage divider

A voltage divider network was used to distinguish between the signals indicating speed and direction. It was observed that identical voltage values resulted for left and reverse positions and the values were again noticed to be the same for right and forward positions of the joystick. An appropriate circuit was used to halve the values for a particular direction, and in our case, we hooked up the direction terminal to the divider as shown below:

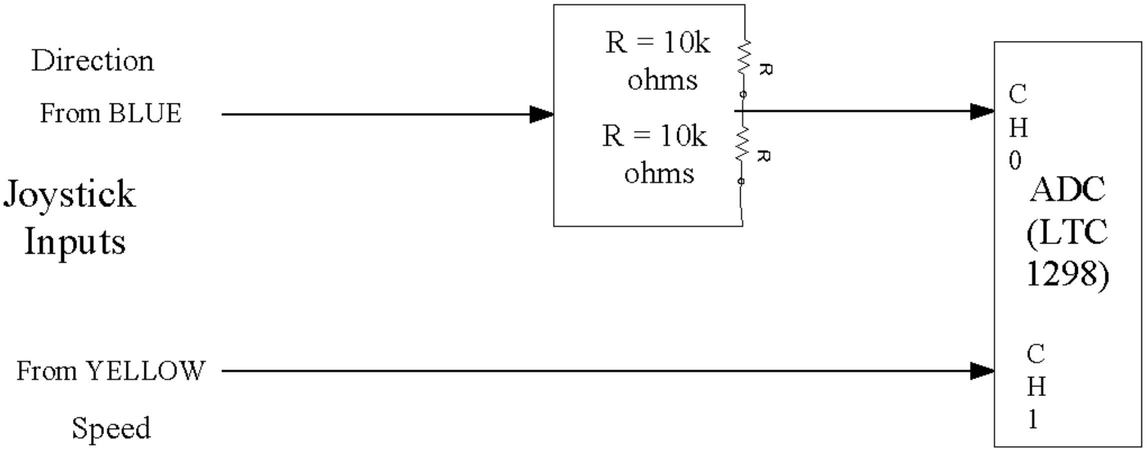


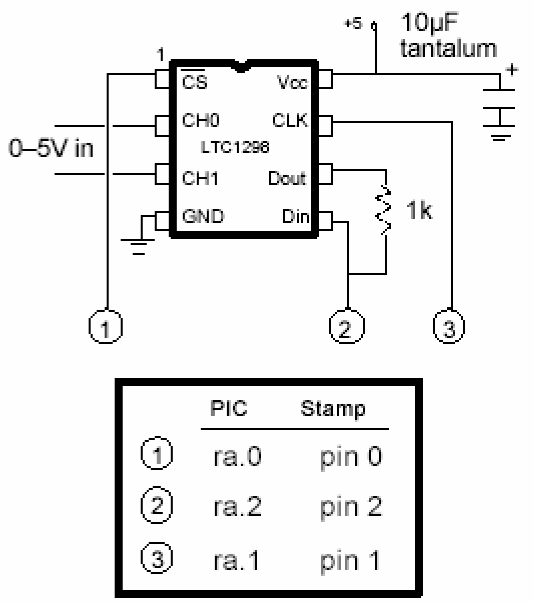
Figure 4.4 Voltage divider circuit

4.5 **A/D Converter** [51]

The LTC1298 is used as an analog-to-digital converter (ADC) for our present task. It is a switched capacitor, micro-power successive approximation sampling 12-bit converter that provides voltage measurements with 1.22-millivolt resolution operating between 5V to 9V supplies. It has an internal sample-and-hold feature that prevents errors when it is used to measure rapidly changing signals. The LTC1298 can be configured as a two-channel ADC or single-channel differential ADC. We use the two-channel mode where the selected channel’s voltage is measured relative to the ground and returned as a value between 0 and 4095, 5 V being the input to the joystick. The maximum clock rate for the LTC1298’s three-wire serial interface is 200 kHz, permitting up to 11,100 samples to be taken per second. It offers a software selectable 2-channel MUX with on-chip serial ports allowing efficient data transfer to the micro-controller over three wires and makes remote location possible and facilitates transmitting data through isolation barriers [74].

4.5.1 Hardware interface

The LTC1298 interfaces with controllers through four pins: chip select (CS), clock (CLK), data in (DIN) and data out (DOUT). The pins are connected to the BASIC Stamp, as shown below:



	PIC	Stamp
①	ra.0	pin 0
②	ra.2	pin 2
③	ra.1	pin 1

Figure 4.5 ADC and its connections to BASIC Stamp

The conversion process starts by activating the CS by taking it low and sending (shift out) configuration bits to the LTC1298. The 12-bit measurement is read (shift in) from the LTC1298 and finally, the CS is deactivated by taking it high.

4.5.2 Features

- Low Cost
- Single Supply 5V to 9V Operation
- On-Chip Sample-and-Hold
- 60µs Conversion Time
- Sampling Rates: 11.1 ksps (LTC1298)

4.5.3 Pin functions

CS (Pin1): Chip Select Input – A Logic Low on enables the chip & a Logic High disables and powers the chip.

CH0 (Pin2): Analog Input

CH1 (Pin3): Analog Input

GND (Pin4): Analog Ground

Din (Pin5): Digital Data Input into which multi-plexer data is shifted

Dout (Pin6): Digital Data Output out of which the AD conversion result is shifted.

CLK (Pin7): Shift Clock synchronizes serial data transfer and determines conversion speed

Vcc/Vref (Pin8): Power Supply and Reference Voltage provides power and defines the span of the chip

4.6 **BASIC Stamp** [51]

BASIC Stamp 2 SX is used as the micro-controller to drive the motors for the wheels and the motor and servos for the arm and gripper, using PBASIC, a customized form of BASIC, to suit the Stamp's architecture. The availability of the EEPROM makes it possible to store the program in the memory so the device can be used independently without being constrained by the need for a computer for computation and storage purposes. The 16 general-purpose I/O pins (TTL-level, 0-5 volts) enable in making the required connections to the Motor Controller and the Servo Controller. We have used the Windows version (1.1) of the BASIC Stamp Editor for programming purposes.

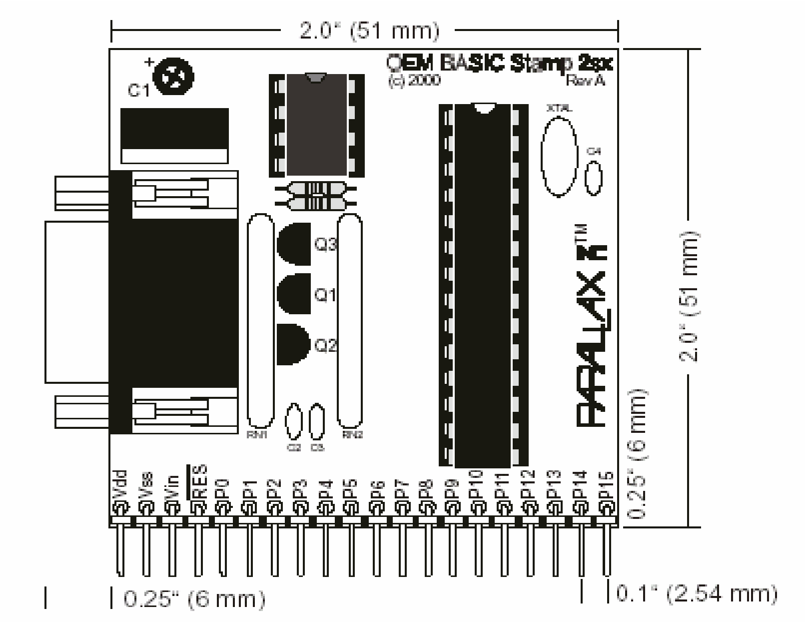


Figure 4.6 OEM BASIC Stamp 2sx (Rev.A)

Table 4.1 STAMP specifications

Specifications	
Microcontroller	Scenix SX28AC

Table 4.1 STAMP specifications (contd.)

Processor Speed	50 MHz
RAM Size	32 Bytes (6 I/O, 26 Variable)
Scratch Pad RAM	64 Bytes
EEPROM (Program) Size	8x2K Bytes, ~4,000 instructions
Program Execution Speed	~10,000 instructions/sec.
Number of I/O pins	16 + 2 Dedicated Serial

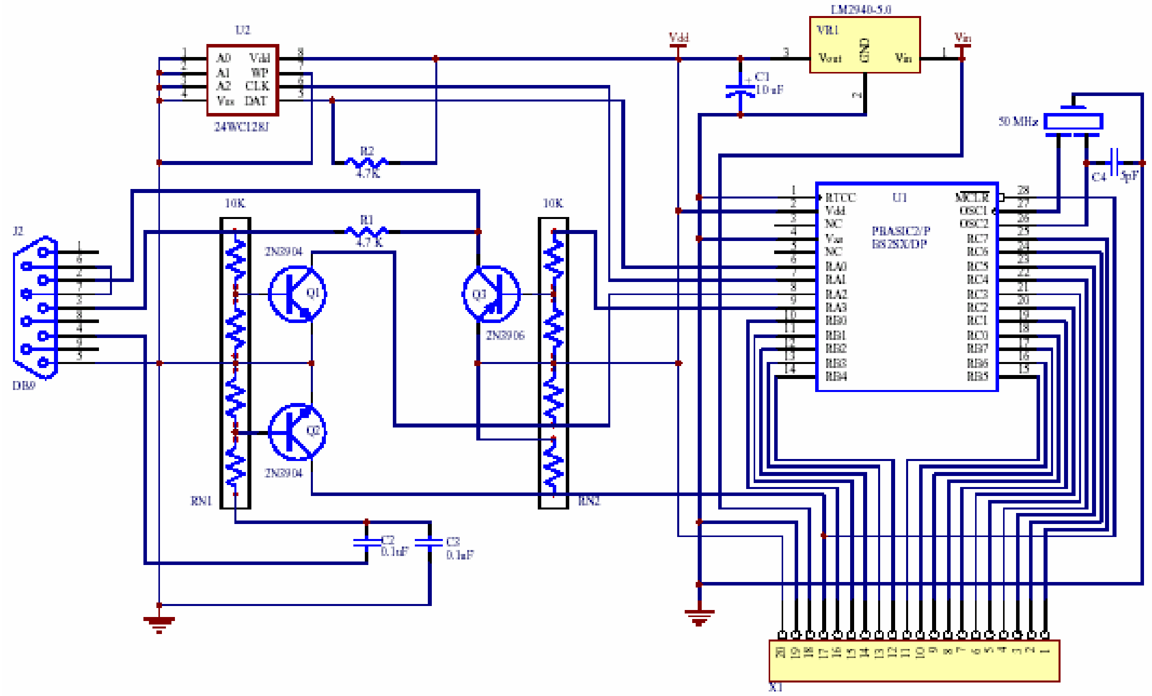


Figure 4.7 Internal architecture of BASIC Stamp 2sx (Rev.A)

Table 4.2 Stamp pin descriptions

Pin	Name	Description
1	SOUT	Serial Out: connects to PC serial port RX pin (DB9 pin 2 / DB25 pin 3) for programming.

Table 4.2 Stamp pin descriptions (contd.)

