CORP 4 CRITICAL DESIGN REVIEW

OATS AUTOMATED CARRIAGE

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AUBURN UNIVERSITY

MECHANICAL ENGINEERING

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ABSTRACT:

The aim of this project is to design, test, and manufacture an automated moving carriage that transports a receiver around a circular track. The design of the carriage will meet or exceed the requirements set forth by the sponsor, Neptune Technology. The carriage and track design must be developed according to the System's Engineering process outlined in MECH-4240, Comprehensive Design 1. The purpose of this report is to detail and illustrate the progress made towards the embodiment of the final design by showing the steps of a proper design analysis. Important factors to be considered in this design include weight, cost, maintenance, and reliability, and a reduction of radio frequency interference due to physical components. The report will detail the subsystems developed for the final concept, the functions each subsystem accomplishes, and the parts and necessary cost and labor required for each subsystem. A manufacturing plan, as well as current efforts made in prototyping the final design will also be discussed. It should be noted that, while the report summarizes the conceptual design process (i.e. developing feasible alternatives to the solution), the primary goal of this report is to detail the engineering analysis for the chosen design.

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INTRODUCTION:

Neptune Technology Group has been a major producer of water meters since 1892 and has over 119 years of experience in providing better-quality service to the water utility industry. They have been able to produce mobile data collectors such as the MRX920 that has the ability to take 5000 reads per hour along with being wireless and weighing less than 5 pounds. They are a well experienced and technologically advanced organization that will continue to be an aggressive competitor in the water utility industry. The projects taken on by Neptune Technology Group, such as the automated receiver, go to show that they are not slowing down anytime soon.

Neptune currently has an outdoor test setup comprised of a rolling carriage on a 50 foot diameter circular track. A test water meter is placed in the center of the track and emits a wireless signal to a test antenna designed to measure the signal strength coming from the water meter. An example of a typical signal strength measurement is shown in Figure 1. The test antenna is mounted on the moving carriage and is moved to various locations around the track by two technicians who manually collect signal strength data from the receiver. This set-up is time consuming, uncomfortable, and inefficient. Since measurements are taken every 15 degrees, the current setup also has a low resolution and could be made much more accurate if automated.

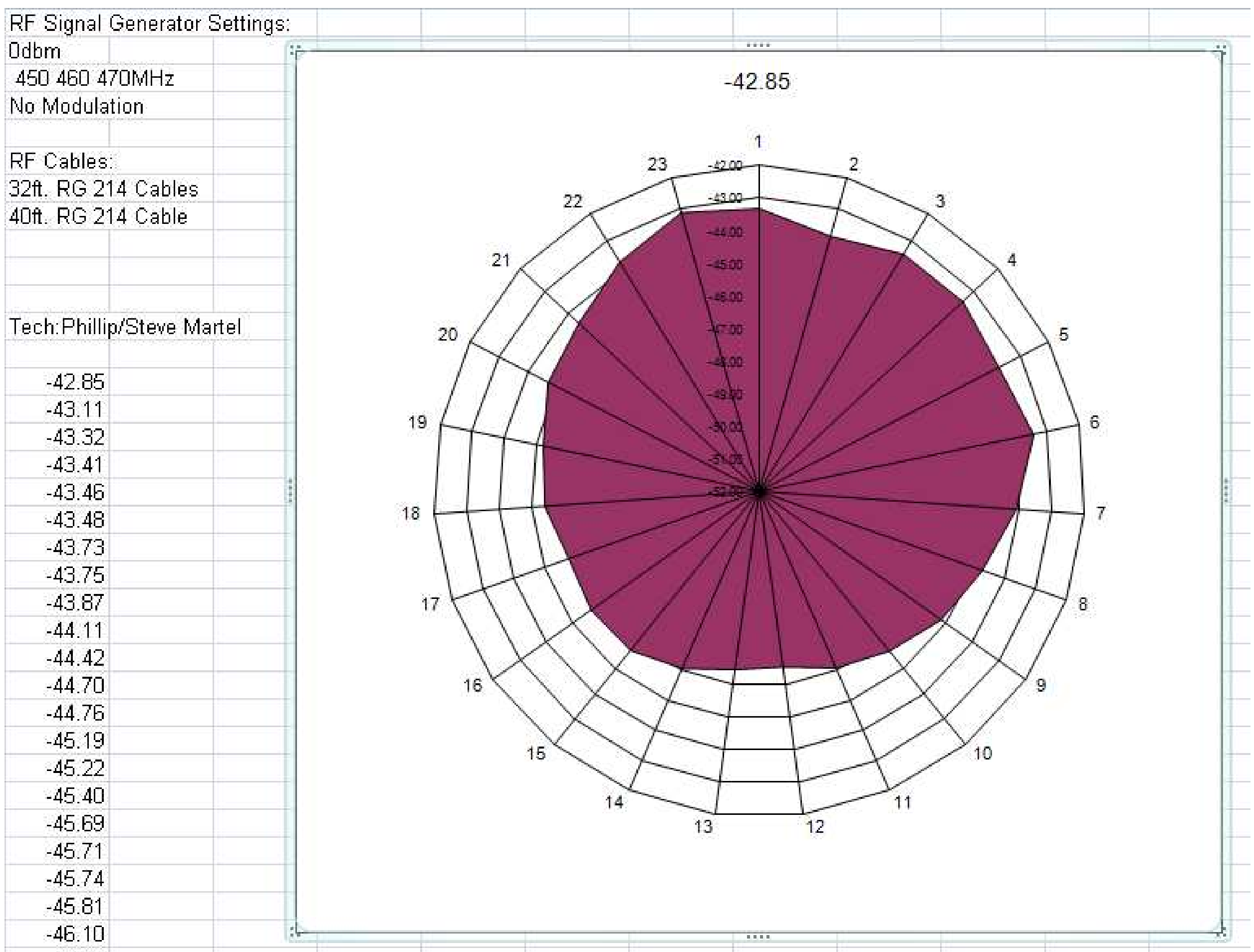


Figure 1 – Typical Signal Strength Plot

The design task at hand is to create an automated carriage that will travel on a track 50 feet in diameter. The test antenna and receiver that measures the signal strength emitted by the test water meter will be mounted to the automated carriage, which will be remotely controlled from a base station or inside the Neptune Engineering building. The receiver will wirelessly send measurements of the signal strength for review by Neptune technicians and engineers. There are not currently any designs that will be sufficient at accomplishing this task, so the goal behind the design will be to create and manufacture this automated carriage from scratch. The current track design is shown below in Figure 2.

