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MAP-GUIDED POWER-CHAIR AUTOMATION
AND
DRIVER ASSISTANCE

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ABSTRACT

Assistive wheelchair research has been very active in the last few years. Scientist are constantly looking for ways to improve wheelchairs for the physically handicap. There has been many successful research and test done for indoor autonomous wheelchairs but outdoors has yet to be explored.

This research on outdoor autonomous wheelchair will focus on using existing work done by previous researchers along with incorporating a global positioning system (GPS), light detection and range (LIDAR), optical encoders, and a caster system. The main goal is to help the severely disabled with their freedom of mobility while keeping them safe.

First, an algorithm for the caster system had to be established for position and odometry of the wheelchair. Position and odometry are crucial in this process because it tells the computers where the chair is located and proceed to its destination from there.

Second, using the algorithm from the first step, a successful simulation had to be completed using MATLAB. The simulation will show a ‘trial’ run of the wheelchair in motion before the actual chair is brought outside.

Finally, troubleshoot all hardware and software to assure no ‘bugs’. Implement all hardware onto chair for test runs.

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Chapter 1

Introduction

This thesis will focus on implementing indoor autonomous wheelchair technology along with a global positioning system (GPS), light detection and range (LIDAR), optical encoders, and a caster system for outdoor use. The main goal is to help the severely disabled with their freedom of mobility while keeping them safe.

1.1: Literature Review

Assistive wheelchairs for the handicapped have been an active area of research for the last few years. Recent advancements in artificial intelligence and robotics technology have drawn more attention towards this area. The common goal in this field has been to develop a Smart Wheelchair Component System (SWCS) that can be added to a variety of commercial power wheelchairs with minimal modifications. Many prototypes have been developed over the years that try to accomplish certain criteria in everyday life of the severe handicap. Studies have shown that both children and adults benefit substantially from access to means of independent mobility [5],[6]. Independent mobility not only increases vocational and educational opportunities, but also it reduces dependence on caregivers and family members, and promotes feelings of self-reliance [5],[6]. Smart Wheelchairs are not on the commercial market yet because engineers are still in the process of trying to understand the needs of the severely handicapped and to make it safe for everyday use. These mobility devices are often referred to as “Smart Wheelchairs” or “Intelligent Wheelchairs”, in literature.

A “Smart Wheelchair” typically consists of a standard powered wheelchair which has been augmented by a computer and various sensors. These chairs have been designed to provide navigation assistance to a user in a number of different ways, such as assuring collision-free travel, aiding the performance of a specific task, and autonomously transporting the user between locations [5],[3]. By adopting a behavior-based approach, it is possible to build wheelchairs which can not only operate daily in complex real-world environments but also deliver better performance, efficiency, safety, and flexibility.

Prior to the start of the project, a study has to be conducted to identify various requirements by potential users of the autonomous wheelchairs. Causes of the handicap that were presented included gradual mobility loss by aging, sudden loss of body control due to brain damage, and prolonged motion limitations due to strokes suffered at a young age [1]. Due to these causes of handicap, when patients were asked specifically about steering and maneuvering tasks, the percentage of patients reported to find these difficult or impossible jumped to 40% [7]. About 85% of responding clinicians reported coming across patients each year who are unableuse a powered wheelchair because they lack the requisite motor skills, strength, or visual perception [7]. Clinicians also indicated that about 9% to 10% of patients who receive power wheelchairs training find it extremely difficult or impossible to use the wheelchair for activities in their daily life.

Engineers and rehabilitation clinicians have often collaborated together to design prototypes of multifunctional intelligent wheelchair to assist those with mobility impairment in their daily lives. Their efforts reveal that many challenges arise including deciding the “best” physical design of wheelchairs, which assistive algorithms should be used to control the chair, etc. One of the first published automated wheelchair prototypes was developed by Simon Levine at the University of Michigan and Richard Simpson [1],[4]. The chair was named NavChair (Figure 1) and was designed to avoid obstacles, follow walls, and travel safely in cluttered environments. It is equipped with twelve ultrasonic sensors and an on-board computer. This chair uses a shared control system in which the user plans the route, assists in some navigation, and indicates desired direction and speed of travel. The system does automatic wall following and overrides unsafe maneuvers with autonomous obstacle avoidance [1].

Figure 1 - NavChair developed at University of Michigan [1]

An underlying assumption in developing an intelligent wheelchair is that it will have some degree of human control over it. Task sharing in such shared-control systems can be difficult, and can take several different forms. Shared control is often known as“task transformation” in the literature [4]; in this case, the machine makes the task easier by performing part of the task with the operator. Task “partitioning” refers to the situation in which the machine does part of the task and the operator does the remaining portion, and thus the machine/human interaction is one of separate and parallel tasks operating concurrently. When the machine takes total control, or does the whole task independently at various portions of the operation, it is known as task "allocation" [4], e.g. the operation of the chair is one of a series of hand-offs between the user and automation system, where the tasks being performed operate serially and usually fully in either completely human or completely automated fashion for one task. In task allocation, the system also has two modes of operation, the "teach" mode and the "run" mode. In the teach mode, the user selects the desired paths from a topological diagram of the robot's environment. Once these paths are trained or selected, the user selects a path in the run mode, wherein the system will follow the selected path based on the stored information obtained during the teach mode [1].

There are prototypes that are developed that can provide navigation assistance on a wheelchair using many different input methods (analog joystick and switch joystick), many different wheel configurations (front, mid, and rear-wheel drive), and many different sets of control electronics (MKIVA, Penny+Giles, Curtis) [6]. Extensive research is still ongoing to ensure the safety of the equipment when used in the real-world, with various combinations of physical systems. Figure 2 shows a typical modified chair in a lab testing environment with eight sensors and computers located in the rear of the chair. The sensors detect obstacles around the entire chair circumference to avoid collision when chair is doing autonomous tasks. One can observe that a significant amount of equipment is required for the chairs to carry out its objective and to simultaneously ensure that all risk factors are considered.