2	SIN	Serial In: connects to PC serial port TX pin (DB9 pin 3 / DB25 pin 2) for programming.
3	ATN	Attention: connects to PC serial port DTR pin (DB9 pin 4 / DB25 pin 20) for programming.
4	VSS	System ground: (same as pin 23 on BS2p24, or pin 39 on BS2p40) connects to PC serial port GND pin (DB9 pin 5 / DB25 pin 7) for programming.
5-20	P0-P15	General-purpose I/O pins: each can source and sink 30 mA. However, the total of all pins (including X0-X15, if using the BS2p40) should not exceed 75 mA (source or sink) if using the internal 5-volt regulator. The total per 8-pin groups (P0 – P7, P8 – 15, X0 – X7 or X8 – X15) should not exceed 100 mA (source or sink) if using an external 5-volt regulator.
21	VDD	5-volt DC input/output: if an unregulated voltage is applied to the VIN pin, then this pin will output 5 volts. If no voltage is applied to the VIN pin, then a regulated voltage between 4.5V and 5.5V should be applied to this pin
22	RES	Reset input/output: goes low when power supply is less than approximately 4.2 volts, causing the BASIC Stamp to reset. Can be driven low to force a reset. This pin is internally pulled high and may be left disconnected if not needed. Do not drive high.
23	VSS	System ground: (same as pin 4) connects to power supply's ground (GND) terminal.
24	VIN	Unregulated power in: accepts 5.5 - 12 VDC (7.5 recommended), which is then internally regulated to 5 volts. May be left unconnected if 5 volts is applied to the VDD (+5V) pin.

The BASIC Stamp's memory is organized into 16 words of 16 bits each. The first three words are used for I/O. The remaining 13 words are available for use as general-purpose variables.

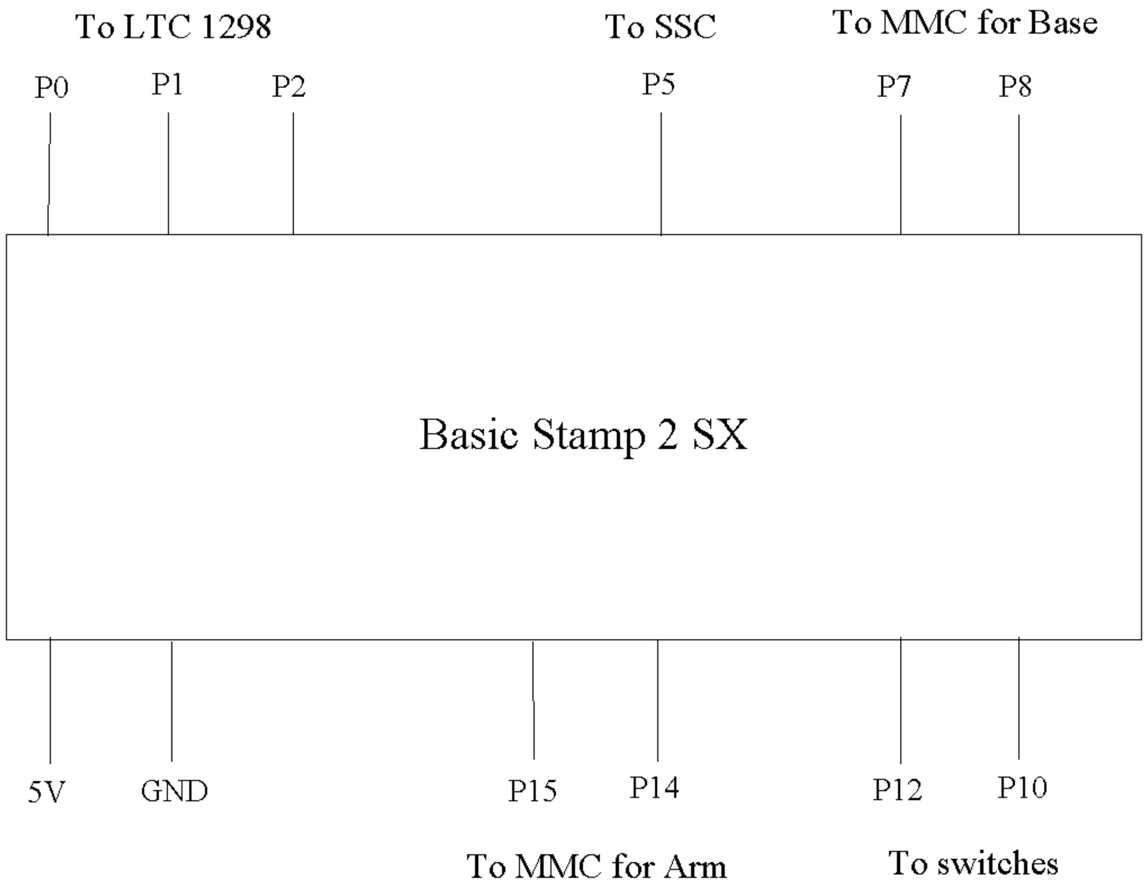


Figure 4.8 Basic Stamp pin connections in the present set-up

4.7 Switching modes

The typical method of switching modes is to press a specific switch provided at the input device. Two heavy-duty toggle switches (SPST contacts rated 6A at 250 VAC) are connected to P12 and P10 of the BASIC Stamp and the preferred motion is attained depending on the state of the switch, which in turn, determines the state of the pin. The user is allowed to access only one kind of mode per each switch – either the base or the arm for one switch (connected to P12), and either the links or the gripper for the other (connected to P10), thereby selecting the desired movement to be made.

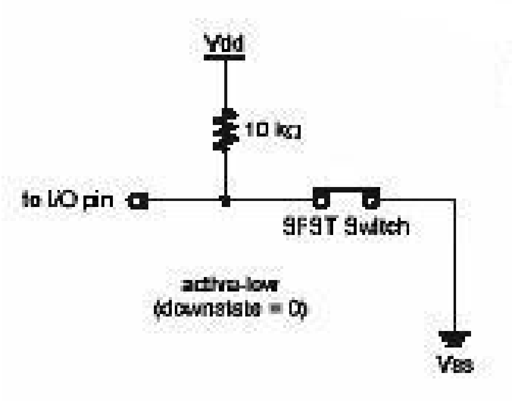


Figure 4.9 Circuit for SPST switch

4.8 Motor Mind C controller [62]

The Motor Mind C (MMC) provides versatile control of one or two small brush DC motors. Motor speed and direction can be controlled up to 2.25A continuous current per motor. The MMC accepts serial commands enabling the user to have direct control over the motor speed and direction. When configured for two motors the motor speed and direction for each motor are controlled independently, but it is not possible to power them at different voltages with the Motor Mind C. The PWM step limit (1-255), the PWM dead-band, and brake mode (dynamic or free spinning) can also be modified by the user. It may also be configured for analog control inputs (0-5VDC w/ 2.5V being stopped) or radio control signals (1.0-2.0ms signals w/1.5ms being stopped) [72].

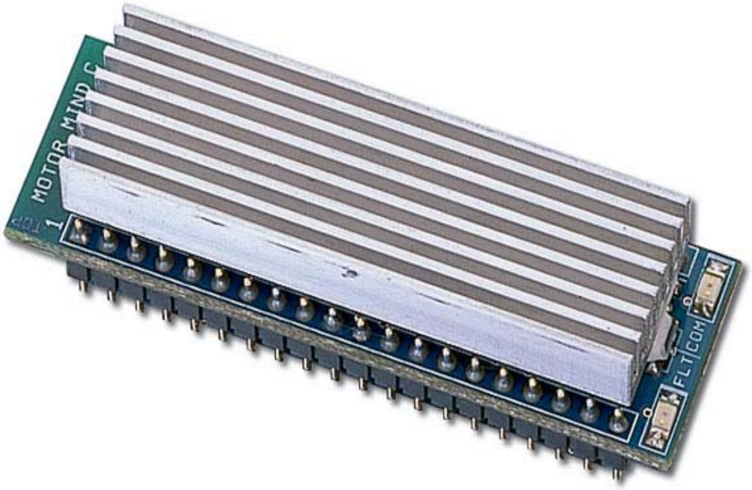


Figure 4.10 Motor Mind C

4.8.1 Features

Up to 4.0A continuous current

Up to 24VDC brushed motors

Control 1 or 2 DC Motors

3 modes of operation

Mode1: Direct serial control of 10-bit PWM

Mode2: Bi-directional 8-bit ADC based PWM control

Mode3: R/C 1-2ms pulse based PWM control

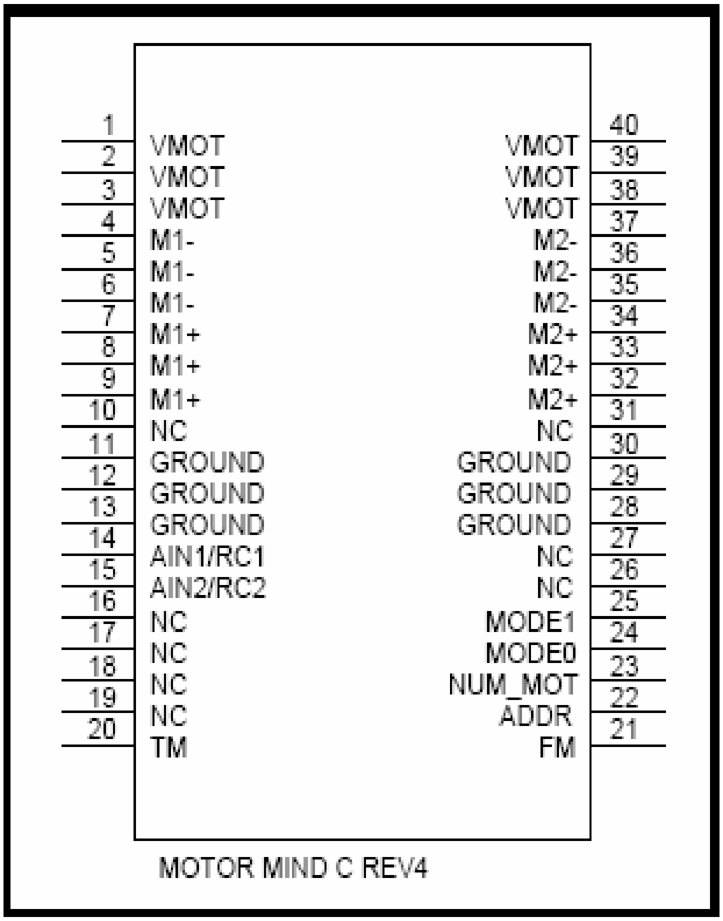


Figure 4.11 Motor Mind C pin connections

Table 4.3 Motor Mind C pin definitions

Pin	Name	Type	Definition
1	VMOT	POWER	Motor Voltage Input
2	VMOT	POWER	Motor Voltage Input
3	VMOT	POWER	Motor Voltage Input
4	M1-	POWER	Negative Motor lead connection for motor 1
5	M1-	POWER	Negative Motor lead connection for motor 1
6	M1-	POWER	Negative Motor lead connection for motor 1
7	M1+	POWER	Positive Motor lead connection for motor 1

Table 4.3 Motor Mind C pin definitions (contd.)

8	M1+	POWER	Positive Motor lead connection for motor 1
9	M1+	POWER	Positive Motor lead connection for motor 1
10	NC	No Connect	No Connection
11	GROUND	POWER	Ground return
12	GROUND	POWER	Ground return
13	GROUND	POWER	Ground return
14	AN1/RC1	INPUT	Analog input for control; of motor 1 when in analog mode, R/C mode unconnected in serial mode used as control input for analog and R/C modes when Motor Mind C is configured for Single motor operation.
15	AN2/RC2	INPUT	Used only in motor 2 configuration analog input for control of motor 2 when in analog mode ,R/C pulse input for control of motor 2 when in R/C mode, unconnected in serial mode
16	NC	No Connect	No Connection
17	NC	No Connect	No Connection
18	NC	No Connect	No Connection
19	NC	No Connect	No Connection
20	TX (TM)	OUTPUT	TTL level,8N1,38.4 KBPS or 9.6KBPS serial transmission pin(data to the Master unit)
21	RX (FM)	INPUT	TTL level, 8N1, 38.4KBPS or 9.6KBPS serial reception pin (data from the Master unit)
22	ADDR	INPUT	Left unconnected for Motor mind C to default to address 1 tied to ground to force address to 2, used as address only in serial mode of operation. In analog of R/C, modes this pin can be tied to enable dynamic breaking.