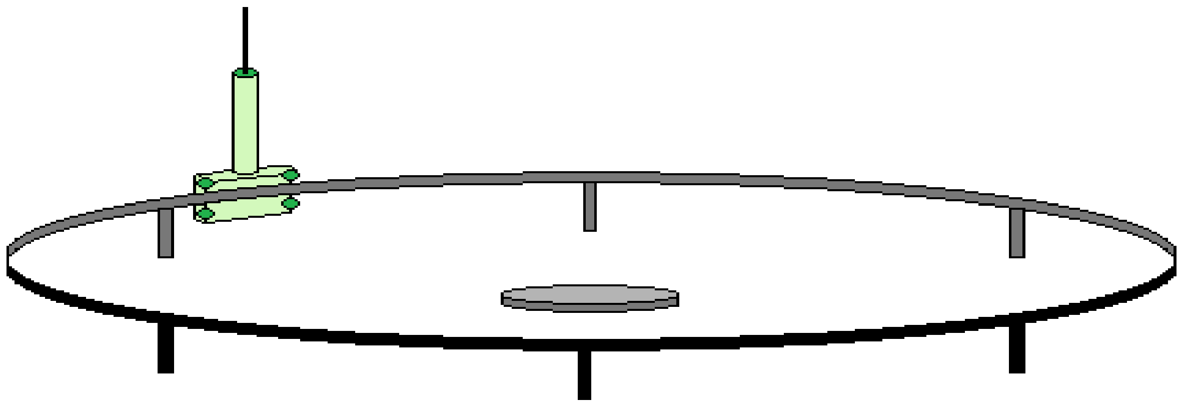


Figure 2 – Current Track Design

In this critical design review, a brief summary of feasible concepts for the automated carriage is presented as well as the assessment of these concepts and the selection of the final design. The development of each required subsystem is discussed as well as the integration of these subsystems and their parts into the final assembly. Plans for manufacturing and purchasing the required parts will also be included.

MISSION OBJECTIVE:

The overall purpose of this project is to design, evaluate, and create an automated test antenna that emits a low radio frequency and is weather resistant. The target users for this project are the technicians and the engineers that will be running tests with the automated carriage. This new device will be need to be lightweight in order to reduce physical exertion and heavy lifting while transporting it to and from the base station, while at the same time providing better removability for the technicians for the purpose of carrying it indoors in case of severe weather. The major use for this device will be for transporting a test antenna used to receive a signal produced by a water meter in the middle of the 50 foot diameter circle and house the wireless receiver and electronics required for measuring the intensity of the signal; therefore the apparatus will have to be secured safely to the track.

ARCHITECTURAL DESIGN DEVELOPMENT:

One of the first steps taken in the generation of concepts for this project was to create a functional decomposition for the design. This tool enabled brainstorming ideas for the design on a sub-function and a sub-sub function level, allowing the selection of a more feasible design. Creating a functional decomposition is an important part of the Systems Engineering Process. Corp_4's functional decomposition is shown below (Figure 3).

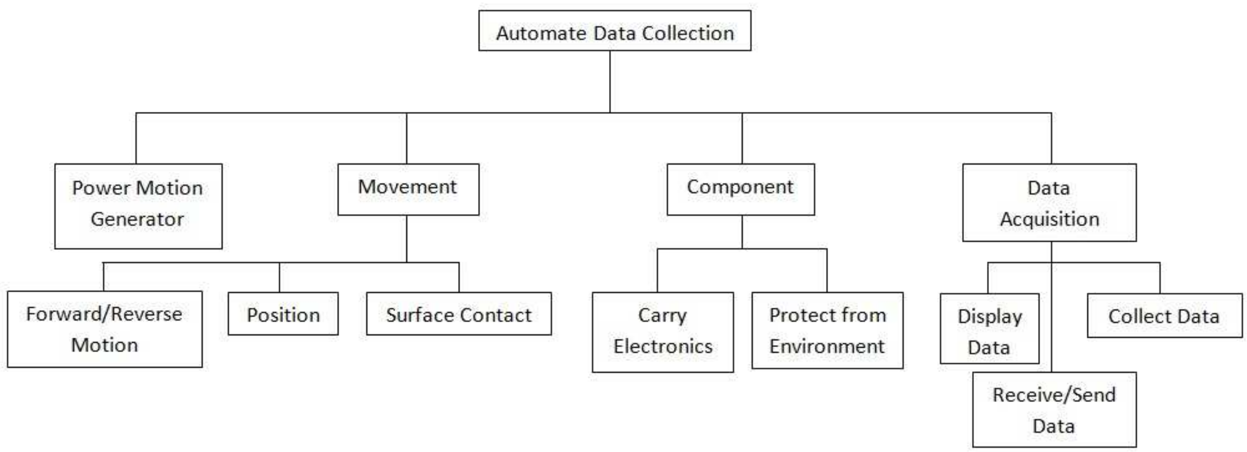


Figure 3 – Corp_4 Functional Decomposition

- **DEVELOPMENT OF FEASIBLE CARRIAGE DESIGNS**

  Using the functional decomposition and other engineering design tools such as brainstorming and morphological charts, four feasible designs were developed for the automated carriage. The first concept was battery powered and motor driven. The motor was to drive two front wheels that rested on the circular track. The second concept was powered by a conductor bar on a monorail and was also motor driven. The third concept consisted of a motor driving a long circular chain with the same radius as the track and connected to the carriage. It would be powered by a local AC outlet near the track. The final concept was also battery powered and motor driven, but instead of driving wheels in contact with the circular track, it would drive a sprocket in contact with a stationary chain. These concepts were all determined to be reasonable designs and would accomplish the mission objective.