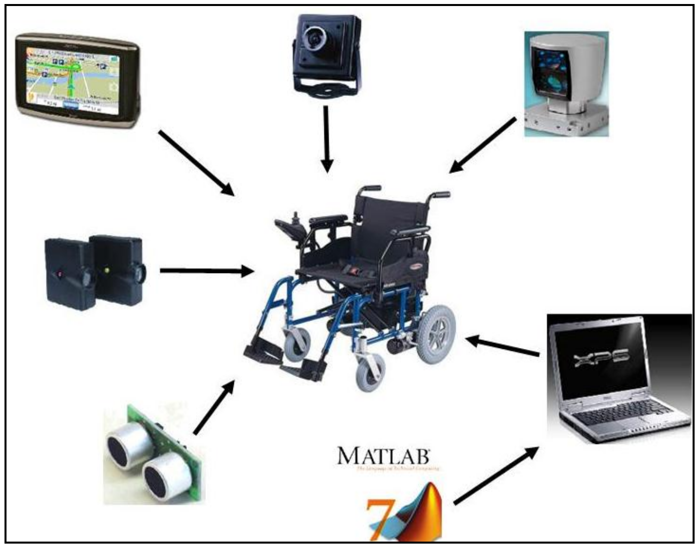

Figure 2 - Typical set-up of a modified chair used in labs

Smart chair component systems are generally placed into a power wheelchair's control system between the user's input device and the wheelchair's motor controller as shown in Figure 3. These specialized control modules and digital drive boxes are designated to accept signals from an input device such as the joystick, and present the user a choice of input, with the choice passed to the chair's proprietary control electronics for implementation. The component system, after reading the signal from the input device, then sends a revised signal to the wheelchair's motor controller. The motor controller then treats the revised signal as if it came directly from the input device. The revised joystick signal is identical to the original signal except that, if an obstacle is detected, the component system *alters* the joystick signal to avoid collision [5],[6]. The chair is equipped with a combination of sonar, infrared, and bump sensors because each sensor has different strengths and weaknesses. Figure 3.1 shows an example setup of the sensors. The front corner sensors (2 and 3), they were mounted so that their beams were perpendicular to each other. This was done because this results in better detection of obstacles by the infrared sensors (between 8cm and 50cm). If the IR beams were parallel with each other, they would not detect an obstacle between either beams until it was at its footrest.

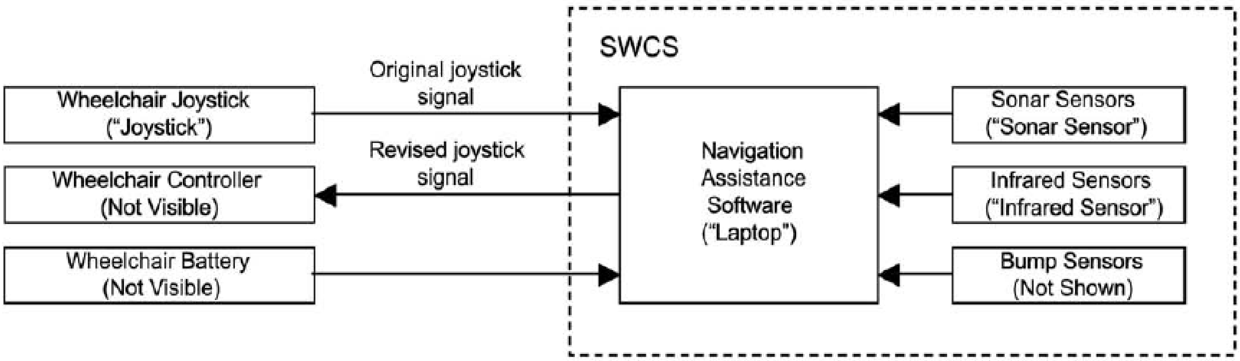

Figure 3 - Smart Wheelchair component system [6]

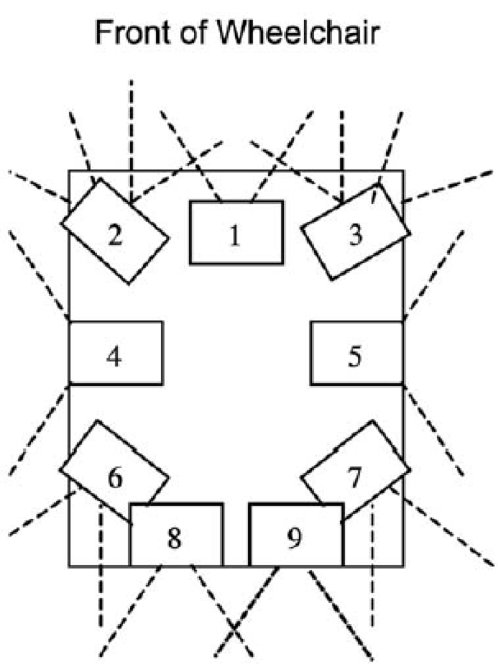

Figure 3.1- Placement of Sensors

Applied AI Systems (AAI) developed a smart wheelchair, Figure 4, in which a set of functions are determined and followed. The first set function is basic collision avoidance using cameras and sensors. When the chair encounters an obstacle, it first reduces its speed, and then, depending on the situation it faces, it stops or turns away from the obstacle to avoid hitting it or continues on. The obstacle can be inanimate such as a light pole, or animate such as a person passing by. If an obstacle is detected, the chair will first attempt to maneuver around it. But if it cannot, then it will slow down and back off. The second function is passing through narrow hallways; this task is rather simple for the chair to get through because the chair is surrounded by walls on each side and the sensors should easily guide the chair through the parallel walls from point A to B with ease. The third function is entry through a narrow doorway; the chair must automatically reduce speed and cautiously pass through a narrow doorway which, depending on door size, may only leave few centimeters of space on each side. The fourth function is maneuvering in a tight corner; the chair must automatically be able to find a break in the surrounding and escape the confinement by itself unless instructed otherwise by the user. The fifth and final function is landmark-based navigation; with the help of functions one, two, and three, the chair will also be equipped with two color cameras that will detect depth and size of free space ahead. Cameras will also identify landmarks in the environment so that the chair can travel from its present location to a given destination by following such landmarks [1],[2],[3].

Figure 4 – Prototype created by Applied AI Systems called TAO-1[1]

Soon after the first prototype, TAO-1 (Figure 4), was in development in Canada, it was brought to a local mall to freely roam around for an hour. TAO-1 skillfully navigates itself through the mall avoiding internal structures such plants, escalators, signs, and benches. People around did not notice that the chair was driving on its own without the help of the rider/tester. The only problem it encountered was that it swerved downward when a sidewalk was slanted. A popular approach to facilitate the wheelchair to be adapted to various scenarios is the idea of learning by intuition. After the tester "trains" the chair to operate in a certain environment, it is able to perform navigation tasks in that environment. During the training process, the system has to build a map of its environment which matches with the real world. Afterwards, it must use the map as a self-localization method. Overall, this prototype did very well and with more modifications to correct the problem, it can be very beneficial to those severely handicapped in limited areas such as small homes or offices.