Table 4.3 Motor Mind C pin definitions (contd.)

23	NUM_MOT	INPUT	Tied to ground to force Motor Mind C to operate in single mode, left unconnected for dual motor mode of operation
24	MODE 0	INPUT	Used in conjunction with MODE 1(Pin 25) to determine mode of operation on power up
25	MODE 1	INPUT	Used in conjunction with MODE 0(Pin 24) to determine mode of operation on power up
26	NC	No Connect	No Connection
27	NC	No Connect	No Connection
28	GROUND	POWER	Ground Return
29	GROUND	POWER	Ground Return
30	GROUND	POWER	Ground Return
31	NC	POWER	No Connection
32	M2+	POWER	Positive motor lead connection for motor 2
33	M2+	POWER	Positive motor lead connection for motor 2
34	M2+	POWER	Positive motor lead connection for motor 2
35	M2-	POWER	Negative motor lead connection for motor 2
36	M2-	POWER	Negative motor lead connection for motor 2
37	M2-	POWER	Negative motor lead connection for motor 2
38	VMOT	POWER	Motor Voltage Input
39	VMOT	POWER	Motor Voltage Input
40	VMOT	POWER	Motor Voltage Input

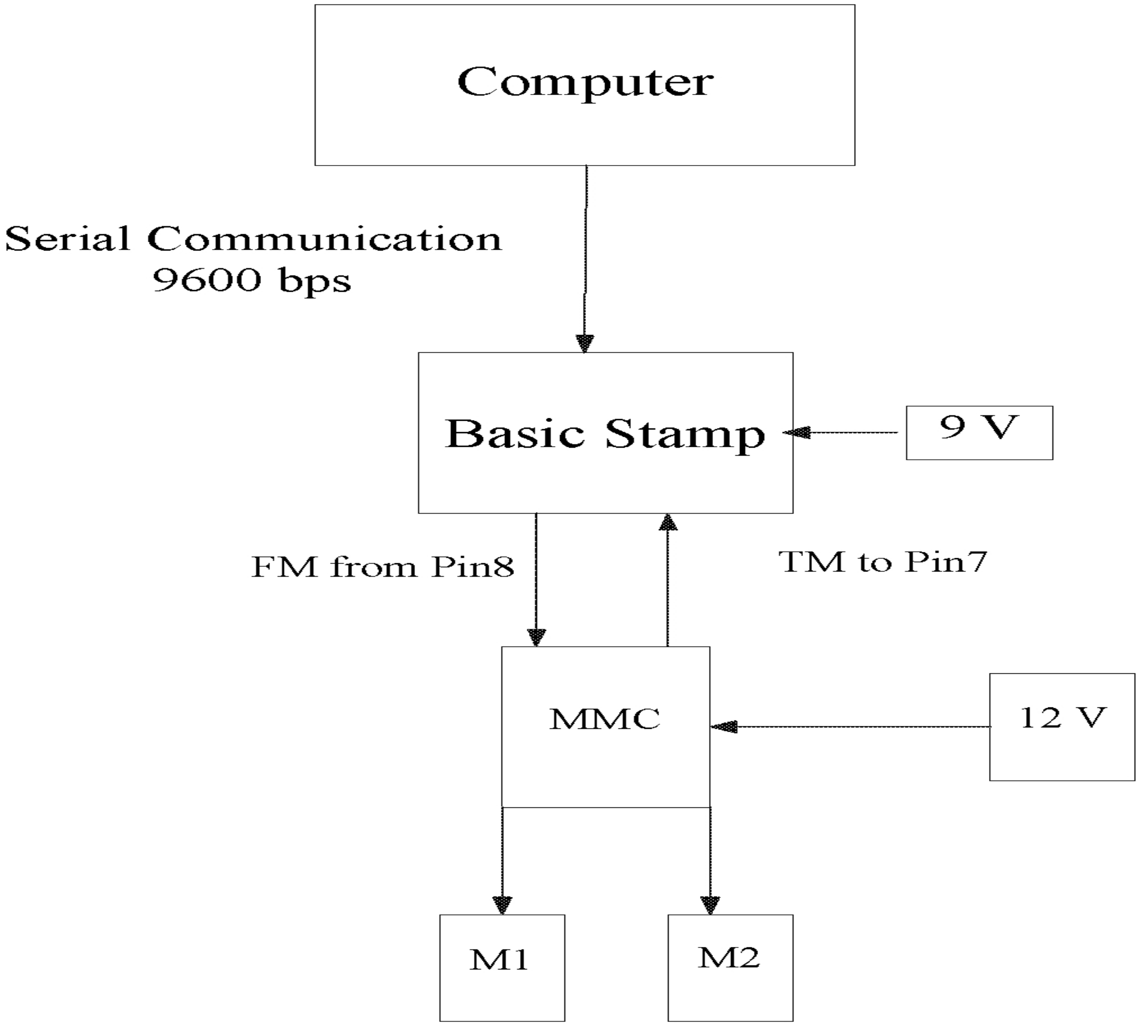


Figure 4.12 Motor Mind C connections to Basic Stamp

4.8.2 Operation

4.8.2.1 Mode selection

The selection of the operating mode is accomplished by setting the state of the MODE0 and MODE1 pins. These pins are either grounded or left floating. We have made use of the serial 38.4 kbps mode since the MMC is driven by the BS2sx.

Table 4.4 MODE Pin Settings

Control Mode	State of MODE0	State of MODE1	Description
Analog	Grounded	Grounded	Voltage controlled
R/C	Floating – no connection	Grounded	Pulse controlled
Serial 9.6KBPS	Grounded	Floating – no connection	Controlled by serial interface
Serial 38.4KBPS	Floating – no connection	Floating – no connection	Controlled by serial interface

4.8.2.2 Dual or single motor operation

The Motor Mind C may be configured to run two motors independently with each motor rated to one-half the current rating of the device. Since our objective is to drive the two base motors, we have left the NUM_MOT pin disconnected.

Table 4.5 NUM_MOT pin settings

Number of Motors	State of NUM_MOT
1	Grounded
2	Floating – no connection

Table 4.6 Single vs. Dual motor configuration connections

Pins	Single Motor Operation	Dual Motor Operation
NUM MOT	Grounded	Floating – no connection
M1+, M2+	Tied together and to positive motor lead	Tied to respective positive motor leads(M1+ to motor1, M2+ to motor2)

Table 4.6 Single vs. Dual motor configuration connections (contd.)

M1-, M2-	Tied together and to negative motor lead	Tied to respective negative motor leads(M1- to motor1, M2- to motor2)
PWM1, PWM2	Tied together	Floating – no connection
S11, S21	Tied together	Floating – no connection
S10, S20	Tied together	Floating – no connection

4.8.2.3 Serial control mode

During motor control using serial interface, the data format is TTL level "true" data (0V signal is a logic 0, and a 5V signal is read as a logic 1) and allows PWM control to 10-bits (1024 steps) in each direction (2047 steps in all).

4.9 Motor Mind C carrier board [62]

The MMC carrier board was used to accommodate another MMC to drive the arm motor at the shoulder joint. Pins 7 and 8 on the board are internally connected to TM and FM of the MMC holder. Therefore, Pins 14 and 15 from the Basic Stamp are connected to them to provide communication between the master and slave thereby enabling motor control. MMC Rev.4 has been used on an MMC board Rev.3 in single motor configuration. PWM_REG4 was used as a dummy variable to go along with PWM_REG3, the variable controlling the motor, in the program.

4.9.1 Features

- Screw terminal for motor connections

- BASIC Stamp 2, 2SX, 2P24, 2E socket and programming port
- MMC_12VAC fan kit mounting holes
- TM, FM indicator and Power LEDs
- Analog and R/C inputs compatible with R/C receivers
- Motor Mind C mode select DIP switch
- 5V 100mA regulator

4.9.2 Absolute maximum ratings

- Storage Temperature -55°C to +150°C
- Operating Temperature -20°C to +85°C
- Motor Voltage (VMOT) -0.3V to 30.0V
- Voltage on control pins -0.3V to +5.5V
- Voltage on VMOT, Mx+, Mx- 30V
- Motor Current Load 5A peak / 4.0A continuous

Table 4.7 DC Electrical Characteristics of MMC carrier board

At TA = 25°C, VMOTOR = 12V, ILOAD = 0.5A V5VDC = 5V

Characteristic	Symbol	Min	Typ	Max	Unit	Notes
Motor Supply Voltage	VMOT	10		24	V	
ANx/RCx input Voltage range	VAN	0		5	V	5V is the full-scale input for the 8-bit ADC
Peak load current	IPK			5	A	Transient <500ns
Max continuous current	ICONT			4.0	A	