- **<u>Concept Assessment and Determination of Final Design</u>**

Once several valid options for different designs were generated, the concepts were evaluated and compared on the basis of cost, safety, reliability and maintenance, accessibility of electronics, the ease of supplying power to the carriage, and the accuracy of carriage position control, among other criteria. The first concept, in motion was induced by wheels in contact with the track, was deemed to be easy to maintain and reliable, but lacked precision in controlling the position of the carriage. The second concept, which utilized a consistent power source via the conductor bar on the monorail system, would require less work since it would not require consistent recharging of a battery, but could be unsafe to technicians and the environment. Also, if the system were to fail, it would be difficult to fix because most of the technical knowledge for a monorail system is overseas and finding a technician who is familiar with this system may be difficult. The third concept, while providing an accurate mode of position control and having a constant power source via the local AC outlet, would require frequent maintenance to ensure reliable movement in the mobile chain and would also be very costly and difficult to manufacture. The fourth concept, although requiring somewhat frequent charging of a battery, was chosen for the accuracy of controlling the carriage position and overall ease of maintenance and manufacturability. The concepts were compared using the same criteria. See Table 1 for a detailed review of concept benefits and drawbacks.

Table 1 – Concept Comparison Chart

Concept Comparison (1-5 scale, 5 being optimal)				
	Battery Power, Wheel Driven	Monorail Powered, Wheel Driven	Outlet Powered, Chain Driven	Battery Powered, Sprocket Driven
Size	3	2	3	3
Cost	4	2	2	4
Weight	4	4	3	4
Maintenance	4	2	2	4
Manufacturability	4	2	3	4
Reliability	4	2	3	4
Simplicity	4	2	3	4
Installation Friendly	4	3	3	4
Power Supply Life	3	5	5	3
Position Control	3	3	5	5
Total	**37**	**27**	**32**	**39**

- **<u>PRODUCT HIERARCHY</u>**

For the final design, the carriage with the battery powered motor driving the platform along a chain profile was chosen. The battery powered design offered some slight advantages of using a lighter chassis that would reduce the amount of weight of the entire system along with having considerably lower maintenance overall. The final design consists of four main sub-systems. The first sub-system is the motor and battery that will power and drive the carriage around the track. The second sub-system is the mechanical drive system that will consist of the gearbox attached to the motor, the gearing and chain profile used to propel the carriage around the track along with relaying the position to the user. The third sub-system is the chassis which is the aluminum structure used to transport the carriage around the track along with providing environmental protection for the electronics carried aboard. The fourth sub-system is the data acquisition system that will collect, send/receive, and display the data collected from the receiver via a wireless card installed in the electronics tower. This design has been modified from the original design to better accommodate the sponsor's requests and compensate for failures in analysis.

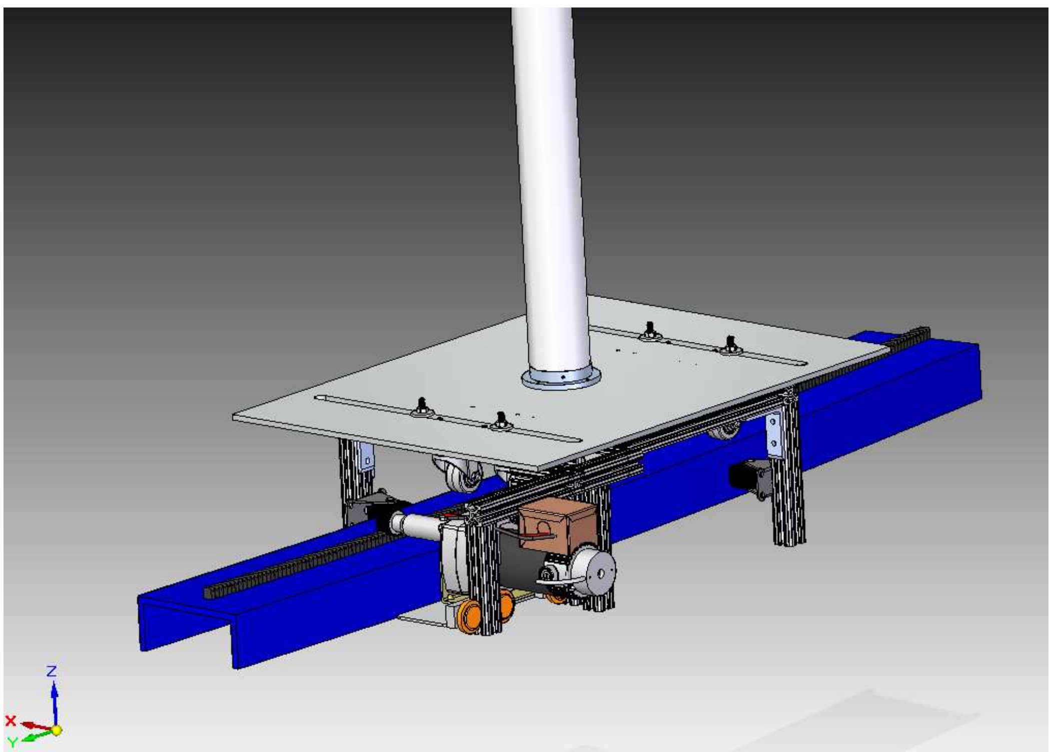


Figure 4 – Battery Powered/Chain Driven Platform

The previous design had several factors that needed to be changed. The original platform was a very basic and it required the technicians to manually push the carriage around the track for testing the antenna's signals. This resulted in one of the major changes from the previous design is the addition of a motor to drive the carriage around the track with the push of a button. A gearbox will be attached to the motor shaft and will be able to control the movement of the chassis using the motor controls in the base station. The gearbox will allow variable speed along with a forward and backward motion of the carriage.