Another example of outstanding research in this field is that done by Richard Simpson of the University of Pittsburgh, and specifically his extensive research on the Navchair Assistive Navigation System [4]. He has developed several mechanisms to allow the NavChair to automatically adapt its behavior to meet changing task requirements and user needs. There are several advantages to his method of integrating the smart wheelchair technology into a commercially-available power wheelchair. First, the user's input can be fed directly into the existing proprietary control electronics, which includes all safety systems that were originally built into the system. For example, early prototypes such as the Hephaestus (Figure 5) were able to utilize analog connections between the joystick and the motor controller. Second, one can easily add optical encoders to the wheels, which allows the chair to track its velocity. Finally, the largest advantage of the "add-on" approach enables a consumer to buy the system and reuse it on multiple chairs over their lifetime. This is good for children who may quickly transition through several chairs as they grow.

Figure 5 – Smart wheelchairs – [5]

The NavChair has three modes of operation: general obstacle avoidance (GOA), door passage (DP), and automatic wall following (AWF). GOA is the “default” operating mode of the NavChair and it is intended to allow the chair to quickly and smoothly navigate in crowded environments while maintaining a safe distances from obstacles. The DP mode is intended for use in situations that require the chair to be maneuvered between two closely spaced obstacles, such as a doorway. This mode may fail in obstacle avoidance because the chair may approach a doorway at an angle rather than directly from the front. When failure occurs, the operator is forced to back up manually and re-approach the door again from a better direction and/or angle. The AWF mode causes the chair to modify the users’ navigation commands to follow the direction of a wall to the left or right of the chair. This mode allows the chair to travel at a faster speed closer to a wall than is possible with GOA mode. Figure 6 shows an environment in which all three tasks are executed. The aim of the project is to show that the smart wheelchair can navigate in confined spaces such as an elevator or in the bathroom, in unknown environment like going through an airport, and in stressful situations such as leaving a building during a fire alarm. These tasks require basic robot navigation capabilities like mapping, localization, point-to-point motion [3].

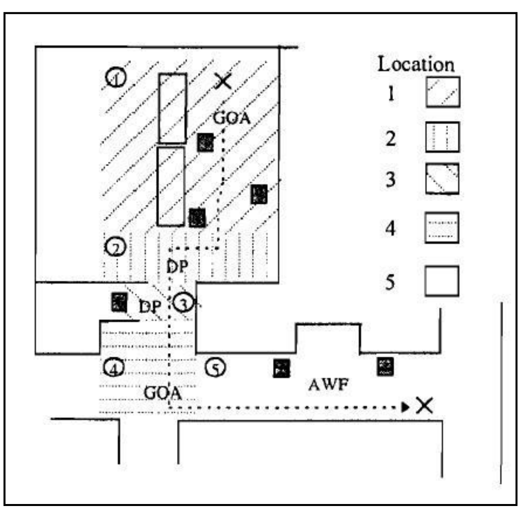

Figure 6

Experimental Task Environment [4]

AWF=Automatic Wall Following

DP=Door Passage

GOA=General Obstacle Avoidance

Simon Levine of University of Michigan has also done extensive research on assistive technology for the physically handicapped. Levine worked on the NavChair with Simpson in both the development and physical construction phases of the project. He co-founded the University of Michigan Direct Brain Interface (UM-DBI) project along with Jane Huggins. The term Direct Brain Interface is intended to emphasize the function of the Brain Computer Interface (BCI) as a direct connection between the human brain and various kinds of technologies (not just computers). This research includes interfacing BCIs to commercially-available assistive technologies, improving BCI response time and no-control performance, identifying features and support necessary for successful independent BCI use by people with physical impairments, and identifying the design preferences and priorities of potential BCI users. The UM-DBI project's current work focuses on the development of electroencephalogram (EEG)-based BCIs into practical clinical tools for use by people with physical impairments, see Figure 7.

Figure 7 – EEG with Artificial Intelligence

1.2: Objective

The objective of my research is to give the severely disabled freedom of mobility not only indoors but outdoors as well. The goal is to design a “prototype” of a self-driven motorized wheelchair that utilizes pre-recorded maps to assist in the guidance over areas of repeated travel. Outdoor use gets a bit complicated due to the fact that there are no walls surrounding the chair for close range scans to detect. Because the chair will be completely autonomous, we have to consider many factors such as inclines, people running or walking at a face pace, and drops or curbs. The wheelchair will have the addition of encoders and a caster system to help collect data for precise calculations. A GPS will also be integrated for map guidance in unknown environment once all the hardware and software are debugged and tested.

Before working on the hardware, some ‘preliminary’ design work had to be done. Extensive calculations and algorithms are required for the caster system and also a circuit system to regulate the chair’s speed and assure safety. The algorithms will help the measurement of the odometry of the wheelchair in an unknown environment. The circuit system will also help maintain a constant speed to assure safety. The nominal or “rest” value stands at 2.5 volts, with the circuit system incorporated we will be able to add and subtract from that nominal value for forward and reverse commands.

Chapter 2

The Caster Odometry System

2.1: Why a Caster System?

The objective of the caster system in this autonomous wheelchair project is to calculate position and orientation of the chair. A caster system is used for the autonomous wheelchair project because of its ease of use and versatility in that it works indoors and outdoors. The caster system can be easily mounted temporarily onto the chair and alsoonto other research projects. Attached to each caster are encoders to help determine the caster movement. If the encoders were just mounted on the wheels of the actual wheelchair, thenthe wheels could slip when the tires are being driven resulting in errors. With the caster trailing behind and under the wheelchair, this will allow the caster to freely move with the chair thus giving accurate odometry readings.

2.2 Set up of Caster System

There are two types of casters: a swivel type and rigid. A swivel caster has a set arm length from therigid caster wheel to the mounting point, and can rotate around the mounting point. The pivot allows the caster wheel to automatically align itself to the direction of travel. In contrast, a rigid caster consists of a wheel mounted to a stationary fork, as shown in Figure 8. The orientation of the fork, which is fixed relative to the wheelchair, is determined completely by the wheelchair. The rigid caster wheel is often used instead of a swivel caster because of its simpler motion.