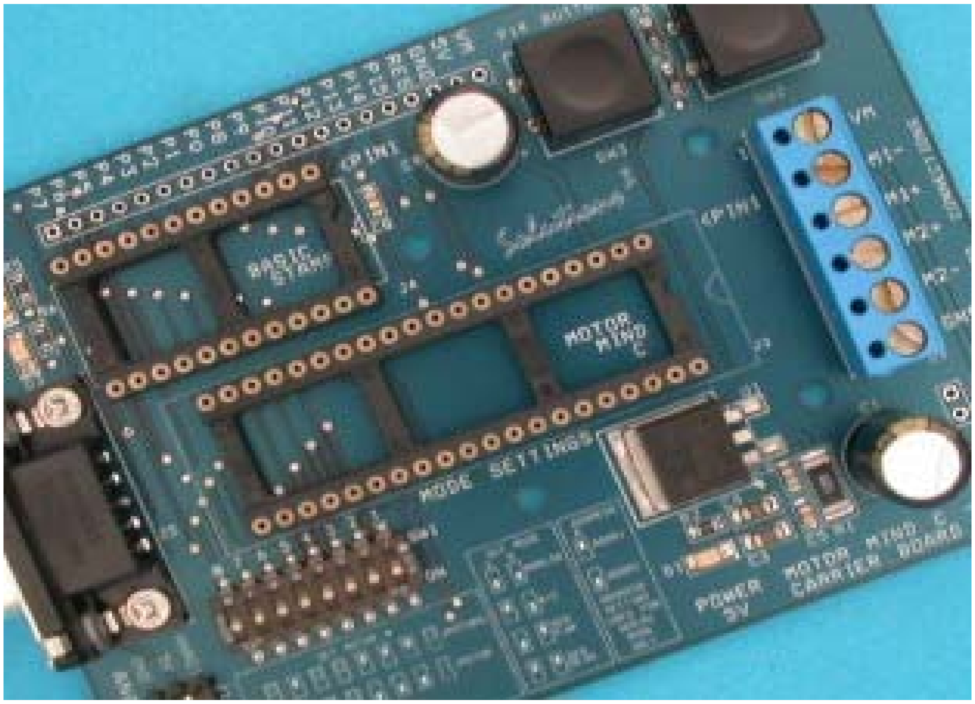


Figure 4.13 Motor Mind C carrier board

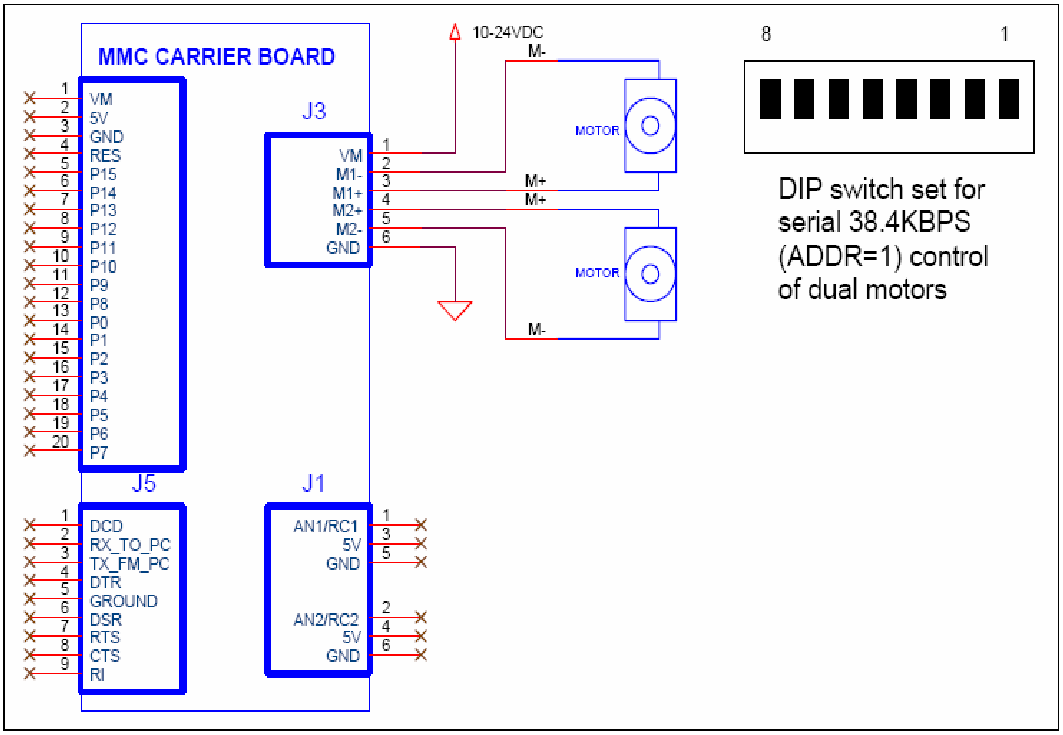


Figure 4.14 MMC carrier board connections

4.10 **Serial Servo Controller** [61]

The mini SSC is an electronic interface that allows a computer to control eight servos. We have used the Basic Stamp to send simple commands to the mini SSC at 2400 baud upon which channels of precise, stable servo-control pulses are generated. Instructions have a simple format consisting of a sync byte (always ASCII 255), the servo number (0-254), and relative position (0-254, where 127 is centered). Sending the appropriate three bytes (*unsigned chars* in C parlance) will result in the mini SSC sending the specified servo control pulses that will make it move to the commanded position. Servos are held in the last commanded position until instructed otherwise [73].

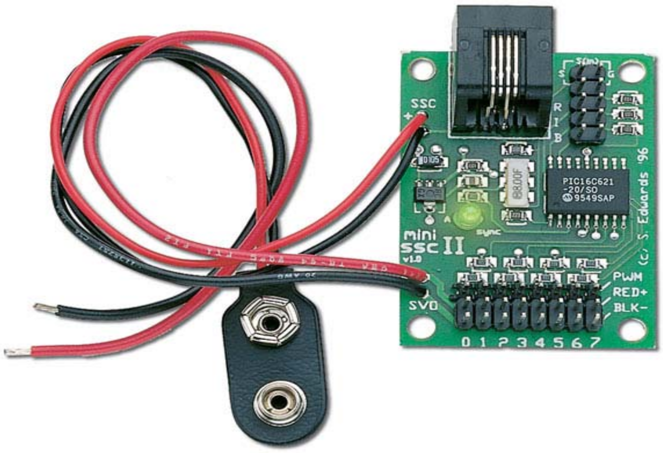


Figure 4.15 Serial Servo Controller

4.10.1 Basic specifications

Power requirements (Mini SSC) ....7 to 15 Vdc @ 10mA

Power requirements (servo) ....4.8 to 6.0 Vdc (current varies)

Serial input...............RS-232, or inverted TTL/CMOS, 9600 or 2400, N81

Servo output connector ......3-pin header, 0.1"spacing: (PWM)(+V)(GND)

Pulse frequency... 60 Hz

Pulse width range (normal) ....1.0 to 2.0 ms

Pulse width range (Mini SSC II, “R” jumper on) ....0.5 to 2.5 ms

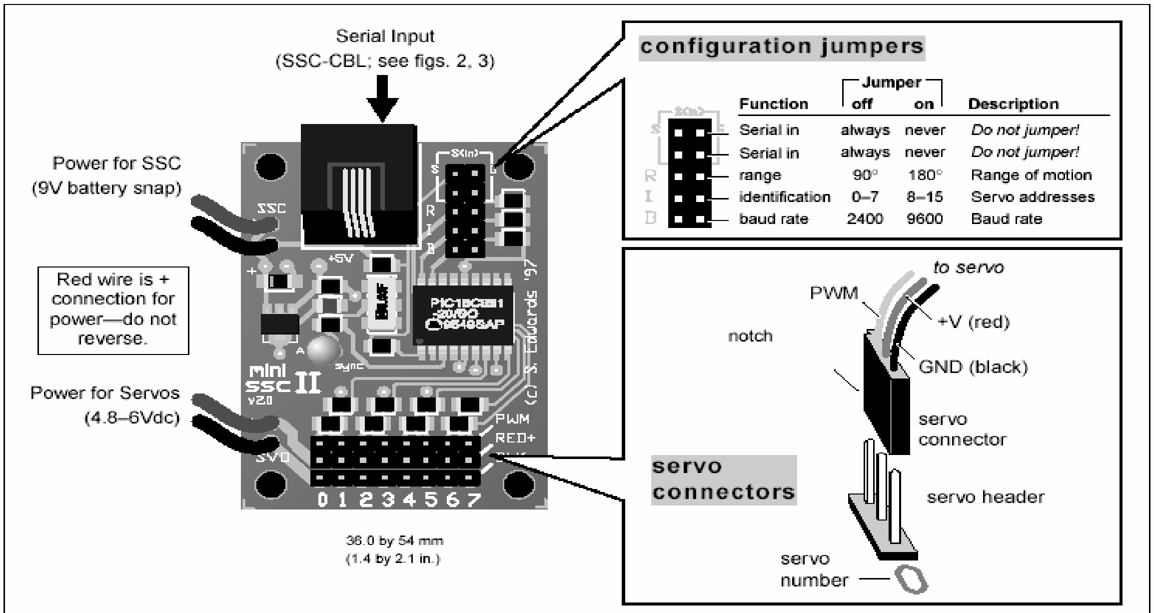
Pulse width at startup (centered) ....1.5 ms

Pulse width resolution (normal)...4 µs

Pulse width resolution (Mini SSC II, “R” jumper on).............................8 µs

Servo numbers (“I” jumper off) ....0—7

4.10.2 Connections and configuration jumpers



configuration jumpers

Function	Jumper off	Jumper on	Description
Serial in	always	never	*Do not jumper!*
Serial in	always	never	*Do not jumper!*
range	90°	180°	Range of motion
identification	0–7	8–15	Servo addresses
baud rate	2400	9600	Baud rate

Do not reverse power polarity, even momentarily. Reversed power will destroy the electronics.
Do not exceed 10V into SSC 9V input. Overvoltage may damage the unit or shorten its life.
The “phone” jack is for serial input only. Connecting it to the telephone system will damage the unit.

Figure 4.16 Layout of the mini SSC II circuit board with connectors and configuration jumpers’ locations

4.10.3 Configuring the mini SSC II

The mini SSC II's default configuration (all jumpers removed) is:

2400 baud • servos 0 through 7 • range of motion = 90°

4.10.3.1 (R)ange

With no jumper at R, the mini SSC II controls servos over a 90° range of motion. Servos' positions are expressed in units from 0 to 254, so each unit corresponds to a 0.36° change in the servo's position. With a jumper at R, it controls servos over as much as 180°, with each unit corresponding to a 0.72° change in position. Servos are designed for 90° motion and the 180° mode exploits additional range that is meant as allowance for mechanical and electrical tolerances. We have made use of this tolerance to provide a greater degree of freedom of operation of the arm by using a jumper on R.

4.10.3.2 (I)dentification

With no jumper at I, servo addresses match the numbers printed next to the servo headers—0 through 7, which is what we have used in our set-up.

4.10.3.3 (B)aud

With no jumper at B, the mini SSC II receives serial data at 2400 baud; with B jumpered the baud rate is 9600. In either case, the data is to be sent as 8 data bits, no parity, 1 (or more) stop bit(s); abbreviated N81 and it has to be inverted. In the present case, we have jumpered B to control the SSC at 2400 baud.

4.10.4 Serial input

The mini SSC II requires only two connections to a computer—serial data and signal ground. There are two places to make these connections; a modular ‘phone’ jack and two pairs of pins marked S(in) on the configuration header.

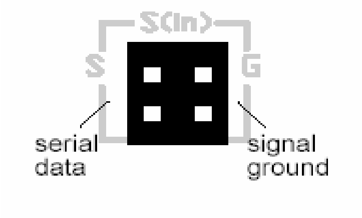


Figure 4.17 Mini SSC II circuit

With BASIC Stamp, the header pins are used. The Stamp I/O pin that the program is using for serial output is connected to S on the mini SSC II. This will be one of pins 0—7 on the Stamp I, or pins P0—P7 on the BS2 and Stamp Ground (Vss) is connected to G on the mini SSC.

4.10.5 Programming for the mini SSC II

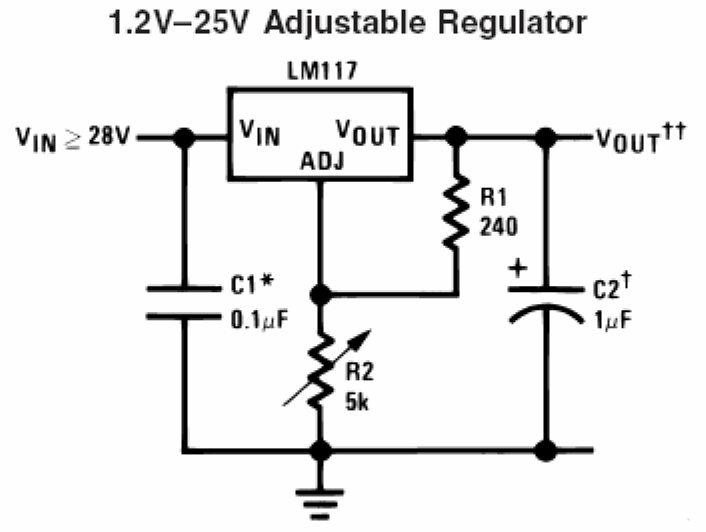
To command a servo to a new position requires sending three bytes at the appropriate serial rate (2400 or 9600 baud, depending on the setting of the B jumper.

Byte 1 Byte 2 Byte 3

[sync marker (255)] [servo # (0-254) [position (0-254)]

4.11 Voltage regulator [54]

LM 317 T has been used as a voltage regulator to supply the SSC with the desired 9V. 12 V is supplied at the VIN pin and using R1 = 240 Ω and R2 = 1.8 k Ω resistor combination, and a net output of 9.3 V is obtained at the VOUT pin.



$$\dagger\dagger V_{OUT} = 1.25V\left(1+\frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

Full output current not available at high input-output voltages

*Needed if device is more than 6 inches from filter capacitors.