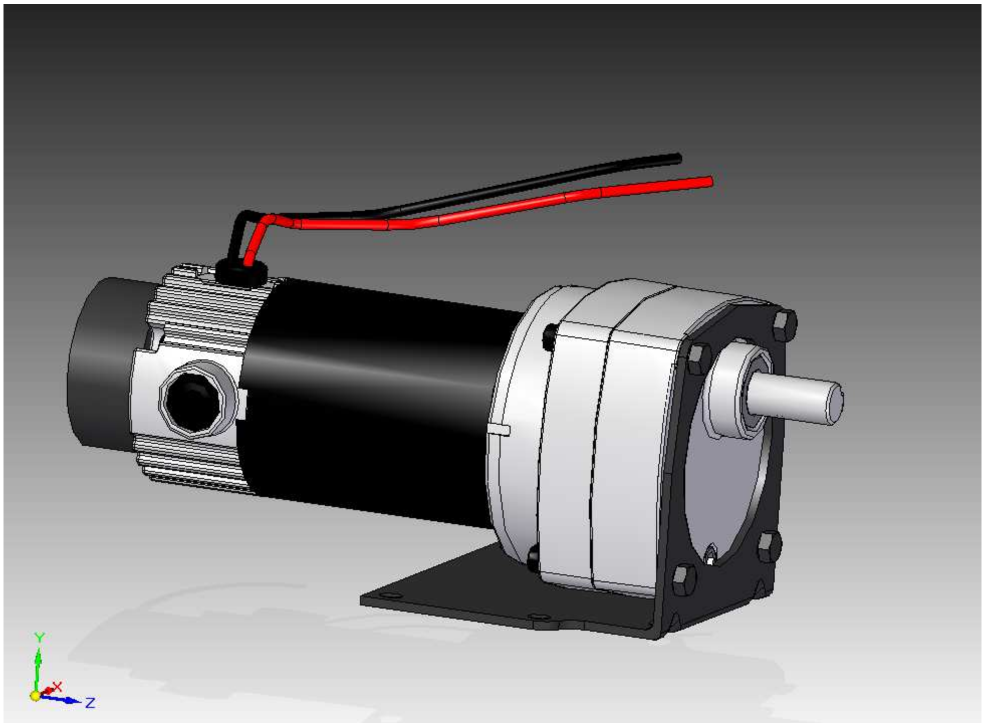


Figure 5 – Motor and Gearbox

The mechanical drive system has the basic components of gears and sprockets but the one thing that has changed throughout the design process is how to essentially put the power to the ground. There have been many different ideas presented including a roller chain being bolted to the channel and even a rubber wheel driving the carriage along the ground. There were many options but it was narrowed down to welding a gear rack to the top of the channel. The gear rack will be bent around the track according to the gear rack manufacturer in order to be aligned with the sprocket. The gear rack has the advantages of having precise control over the positioning system and durability for overall lower maintenance.

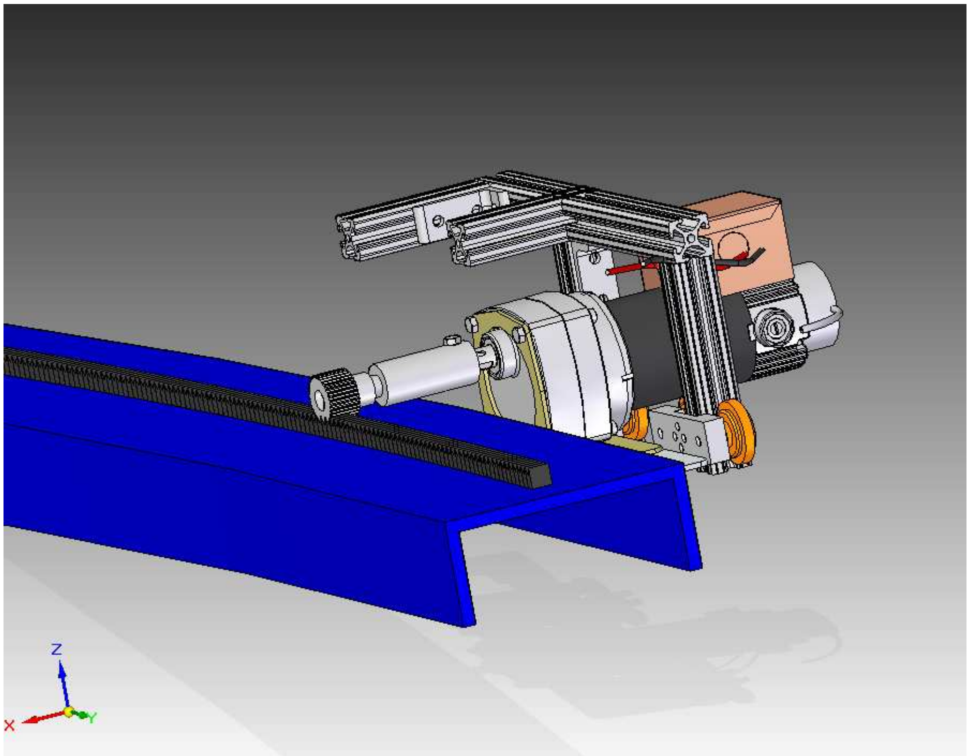


Figure 6 – Mechanical Drive System

The track was changed dramatically from the design in the Preliminary Design Review. The previous design was made out of two steel tubes welded to the modified studs of the existing track. The new track design consists of a U-channel beam that is approximately six inches wide giving a nice clean flat surface for the casters to roll on. The channel is purchased from a manufacturer who is able to cut and bend the track to the exact radius needed for the design. The track will be welded on to the modified studs of the existing track and painted to resist corrosion.