Figure 8 – Rigid caster wheel mounted to stationary fork (Red). Swivel caster (Blue).

In this project, the caster is a swivel type with two encoders: one at the caster wheel and the other at the pivot point where it's mounted to the wheelchair. Encoders are devices that allow one to measure the precise speed, distance, or direction of wheel travel. For this project, optical encoders will be used. Optical encoders detect angular rotation by measuring small increments of movement by counting the number of times a light beam is broken by a slotted diskconnected to the rotating wheel.

2.3: Optical Encoders

The optical encoders used for this project are HP HEDS-5500, Figure 9. A digital optical encoder is a device that converts motion into a sequence of digital pulses. By counting a single bit or by decoding a set of bits, the pulse can be converted to relative or absolute position measurements. Each encoder contains a lensed light emitting diode (LED) source, an integrated circuit with detectors and output circuitry, and a codewheel that rotates between the emitter and the detector integrated circuit (IC). The codewheel rotates between the emitter and detector, causing the light beam to be interrupted by the pattern of spaces and bars on the codewheel. The photodiodes allow an external circuit to count the interruptions.

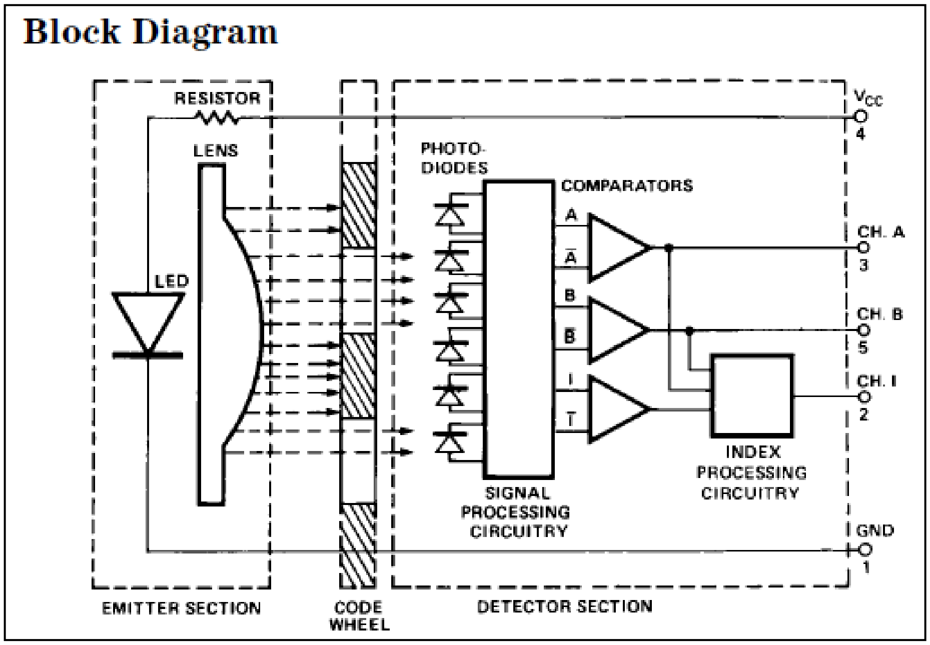

Figure 9 - Block diagram of optical encoder.

2.4: One Caster

Our original approach to the caster system was to only mount one caster to the wheelchair. From the schematic below (Figure. 10), the Robot denoted as 'R' is traveling along the path marked by the dashed cyan color lines. The caster is attached to the robot with an arm length 'L' in the color green, the caster itself is blue. As the Robot moves from position 1 (R_1) to position 2 (R_2), the caster is being pulled from its position C_1 to position C_2. The main goal for this schematic is to find angle of rotation (θ_{motion}) and angle of twist (θ_2).