†Optional—improves transient response. Output capacitors in the range of 1μF to 1000μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

Figure 4.18 Voltage regulator connections

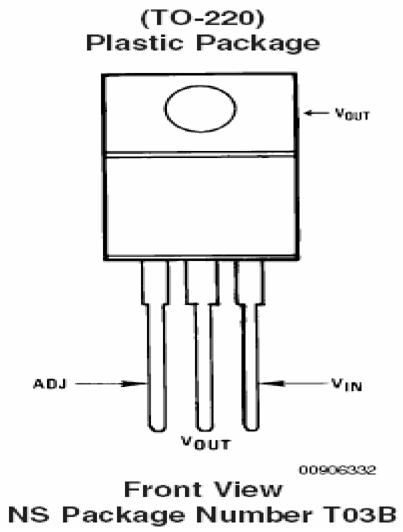


Figure 4.19 LM 317 T schematic

4.11.1 Features

- Internal current-limiting protection
- VOUT adjustable +1.2 to 37V
- COUT limited to 1.5A

4.11.2 **Absolute maximum ratings** (All ratings assume proper heat sinking)

Power dissipation	15W
Input-Output voltage differential	40V
Load regulation (typ.)	0.1%/V
Fine regulation (typ.)	0.01%/V
Ripple rejection (typ.)	80 dB

Chapter 5

Experiments and Results

Voltage outputs from the joystick were measured physically using a multimeter and compared with the output from the ADC, which is collected using the Hyper-terminal through Pin 11 of the Basic Stamp and then stored in text files. Channels 0 and 1 of the ADC correspond to the left/right and forward/backward motions of the base respectively. When switch 1 is turned on, Channel 1 would be the variable controlling the link 1 of the arm and Channel 0 drives link 2 through the Serial Servo Controller. Similarly, Channel 1 would manipulate the wrist and Channel 0 would open and close the gripper when both the switches are on.

5.1 Need for a divider network

In our efforts to simplify the concept and in order to minimize the number of inputs to the controller, an analog joystick was used in conjunction with two toggle switches to control the device. In the process, the output from the ADC is taken as a reference since it is the position and orientation of the joystick that determines the output voltage which in turn ascertains motion in the desired direction. The two toggle switches regulate motion of the base or the arm or the gripper depending on which one is activated. Table 5.1 gives the voltage ranges that were measured and fixed for each direction of the joystick and these in turn were used to send corresponding PWM values to the motors and servo positions.

Table 5.1 Joystick outputs

Joystick orientation	Channel 0 (V)	Channel 1 (V)
Center	1.959 – 2.091	1.963 – 2.89
Forward	2.042 – 2.091	1.625 – 1.947
Reverse	2.035 – 2.051	2.108 – 2.394
Left	2.123 – 2.433	2.027 – 2.096
Right	1.647 – 1.938	1.969 – 2.058

It was noticed that identical voltage values are issued by the joystick both for speed and direction as seen from table 5.1. The voltages at Channel 0 for forward position and Channel 1 for right orientation of the joystick were in the same range. Likewise, voltages at Channel 0 for reverse position and Channel 1 for left orientation of the joystick were in a similar range. This again resulted in identical PWM values being sent to the motors due to which we either had the same motion for two positions or we had no movement at all for the motors and servos on the base as well as the arm. Hence, it was felt that voltages one of the channels had to be brought down and a voltage divider was deemed necessary for proper working of the system upon issuing commands from the joystick.

After the voltage divider network was added, voltage ranges were again determined for the ADC output so that each orientation of the joystick would correspond to a certain range in our program as depicted in table 5.2, which would in turn provide motion in the required direction. Tests were repeated to ensure that any erratic or random movements from the user would not result in abrupt motions of the system and cause harm to the user or surroundings or damage the system itself. After recurrent tests, it was decided that the program should be coded such that the overlap in the values should not produce erroneous results and confuse the user. At the same time, slight deviations from the center position should also not give out unexpected movements of both the arm and base.

Table 5.2 Values used in the program and resulting movements

Joystick orientation	Channel 0 (V)	Channel 1 (V)	Result
Center		1.95 – 2.10	Stop base and arm motors Stop arm, wrist and gripper servos
Forward		1.625 – 1.95	Move base forward Rotate link 1 counterclockwise Rotate wrist counterclockwise
Reverse		2.10 – 2.40	Move base backward Rotate link 1 clockwise Rotate wrist clockwise
Left	0.975 – 1.125		Base takes left turn Rotate link 2 counterclockwise Close gripper
Right	0.725 – 0.90		Base takes right turn Rotate link 2 clockwise Open gripper

5.2 Data from Motor Mind C for base motors

PWM registers' values are responsible for driving the base motors. Plots corresponding to movements in individual directions were obtained while the user was manipulating the device to come out of the wheelchair and move forward to push open a door or move an obstacle away from the user's path.

Note: PWM Values for figures 5.1 – 5.4 are in generic units.