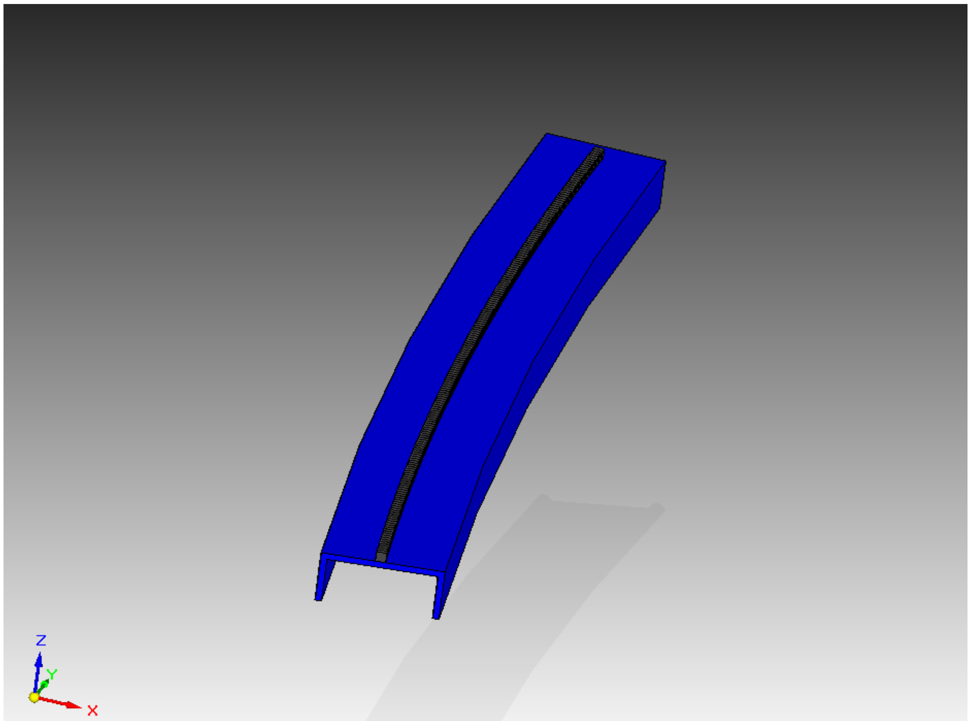


Figure 7 – Track

The main chassis of the carriage was also changed dramatically from the design in the Preliminary Design Review. Where the previous design was made out of steel and had rather large 4" caster wheels, this design uses an off-the-shelf manufactured channels already cut to length and bolted together using the manufacturer's brackets. The original 4" casters are replaced with much lower profile 2" casters which lower the center of gravity for the entire platform. Shorter studs will be implemented in connecting the casters to the platform due to the interference of the rotation of the casters during the prototype testing. The updated design saves weight, reduces cost, and allows for more versatility of the chassis.

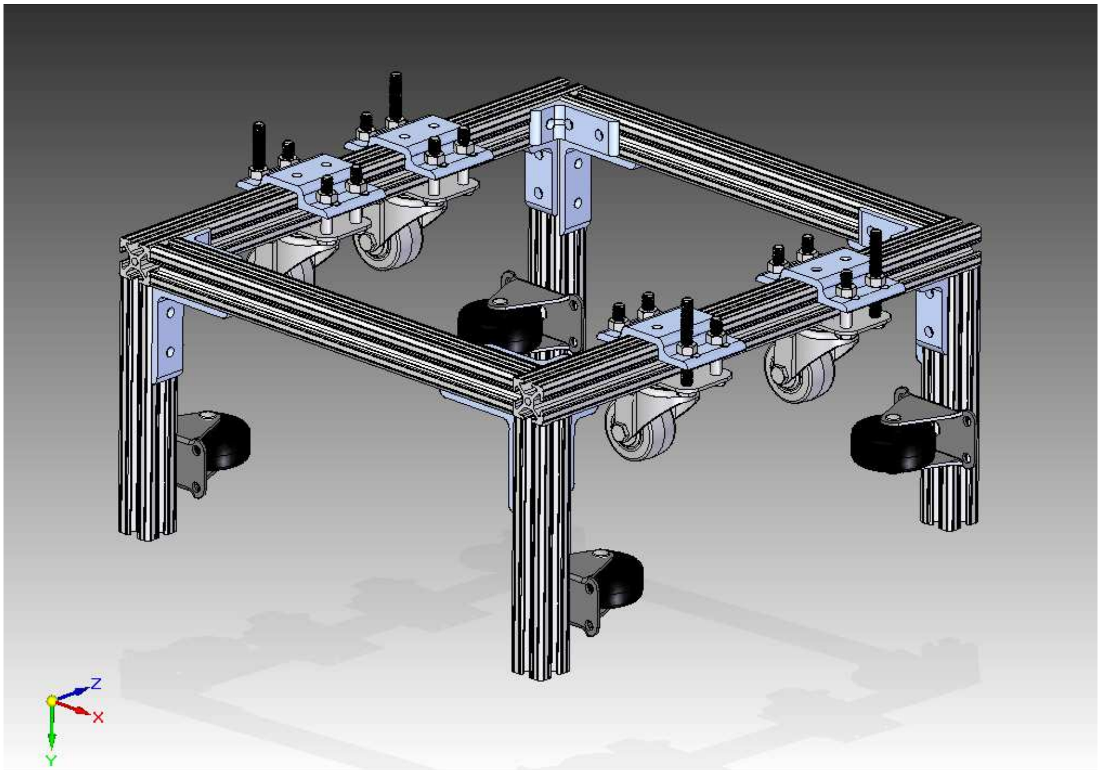


Figure 8 – Chassis with Casters

The platform has essentially stayed the same over the course of the design. The duty of the platform is to carry the mast, electronics, battery and motor around the track. The platform has been chosen to be made of aluminum in order to keep the weight down along with resisting corrosion. There will be one feature of the platform that will allow the motor to be raised and lowered acting as clutch for the motor. The platform will be bolted to the carriage using the T-nuts that are used with the slotted carriage in order to have a secure connection.