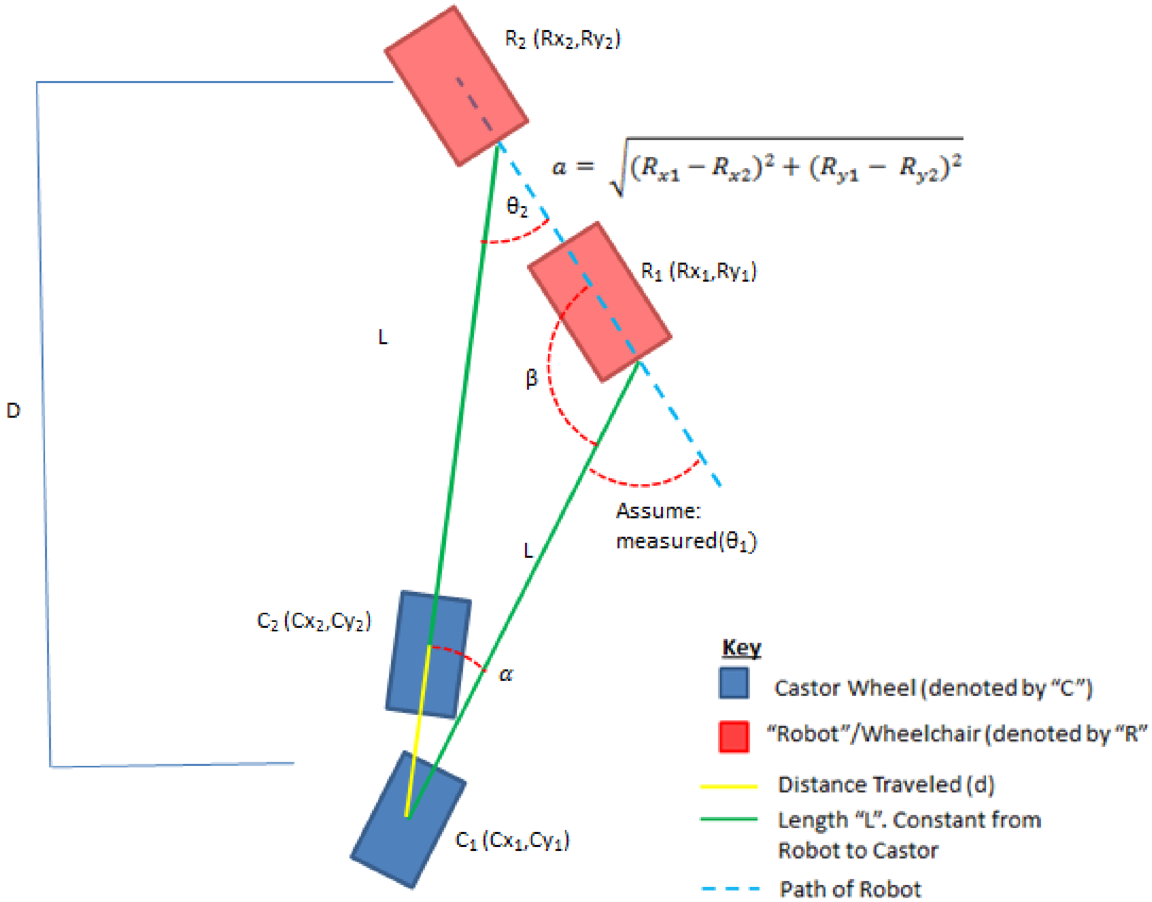

Figure 10 – Schematic of robot and caster with key

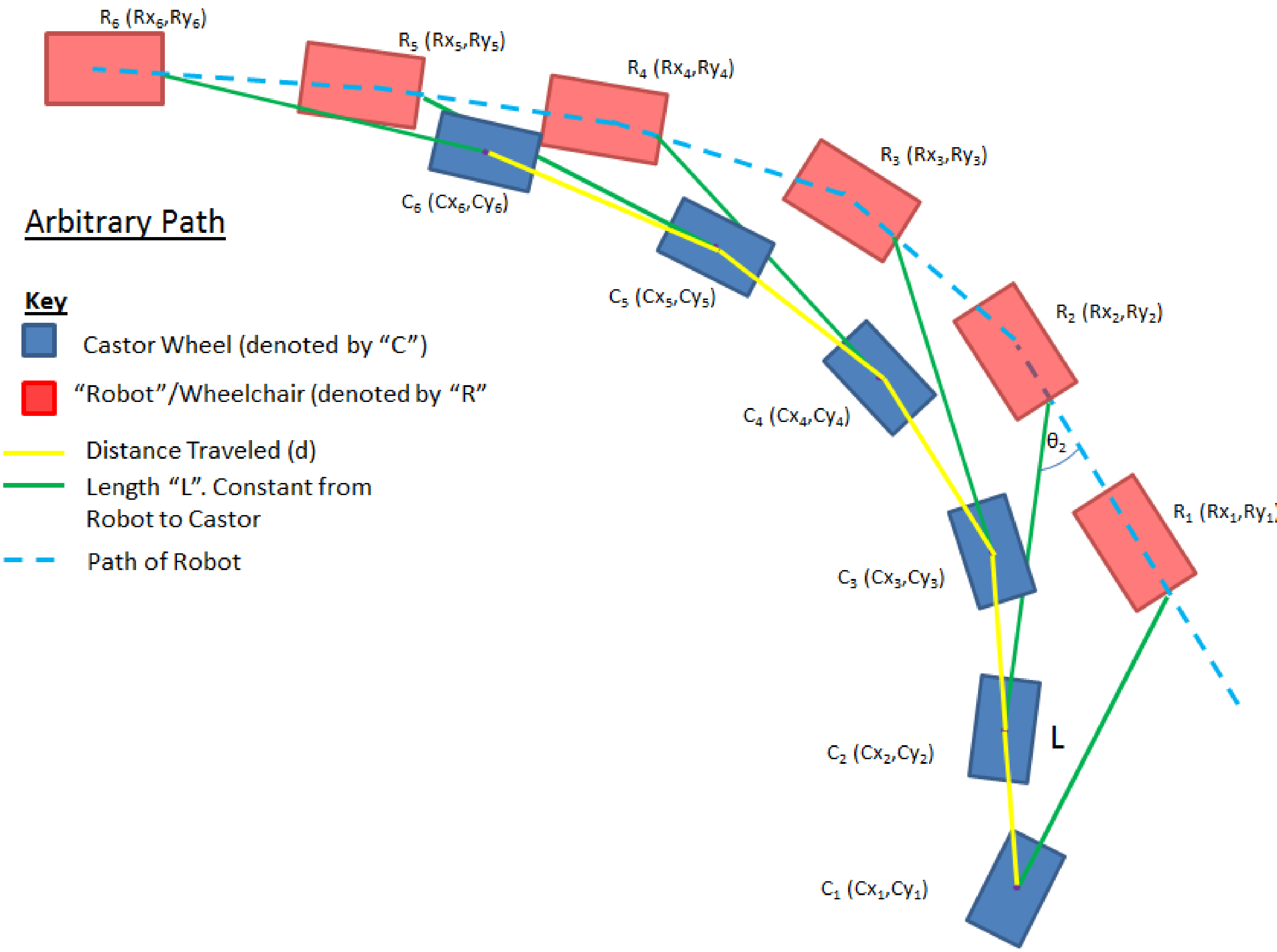

Figure 11 – Arbitrary Path

2.5: Calculations

The calculations to determine robot position from odometry measurements are as follows:

Given:

Position of Robot 1(R_1),

Position of Robot 2 (R_2)

Caster Arm Length (L),

Caster Radius (r)

Find:

Angle of Twist (θ_2)

Angle of Rotation (θ_{motion})

<u>Sides</u>

$$a = \sqrt{(R_{x1} - R_{x2})^2 + \left(R_{y1} - R_{y2}\right)^2}$$

$$b \; or \; D = L + d$$

$$c = L$$

<u>Finding angle β</u>

$$\beta = 180 - \theta_1$$

<u>Finding distance traveled (d)</u>

Using Law of Cosine

$$D^2 = L^2 + a^2 - 2aL - \cos\beta$$

$$d = D - L$$

<u>Finding Angle of Rotation</u>

*using calculated ‘d’ from above and radius of caster

$$\theta_{motion} = \frac{distance\ (d)}{radius\ (r)}$$

Finding Angle of Twist (θ_2)

Using Law of Sine

*using calculated 'D' and 'β' from above

$$\frac{L}{\sin \theta_2} = \frac{D}{\sin \beta} \Rightarrow \sin \theta_2 = \frac{L \sin \beta}{D}$$

$$\theta_2 = \sin^{-1}\left[\frac{L \sin \beta}{D}\right]$$

From the calculations, θ_2 and θ_{motion} can be found; these calculations are repeated every time the robot moves, using its last position as its 'starting' position for each subsequent position calculation. (See arbitrary path in Figure 11.)