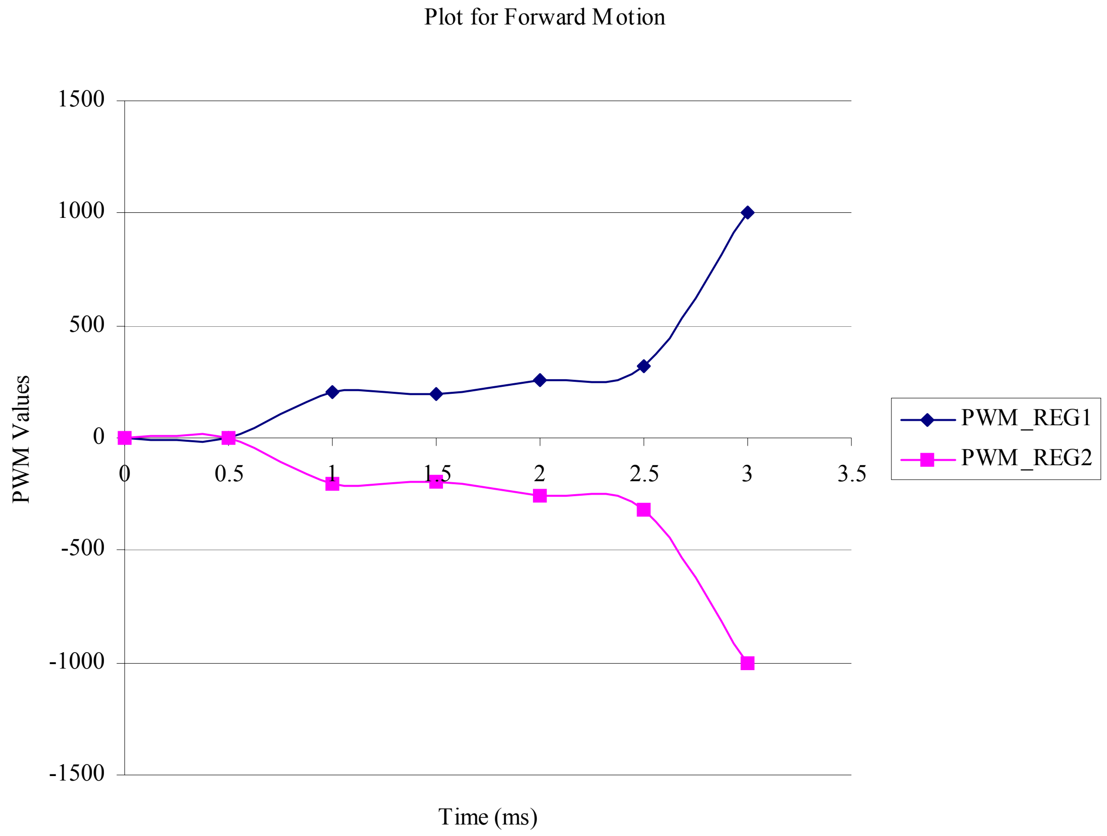


Figure 5.1 PWM registers plots for motion in forward direction

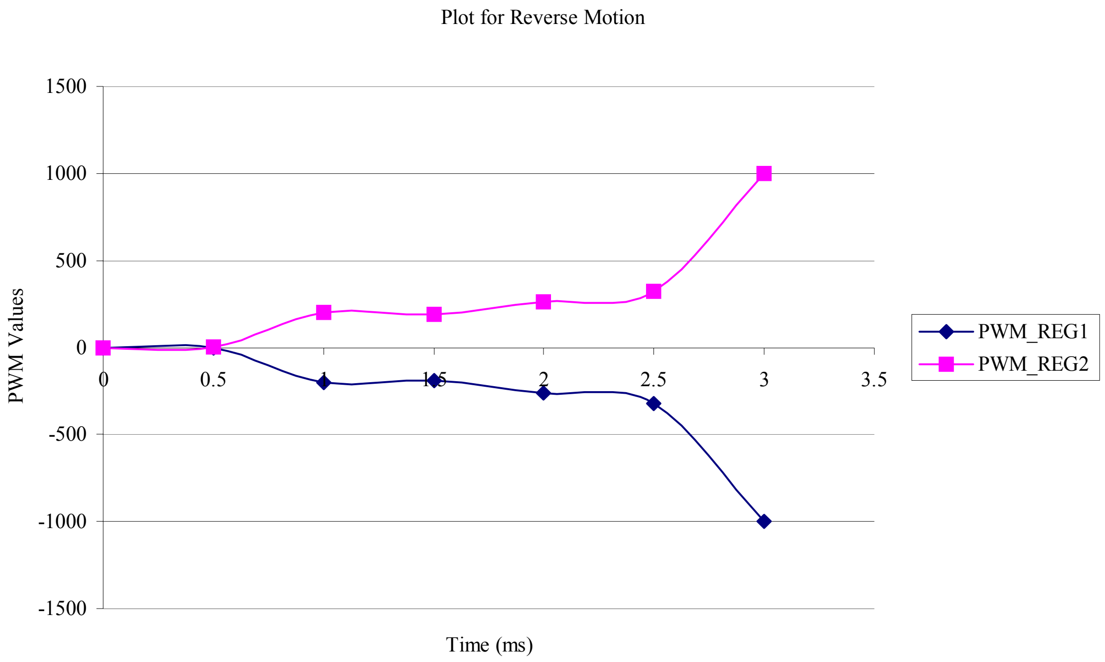


Figure 5.2 PWM registers plots for motion in reverse direction

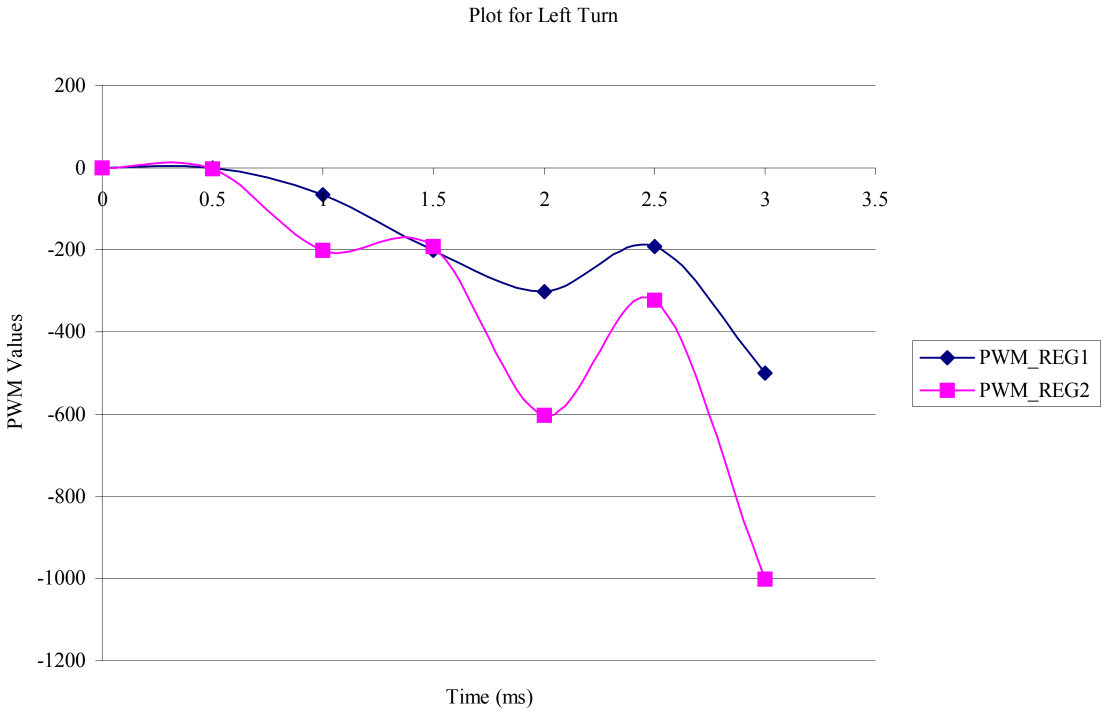


Figure 5.3 PWM registers plots for motion in left direction

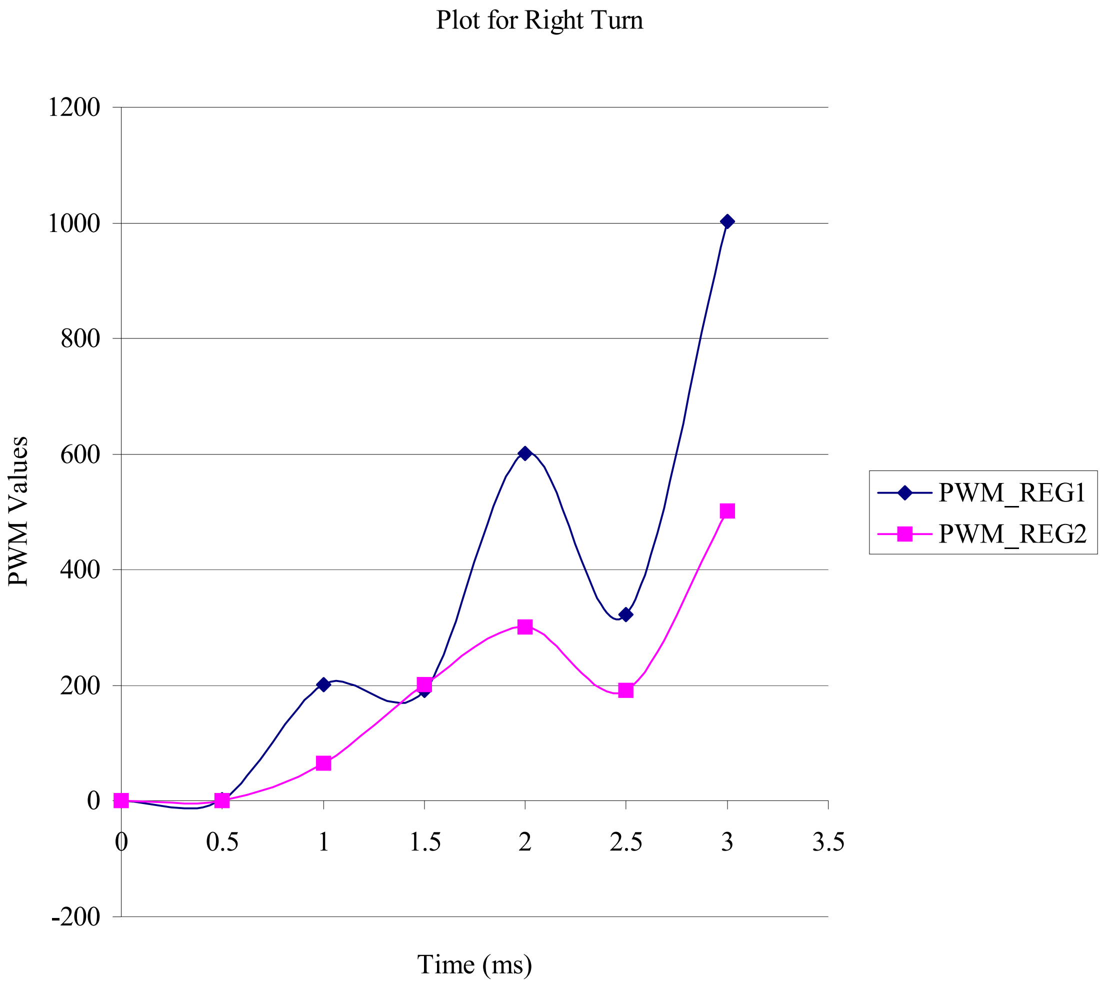


Figure 5.4 PWM registers plots for motion in right direction

5.3 Data from Motor Mind C for arm motor

PWM register values for the arm motor were also plotted when the arm was being used to pick an object from the floor and plots corresponding to upward and downward motion of link 1 were obtained.

Note: PWM_REG3 values for figures 5.5 – 5.6 are in generic units.

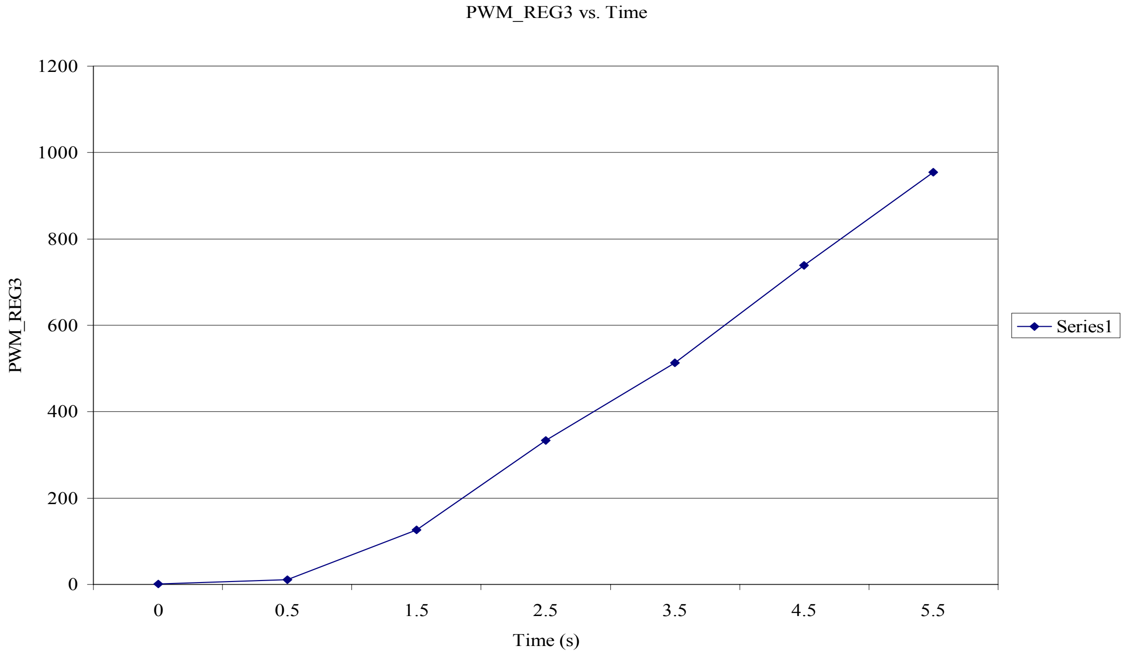


Figure 5.5 PWM registers plots for upward motion of link 1

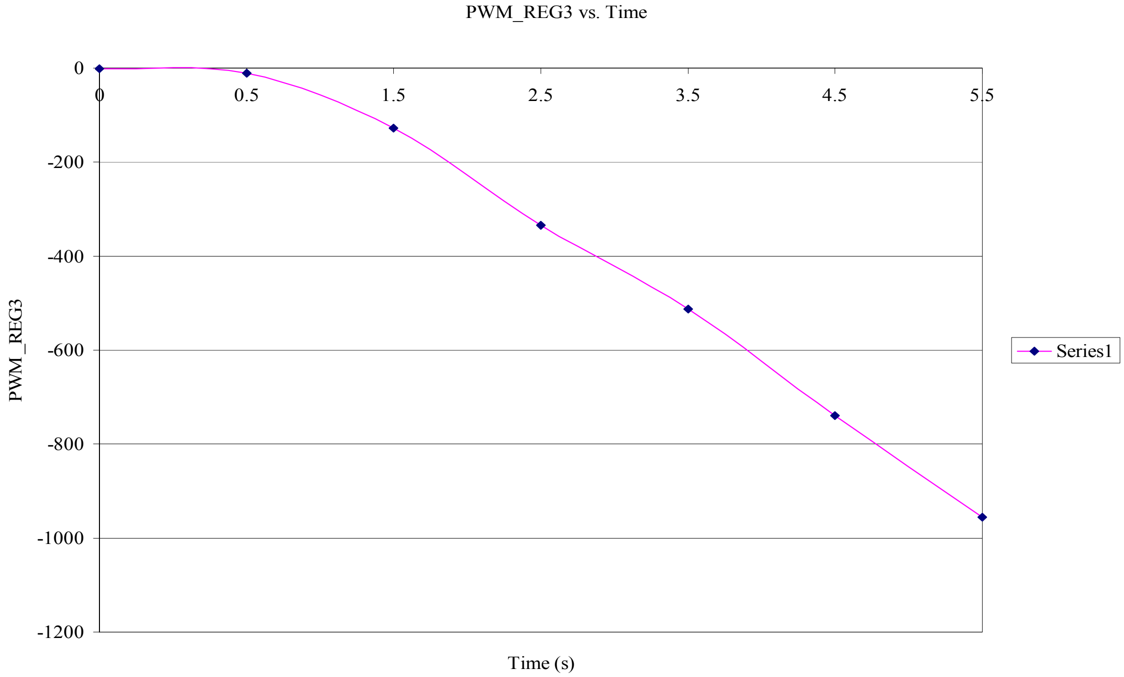


Figure 5.6 PWM registers plots for downward motion of link 1

5.4 Tasks performed

5.4.1 Open a door/push an obstacle

Figure 5.7 shows the robot holding open a door in the laboratory while the user on the wheelchair passed through and figure 5.8 shows the device climbing back onto the wheelchair.