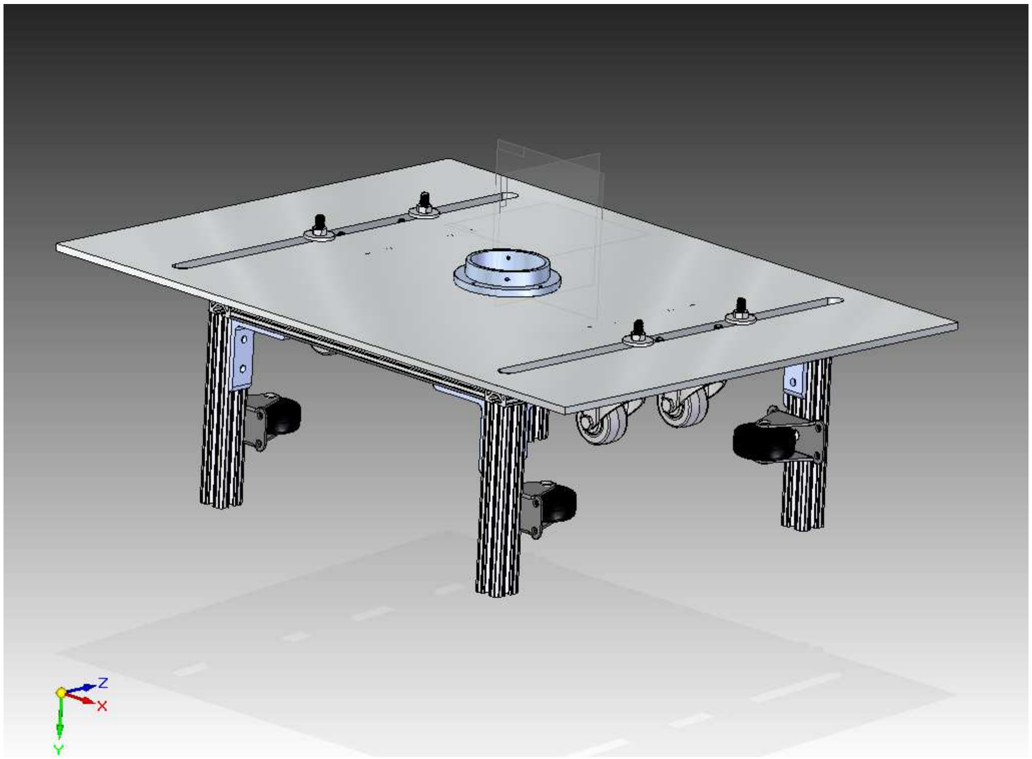


Figure 9 – Platform

The mast will be the same one in the previous design utilizing the 3” PVC pipe but the main difference will be how the mast is mounted to the platform. A 4’ long piece of steel tube will be welded to a plate of steel as a base and the base will be bolted to the platform. The steel tube will have a diameter of 2.875” so the PVC pipe can be mounted over the steel pipe and held into place with several clamps. The steel pipe will add extra weight to the carriage but more rigidity to the PVC pipe to keep the mast from swaying when in motion and under high winds.

Figure 10 – Mast

The electronics tower will house all of the data collecting, receiving and transmitting equipment. The signal sent out from the water meter located in the middle of the track is received by a test receiver mounted on the mast of the carriage. The receiver relays and signal that is transmitted to the base station through a wireless connection. All of the electronics will be located in a tower that will have vents located on the tower with fans blowing out the hot air radiated from the electronics under load. The motherboard, wireless system and the rest of the electronics will have a conformal coating to keep the electronics from corroding.

- **<u>ECONOMIC ANALYSIS</u>**

In designing the carriage, careful attention was paid to all costs associated in the manufacturing process. Special considerations were given to ensure that all materials used were manufactured of the proper quality to ensure a high safety factor and longevity of life. Since the automated carriage is designed for use at Neptune only and is not meant to be mass produced, costs associated with the construction of the carriage were expected to be higher due to ordering a single part rather than ordering a large quantity of each part.

The most expensive part of the test setup, as expected, was the track itself. The materials have extremely high strength and durability, and the horizontal surface made it an excellent choice for the design, even with its higher relative cost. The costs associated with the track were regulated by minimizing the width and depth of the legs, and going with a smaller thickness.

The rest of the materials used in the construction of the carriage were fairly simple and low cost. Most of the cost of the automated carriage can be attributed to the motor, battery and electronics. For this reason, extensive research and calculations were done to ensure that the chosen motor and battery were appropriately sized and would not have to be redesigned. Testing was done at Neptune Technologies with the carriage on a small section of track to insure the casters would hold up to a 100 pound weight. In this design, all of the components are off the shelf parts to insure no custom molded or fabricated parts will be needed, thus reducing overall cost. See Table 2 for a complete Bill of Materials.

Table 2 – Bill of Materials for Final Design

Manufacturer	Part Number	Part Description	Price/unit	Quantity	Subtotal
80/20	1010	T-Slotted Profile- Cut to 6.5"	$1.61	4	$6.44
80/20	1010	T-Slotted Profile- Cut to 12"	$2.76	2	$5.52
80/20	1010	T-Slotted Profile-Cut to 17"*	$3.60	2	$7.20
80/20	2523	Double Mesh Panel Retainers	$5.75	4	$23.00
Neptune Stock	N/A	1.5" 1/4-20 UNC w/ Washer and Nut	$0.00	16	$0.00
80/20	3321	Mounting Hardware for 2523	$0.50	8	$4.00
80/20	4176	3 Hole Inside corner Bracket	$3.85	8	$30.80
80/20	3393	Mounting Hardware for 4176	$0.40	24	$9.60
80/20	4101	4 Hole 2.5" Inside Corner Bracket	$4.10	4	$16.40
80/20	3321	Mounting Hardware for 4101	$0.50	16	$8.00
McMaster Carr	78155T17	2" Rigid Type Casters (For Alignment)	$2.00	4	$8.00
Colson Casters	1.01652.441	1 5/8" Swivel Type Casters (For Load)	$8.00	4	$32.00
80/20	1010	T-Slotted Profile- Cut to 5"*	$1.40	2	$2.80
80/20	1010	T-Slotted Profile- Cut to 10"*	$2.50	1	$2.50
80/20	4176	3 Hole Inside corner Bracket	$3.85	3	$11.55
80/20	3393	Mounting Hardware for 4176	$0.40	3	$1.20
Custom	N/A	Motor Mount Plate	$0.00	1	$0.00
Midwest Motion	MMP D22-376H-24V GP52-016	Brushed DC Gear Motor w/ Encoder*	$600.00	1	$600.00
Deben		12 Volt Lithium Ion Battery	$379.42	2	$758.84
Neptune Stock	N/A	Exension Shaft	$0.00	1	$0.00
McMaster Carr	6325K22	Gear- 12-pitch, 3/4" Face Width	$17.81	1	$17.81
80/20	2750	Roller Wheel Brackets	$6.00	2	$12.00
80/20	2281	Roller Wheels*	$4.50	4	$18.00
80/20	2281_10	Permanent Lubricated Bronze Bushings	$0.00	4	$0.00
CarrLane	CL-150-TPC-S	SS Threaded Body Toggle Clamp	$15.55	1	$15.55
McMaster Carr	3985A42	Double Point Cable Latch w/ T-Handle	$88.84	1	$88.84
White Fab	MC 6X12	33' Section of Steel Channel	$625.15	5	$3,125.75
McMaster Carr	6295K133	3/4" x 1/2" 12-pitch gear rack	$66.92	27	$1,806.84
White Fab	MC 6X12	13' Section of Steel Channel	$475.00	1	$475.00
Bear	N/A	Paint-Gallon	$12.00	2	$24.00
Rustolium	N/A	Spray on Primer	$3.97	2	$7.94
				TOTAL:	$7,119.58