The problem with this approach is that it assumes that the robot is traveling in a straight line. In the case that the robot may be rotating during travel forward, the above equation will be incorrect. Although θ_2 and θ_{motion} are calculated, the robot can be anywhere within a radius shown in the diagram below (Figure 12). The red outer diameter circle shows all the possible locations where the wheelchair can potentially rest, given identical measurements of both encoders. The green is the caster arm length, yellow is the distance traveled, red is the robot, blue is the caster wheel, and cyan is the path of travel. For example purposes, 35 degrees are used to show that θ_2 remains constant. This is a problem because we still do not know the exact position and orientation of the robot.

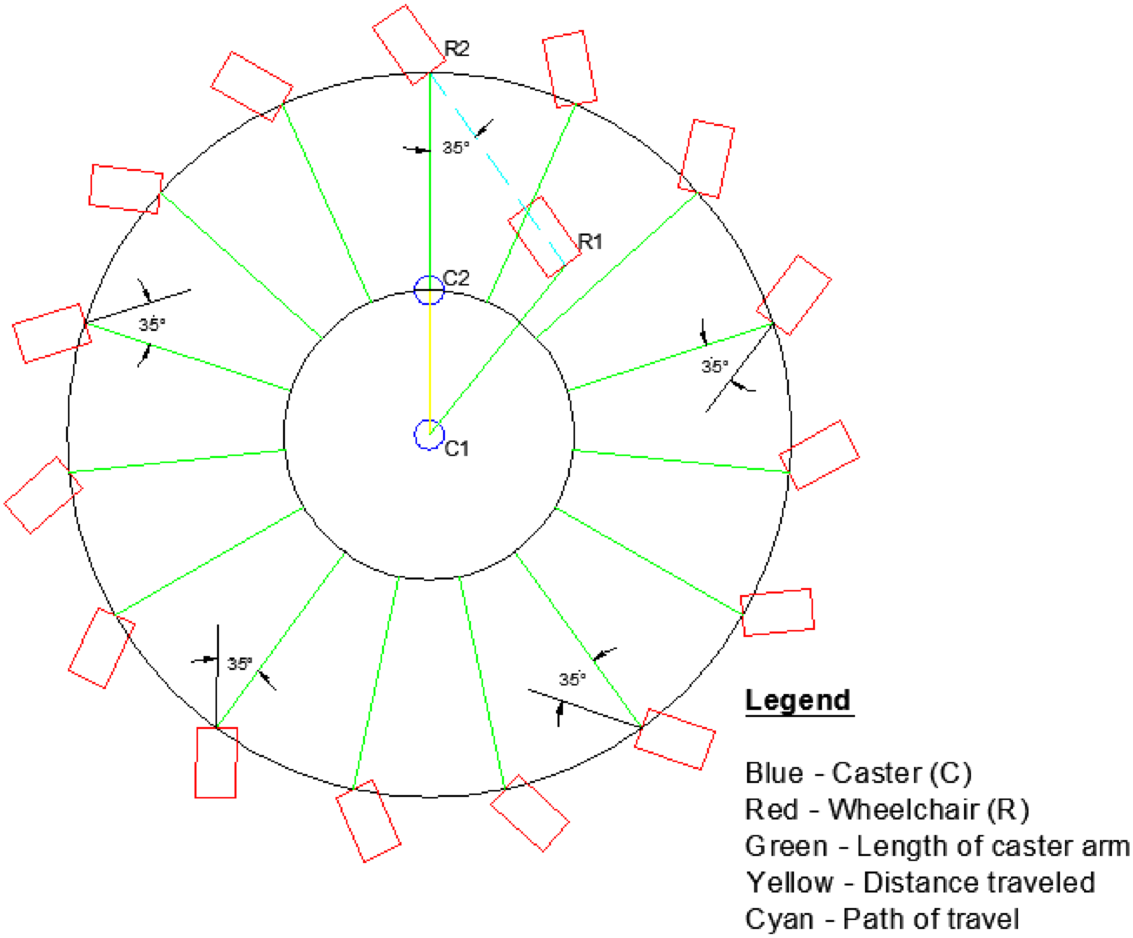

Figure 12 – Diagram of random positions

From here we decided to go forward with using two casters instead of one for the simple fact that, using measurements θ_2 and θ_{motion}, the information from one caster is insufficient to determine where the chair is. Without position information and automated chair can potentially run into a wall and harm the user. Thus, further emphasis must be put into the calculation process because it has to be near perfect for the user.

2.6: MATLAB Simulations

MATLAB simulations were used to check the equations given earlier before the actual robot was deployed out to the environment. Figure 13 shows the Angle vs. Step relation. As the robot moves along a path, the caster will swing around to the rear of the chair and will eventually move to an angle of 180 degrees. For example purposes, 500 time steps were used. As shown, at 500 steps the angle of the caster converges to be very close to 180 degrees.