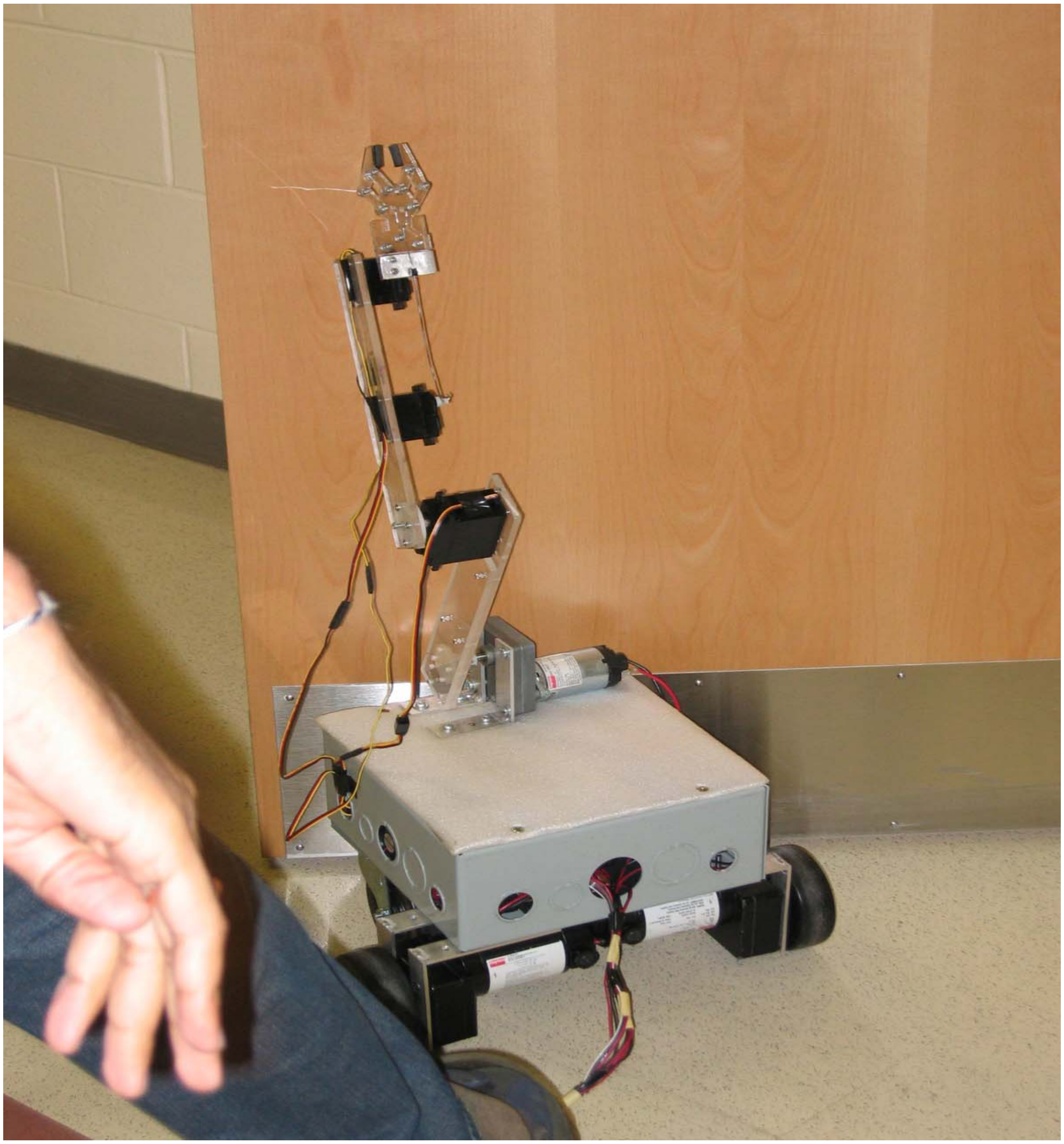


Figure 5.7 Robot holding a door open

Figure 5.8 Robot climbing back after user has passed through

It was also used in a scenario wherein the user had to use a narrow pathway just enough for the wheelchair to pass through with boxes lying around. The robot had to push them away from the path making way for the user to move.

5.4.2 Pick an object from the floor

Figure 5.9 – 5.12 shows the companion robot in action picking objects from the floor either to fetch them to the user or to put them away in a bin.