REQUIREMENTS:

Neptune has several requirements for the automated carriage. The carriage needs to traverse the circumference of the track in less than four minutes. The position of the carriage must be able to be controlled to within one degree of the 360 degree track. It must also be weather resistant and removable from the track. The electronics (i.e. the mobile receiver, the wiring, the battery) must be cooled to within the specifications of each component, which will be approximately 70 degrees C. The electronic components should also be able to be removed individually from the automated carriage.

CONCEPT OF OPERATIONS:

The design that will be implemented is an automated system that will operate from a base station located all the way up to 500 feet away off of a wireless system. The system will ultimately be user controlled (i.e. by a Neptune technician or engineer). Through the use of Labview software, the user will be able to see the current position of the automated carriage and will be able to move the carriage to a new position by inputting a command. See Figure X for a detailed description of different part interfaces.

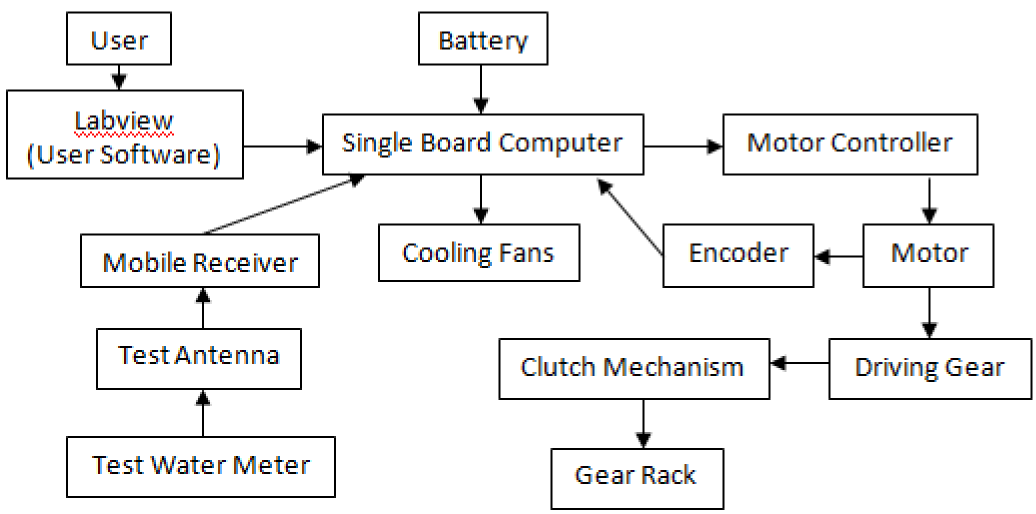


Figure 11 – Concept of Operations Detail

DATA COLLECTION AND POSITION SENSING:

As the motor travels around the track, the mobile receiver will be continually gathering data measuring the strength of the signal being emitted by the test water meter. The collected data will then be communicated to the single board computer (mounted on the carriage), which will wirelessly transmit the data back to the user in the base station. At the same time the motor is travelling around the track, an encoder mounted on the motor, will communicate to the single board computer the number of motor shaft revolutions, which will be used in Labview to determine the angular position of the automated carriage with respect to the test water meter located in the center of the test set up.

CARRIAGE MOTION AND POSITION CONTROL:

When a new carriage position is desired, the user will input the desired coordinates to Labview. This software will then wirelessly communicate with the single board computer which will adjust the speed of the motor through the use of a motor controller. The motor will spin a driving gear that connects to a circular gear rack that mounts to the track on which the carriage rests.

POWER AND COOLING CONSIDERATIONS:

The system will be powered by two lithium batteries connected in series and will provide up to 22 amp-hours at 24 volts. The batteries will supply power to all of the electronics on the platform including the 24 volt motor, the motor controller, the single board computer, the mobile receiver, and the necessary fans required to cool the electronics. The electronics tower will contain the battery, receiver, motor controller, single board computer, wireless card, and several fans/heat sinks to keep the electronics cool under heavy loads and high temperatures.

MANUAL CONTROL OPTION AND CHASSIS:

The driving gear will continually be in contact with the track mounted gear rack unless manually disengaged by a user at the location of the test setup. The user will be able to move the motor, shaft, and driving gear up and down to engage or disengage the gear rack by means of a manually operated clutch system. The clutch system and the motor assembly will be mounted to the chassis, which will contact the circular track at the locations of the four caster wheels that support the carriage and the four rigid wheels that provide added stability to the automated carriage.

VALIDATE AND VERIFY:

Plans to validate the final design originated during a meeting with Neptune engineers on June 29, 2011. At this meeting, it was suggested that a prototype be built for the purposes of verifying the torque and power calculations that had been developed for the model and developing a bill of materials and a manufacturing plan for the design. The chassis parts for the prototype were ordered after Neptune engineers reviewed and confirmed the concept. The chassis parts were assembled and prepared for testing.

On July 29, 2011 members of Corp 4 traveled to Neptune in order to test the current prototype for the chassis on the curved C-channel test track that was purchased from White Fab, Inc. The carriage's rigid, side wheels were adjusted to fit the track snuggly while allowing for smooth rolling. Next a load of 100 lbs was placed onto the platform to simulate the weight of the electronics, motor and batteries. This was a conservative assumption. The prototype was then pulled with a dynamometer in order to find the startup and steady state forces.