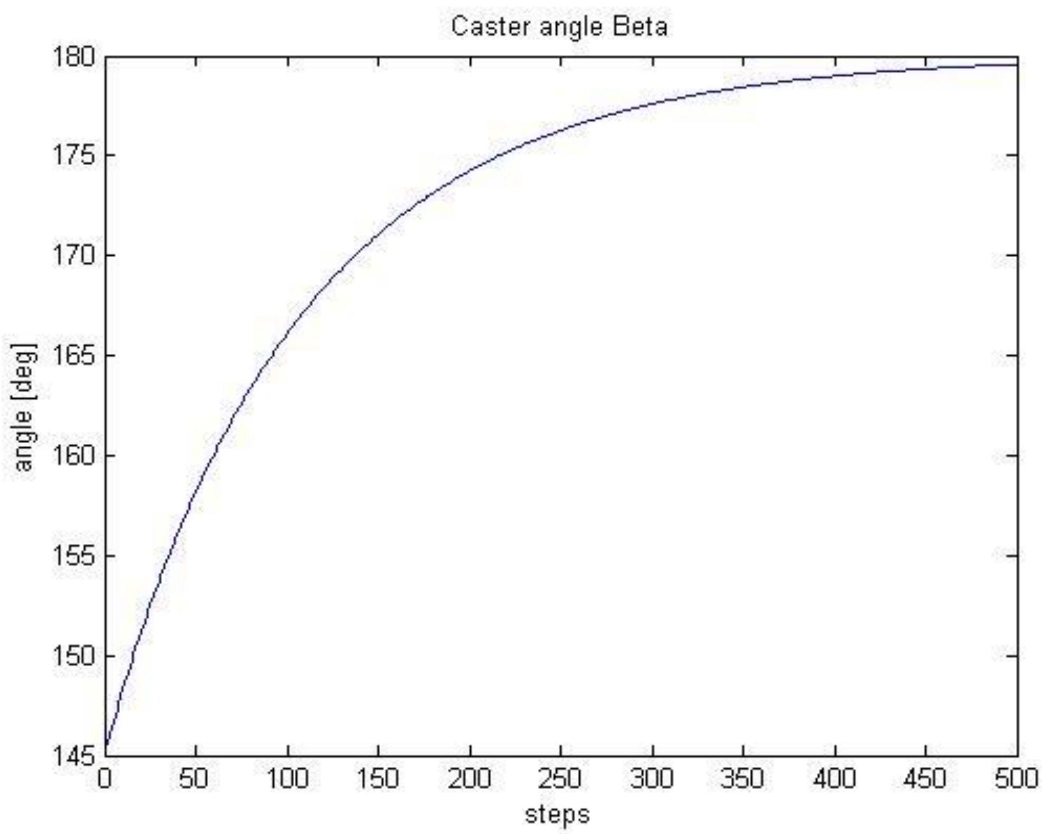

Figure 13 – Angle vs. Steps

For Figure 14, the distance traveled is linear because we are assuming the robot is under constant velocity.

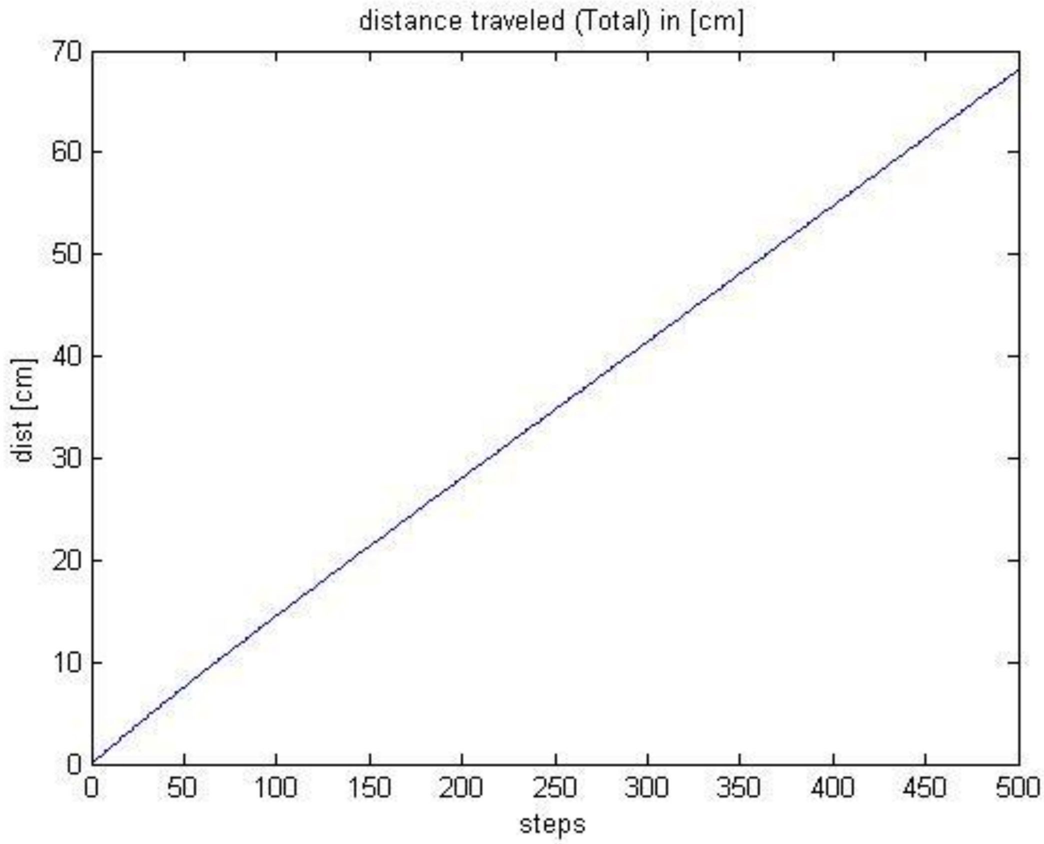

Figure 14 – Distance vs. Steps

The simulations proved that the calculations for the caster system indeed work for forward and reverse, as long as the robot is not rotating. This simulation is for the one caster system, but gives confidence that similar algorithms would work for a double castor odometry system.

Chapter 3

Two Casters

As will be shown shortly, the two caster odometry system may provide an estimate of the robot's position. But even this solution still gives at least two solutions. Both possibilities are mathematically indistinguishable given the encoder measurements, but only one is correct. The difference between the two is that one is a solution of the robot traveling forward, while the other is for traveling backward. Thus, knowledge of the orientation of the travel direction will tell us which way the wheelchair is facing.

The mathematical geometry of a double caster system is no different than the set up of one caster. It is assumed that one caster will be mounted in the rear of the wheelchair and second directly mounted in the front of the wheelchair, and that both casters will trail the wheelchair as it moves, see Figure 15. However, the casters can be mounted anywhere on the chair with little modification to the equations below. Looking at Figure 15, this narrows down the 'possible' locations where the chair may rest after travel. From earlier, Figure 12 the possibilities were endless. Now looking at the intersecting circles, it shows a clear picture of where the robot can end up.

Figure 16 are actual pictures of the robot with the casters and encoders. Some modifications had to be done to the robot in order for the system to sit properly and measure what we desire. From the figure, you can see how this system will work. As the robot wheel (grey) rolls forward or backward, the caster wheel (black) will roll backwards or forward respectively. The encoder that is place under the caster wheel will measure its rotation.