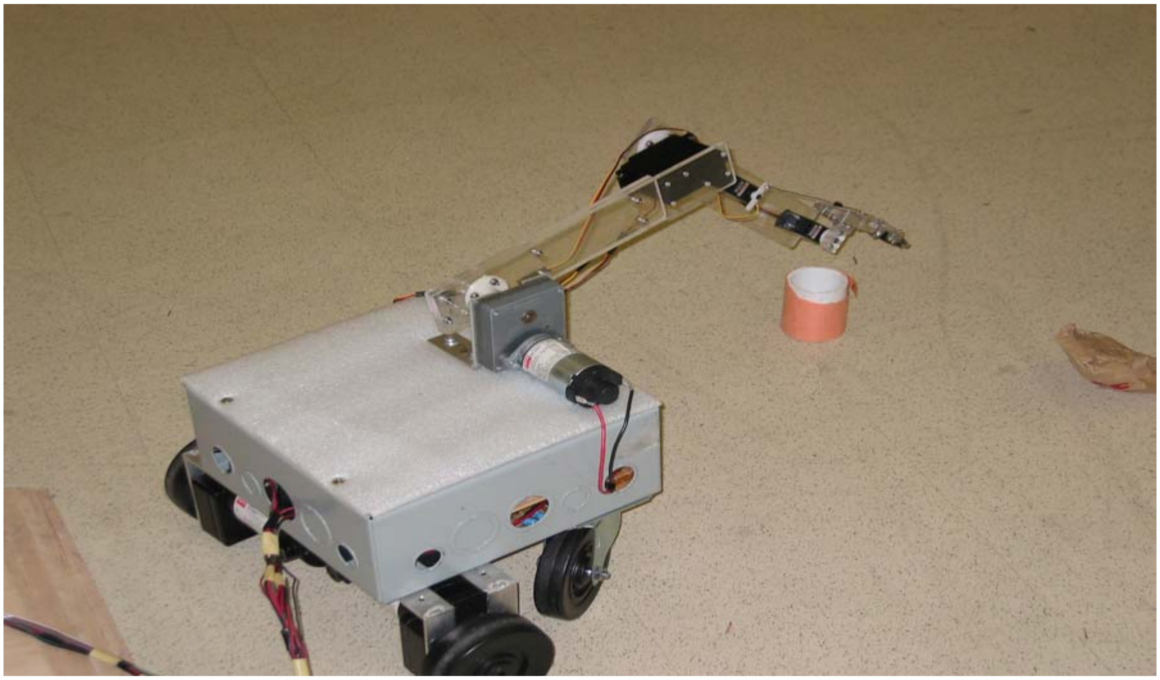


Figure 5.9 Arm bending down to reach for objects on the floor

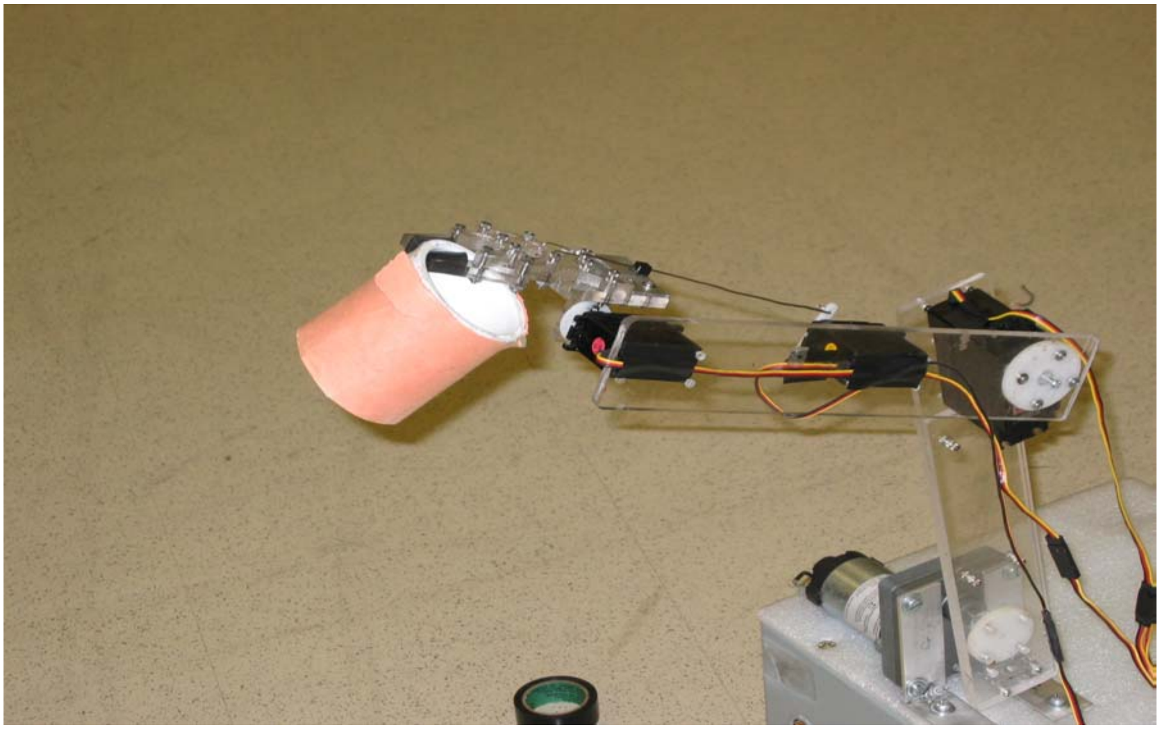


Figure 5.10 Arm holding a cylindrical object

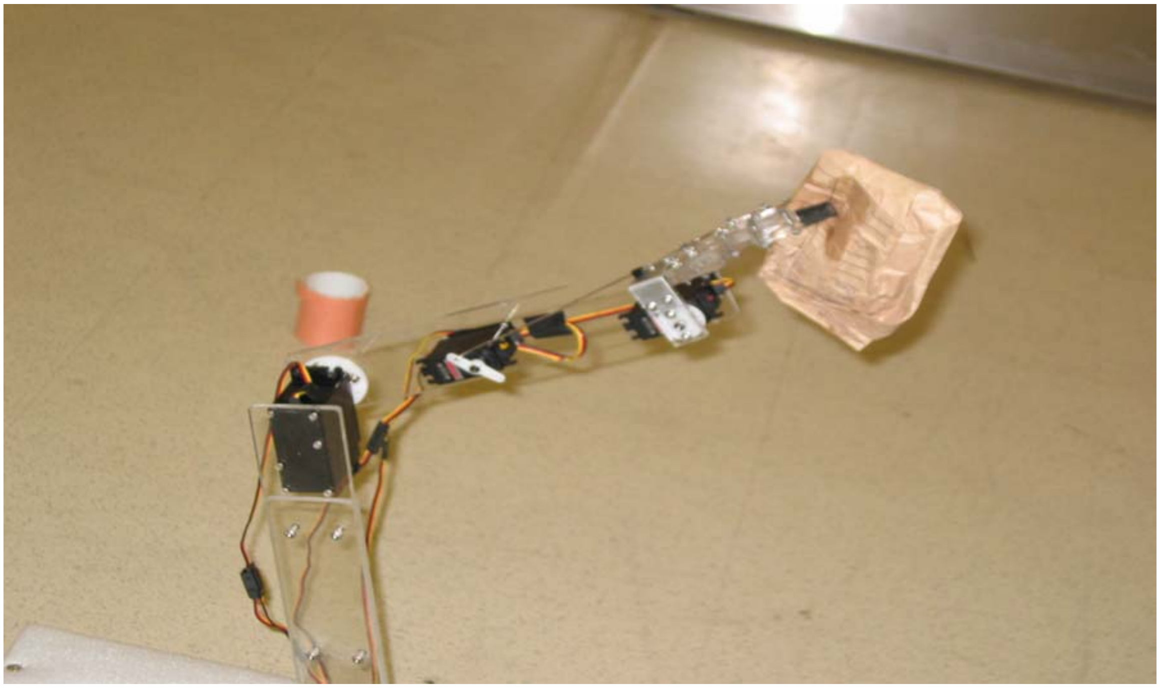


Figure 5.11 Arm in the process of dropping a packet in the bin

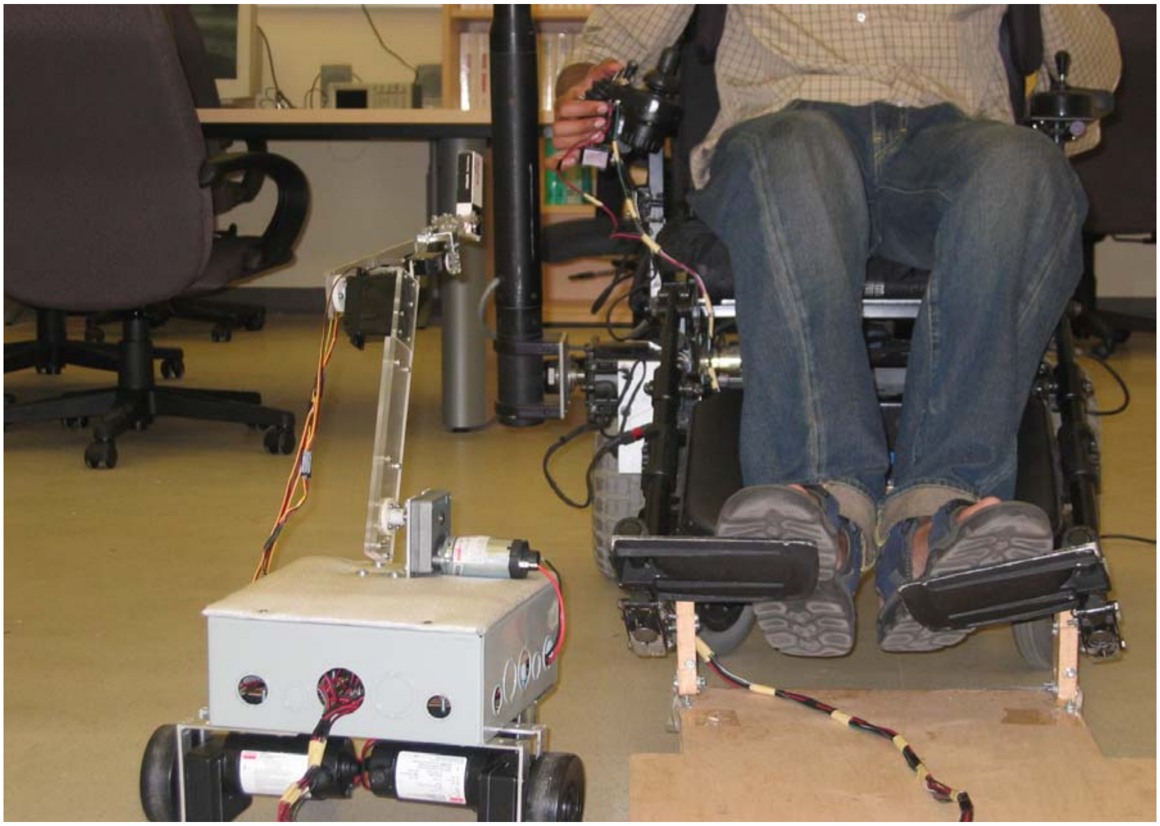


Figure 5.12 Robot fetching a box to the user

The above tasks were performed repeatedly and it was noticed that the system would produce the desired effect irrespective of whether the user goes all the way to the extremes or whether he/she applies enough force just to move the joystick from the center position. Jerky movements are also avoided by providing a constant ramp-up which is allowed only if the user is able to apply a sustained force on the joystick. This can be thought of as a safety feature making the device reliable enough to be operated by people with disabilities without any cause for concern.

5.5 User trials and response

The two major tasks of pushing open a door and picking up an object to fetch it to the user were conducted 15 times recurrently by four different subjects and the average time taken for each of them for each of the tasks was measured as shown in table 5.3. Later, the performance of the robot was evaluated from the response to a questionnaire given to the subjects which is given in table 5.4.

Table 5.3 User trials for two tasks

Subject	Task	Average time taken (s)
1	1	75
	2	125
2	1	72
	2	130
3	1	69
	2	126

Table 5.3 User trials for two tasks (contd.)

4	1	80
	2	135

Task 1: Push open a door

Task 2: Pick up an object lying on the floor and fetch it to the user

Table 5.4 Questionnaire and user response

S. No.	Question	Response	Reason
1	How difficult was task 1 using wheelchair-mounted arm?	Very difficult	Passing through a doorway with folded arm mounted on the side was as such difficult. To accomplish the same with arm stretched out does not make things any easier.
2	How difficult was task 1 with the marsupial robot?	Quite easy	Overall dimensions of the wheelchair are reduced, arm being out of picture. It is easy to maneuver the wheelchair while the door is being held open.
3	How difficult was task 2 with the robotic arm?	Easy	User could approach the vicinity of the object and manipulate the arm to pick the object.
4	How difficult was task 2 with the companion robot?	Fairly tough	Though the user did not have to go to the object, which is not always possible, it was not easy to observe the action of each joint from a distance and grasp an object
5	Is it easy to operate the wheelchair-mounted arm to carry out a given task?	Difficult	The user had to remember all the orientations of the joystick for obtaining movement of every link.

Table 5.4 Questionnaire and user response (contd.)

6	Does the user-interface make it easy for the user to perform a given task?	Very easy	With the provision of two toggle switches and using the four directions of the joystick, it was quite simple to manipulate the robot and also each joint of the arm and the gripper

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The aim of this thesis was to introduce the use of a robotic device to help people with disabilities, the main advantage being a low-cost solution to a few important everyday activities. This is the first time that the concept of a marsupial robot was experimented with for rehabilitation purposes. A prototype was fabricated from commercially available components and integrated with a powered wheelchair. The device is controlled with an analog joystick similar to one on an electric wheelchair. Experiments were conducted to perform the pre-determined tasks and results revealed that the device can provide assistance to people with disabilities.

A simple micro-controller having a provision of EEPROM and serial interface was selected and compatible peripherals were used. A voltage divider network and a voltage regulator circuit were used to provide the required power to various components at the specified ratings. The system is re-programmable, thereby allowing the functionality to be extended depending on the user needs and requirements.

A relatively basic control configuration has been developed to start with, and more complex and faster ones are expected to evolve soon. Our present project was a therapeutic tool intended to provide people with disabilities a means to carry out their activities to avoid the need of a human caretaker. The prototype for the actual system is ready; a mobile base was designed and a two degree-of-freedom manipulator was mounted on it. A servo-driven wrist provides a small amount of pitch and a two-fingered end effector powered by another servo accomplishes the gripping action. A provision has been made on a powered wheelchair for the robot to climb into when not in use.

Our system was able to exert enough force to push open doors and hold them while the user seated on the wheelchair passed through. We were also able to achieve picking of small objects and fetching them to the user. The arm could reach and hand objects to a maximum height of 28”. Tasks involving moving obstacles from the user’s path and disposing objects as per the user’s needs were executed. After performing the designated task, the user was able to guide the robot back onto the wheelchair.

This combination of a wheelchair-mounted mobile robot and the wheelchair itself can provide the desired level of indoor independence with respect to manipulation and transportation. The design was based on the analysis of the user’s needs from relevant literature covering usability, acceptability, efficiency and cost-criteria. This degree of flexibility will have significant implications to the general public and for the care of people with disabilities and elderly with special needs. The time taken to perform the designated tasks was within the satisfaction requirements of the users. The questionnaire supplied to the users and their feedback summarizes their opinions about the prototype.

6.2 Future recommendations

The primary shortcoming in the prototype that has been identified during the user-trials was the limitation on the speed which becomes a source of annoyance to the user. A PID controller with appropriate intermediate units and greater flexibility over current ratings would provide a faster and efficient control of the robot.

A remote joystick can be used to control the robot to avoid the entangling of wires and also extend the range of motion. The joystick to control the wheelchair could also be made to accommodate the mobile robot. Voltage divider and current regulator networks can be set-up to draw required amounts of power from the wheelchair battery to avoid the use of an additional power source.

A rugged wrist and an end-effector with three fingers could be designed to enhance the performance of the arm and pressure transducers can be incorporated to prevent manipulated objects from either being damaged or dropped and also to carry out more intricate tasks. Haptic interface may be incorporated to allow the user to feel the forces and assist functions can be developed to ease burden on the user.

A 3-way switch with center position denoting wheelchair motion, one extreme indicating pure robot motion and the other position for simultaneous wheelchair and robot movement can result in better result in terms of reduction in task time, etc. A ramp, operated by a 3-way toggle switch, would carry the robot and slide in to give unhampered access to the user and the carer. The system, especially the manipulator, could be made more rugged to be able to pull doors open too, making use of a better wrist and end effector.

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Appendices

Appendix 1: Circuitry lay-out in the current set-up

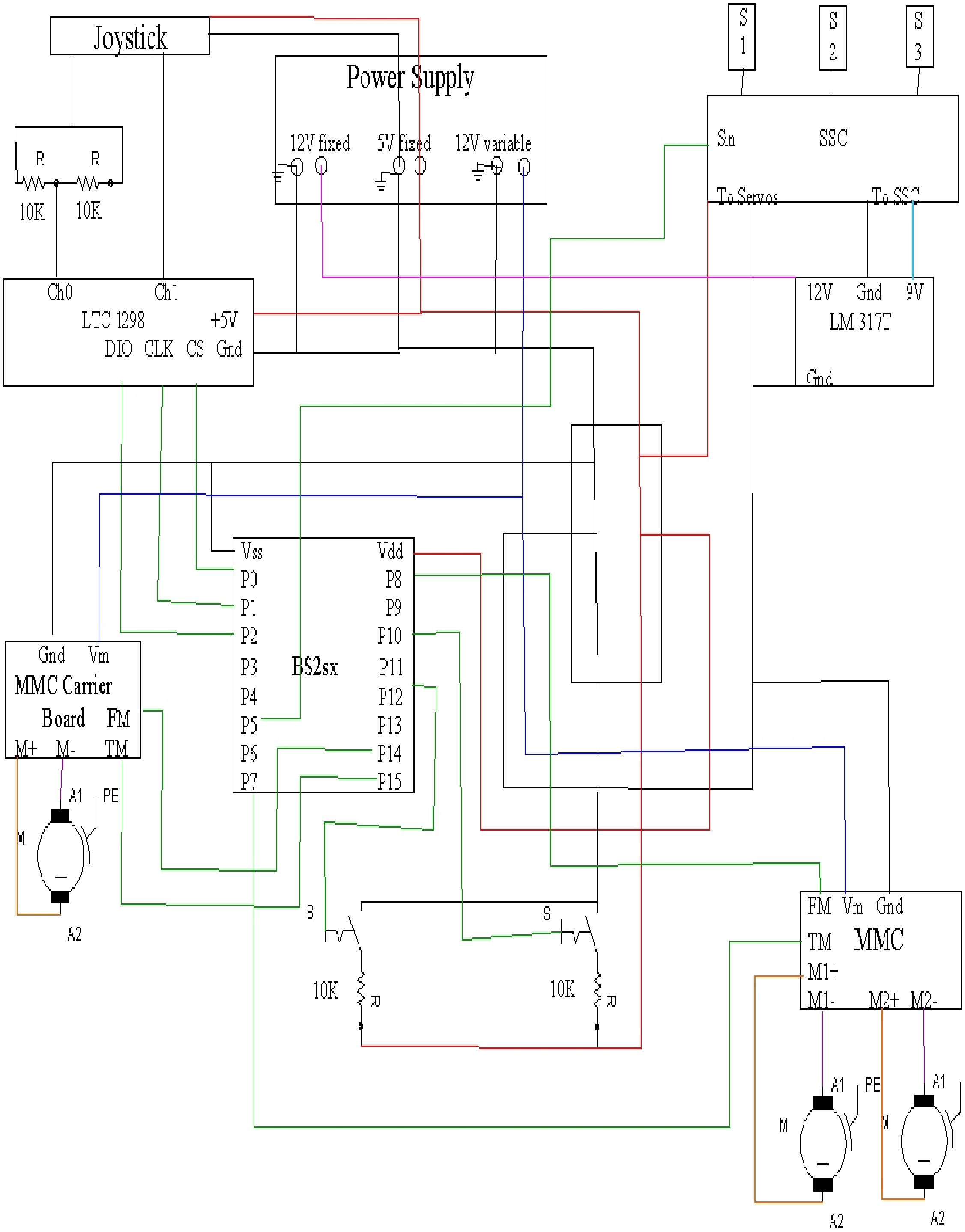

Figure A.1 Overall circuit diagram for the prototype