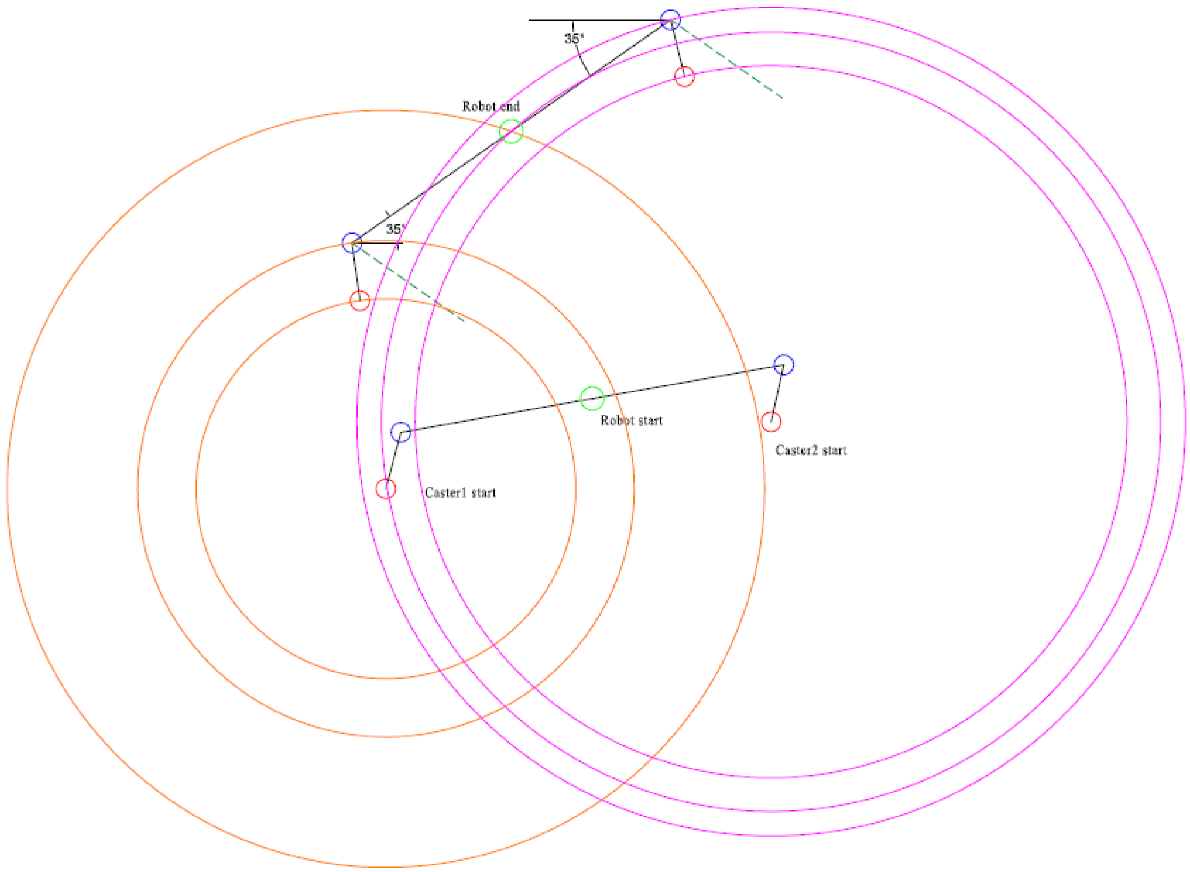

Figure 15 – Double Caster system schematic

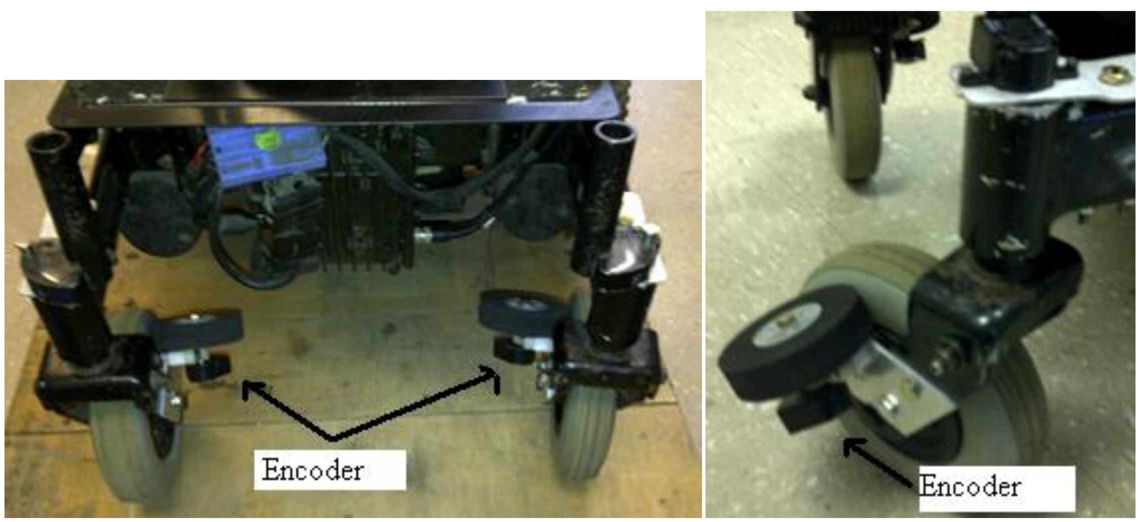

Figure 16 – Actual pictures of the wheelchair with caster and encoder

Chapter 4

Conclusion

Autonomous wheelchair research has been very active these past few years. While much work remains, outdoor autonomous wheelchair is an important contribution to the severely disabled. This will give them more freedom of mobility along with a feeling of independence. This thesis serves as a foundation for future work that needs to be done. Although many considerations go into designing this prototype, position and odometry of the robot stands out. Without the knowledge of where the robot is in relative to the environment, the robot does not know where to go. The caster system was implemented for solely that purpose, finding position and odometry of the robot. This is greatly emphasized because a disable person will ultimately be the users of this autonomous robot and their safely depends on the robot.

Future Work

In future research, the wheelchair should be taken outdoors for trial runs. Unfortunately, this year we were unable to get it out for trial runs and collect data. Most of the time was dedicated to figuring out algorithms and running simulations on MATLAB. Incorporating brain interface was brought to our attention for this autonomous project. I believe this will be a great addition to the project and will definitely further this project tremendously.

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