Several important observations were made during the prototyping session. One observation was that there is a need for the side wheels to be quickly adjustable to allow for the carriage to contact the track without disassembling the chassis- a task that had to be performed for the first prototype. At first the side wheels exerted too much pressure against the track and retarded the motion, but after some adjustment the side wheels fitted to the track and caused minimal friction. The platform used during prototyping was a ¼ inch thick sheet of diamond plate aluminum which experienced some deflection under the load. The thickness will be increased to ½ inch aluminum to counter this problem. The casters performed smoothly during transitions of forward and backward motion, but there was some deflection in the wheels. This increased rolling resistance of the cart and will be analyzed in detail at a later date to determine if harder wheels would be a better selection. The bolts that fasten the casters to the chassis interfered with the swiveling motion, but this can easily be fixed by shortening the bolts or reversing their direction of assembly. Chassis deflection was minimal and should not cause any problems with the carriage's performance. The force tests were conducted in a fashion to minimize error. The track was located on level ground and the force test apparatus was kept tangential to the track while gathering data. A maximum of 18 lbs was recorded as the startup force and 7 lbs as the continuous force needed to keep the cart in motion at a constant velocity.

Plans for future prototyping will begin with the rack placement. The current design is for the rack to be bent and fastened to the top of the track where the gear will mesh with it and provide forward motion. A concern with this design is whether or not the rack will deform too far for a traditional gear to still mesh correctly and if it will wear the teeth of the rack out sooner because of the misaligned contact points. Other options are to bend the rack to the inside or outside radius of the track. Force tests will also be conducted again to insure that a motor is selected correctly. The selected motor and battery combination will be tested to insure optimal battery life and that the motor provides enough torque. This will be calculated by performing different tests with the motor and battery mounted to the prototype. A test will be conducted for the thermal requirement of the electronics once Neptune provides Corp 4 with the data sheets for the single board computer, receiver, and motion controller.

Interfaces and ICD:

While there are few system boundaries at this point, there are several electrical and mechanical boundaries worth noting. The selected caster wheels have a load limit of 90 lbs. Since there are four caster wheels supporting the entire weight of the carriage, maximum weight limit of the chassis, the platform, the electrical components, and all other parts can be estimated at 360 lbs. This mechanical limit does not present a problem for carriage design because the target weight of the carriage and all components is approximately 50 lbs- the lighter the carriage, the longer the battery life in between recharges.

There are also two important electrical boundaries at this point in the design. First, the motor runs on 24 VDC and is rated for 1.7 Amps. If the motor draws too much or too little current, it must be resized for optimal efficiency. Also, the selected motor controller can accommodate motors that run on a DC voltage in between 5.5 Volts and 40 Volts and the motor controller can supply up to 7 Amps continuous current. The current motor and motor controller combination would work well together, but if either the motor or controller must be changed for any reason, these electrical limits must be kept in mind.

There will be thermal boundaries for the carriage and more importantly, for the electronics, but since all the electronics have not been selected at this time, the thermal limitations for the system are- yet to be decided.

Mission Environment:

Environmental concerns for this project include overcoming the heat of the Deep South and moisture from the Gulf of Mexico that will adversely affect the test equipment. Efforts to overcome these effects include the addition of fans and other ventilation equipment for the purpose of keeping the electronics cool. The carriage will also require insulation at certain points on the automated carriage so that the users will be able to install or remove the carriage without burning their fingers and metal parts that have been exposed to the heat for long periods of time. Other environmental considerations include storms and severe weather, rain and high winds. For this reason, the electronics and even the carriage itself must be easily removed from the track and transported indoors.

Technical Budget and Resource Tracking

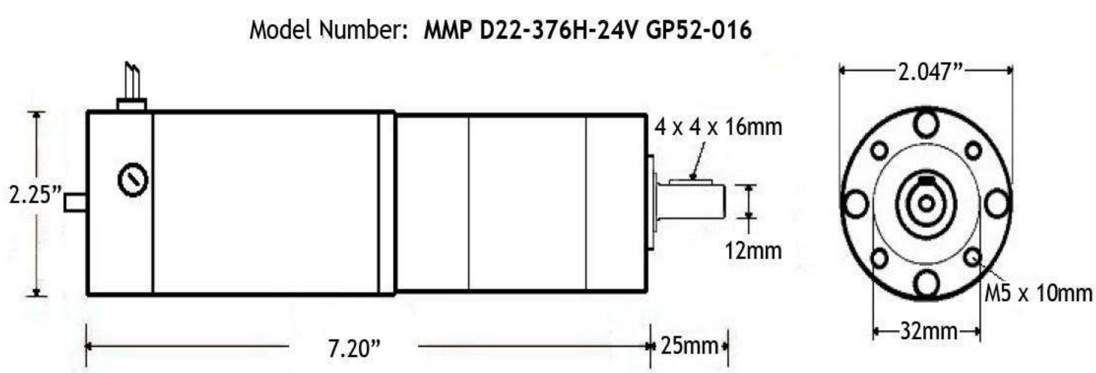
The primary technical resource that needs to be budgeted for this design is battery power. When driving a motor that is correctly sized and draws approximately 1.7 amps of current at the steady state rpm, the estimated battery life of the chosen set of batteries is ~8 hours. In reality, the battery life will not last quite that long because it will be powering the cooling fans, the single board computer and other necessary electronics, but 8 hours is a reasonable first approximation for the life of the selected battery in between recharges. The calculations for estimating the battery life as well as calculations that discuss sizing an appropriate motor can be found in the appendix.

RISK MANAGEMENT:

For the automated receiver, safety can easily be overlooked. The motor that drives the platform could possibly fail and one way to overcome this failure is to add a clutch mechanism to the gearing. In addition to safety, performance and longevity of the carriage must be considered. The carriage cannot be made so rugged that its weight would prohibit proper use, which could in turn lead to failure due to user error. Materials used must be considered for their ability to weather adverse conditions outdoors as well. Note that the track and gear rack will be assembled in sections so that if one section fails for any reason, it can easily be replaced with similar parts. Now that the final concept has been decided, prototypes, scale models, and material samples are available; Failure Analysis and Destructive Testing will be done.

SUBSYSTEMS DESIGN ENGINEERING:

The first subsystem includes the motor with optical encoder and battery which was chosen based on many hand calculations including the torque, velocity, weight of the entire carriage, and acceleration. The motor was chosen based on the rated continuous current of 1.7 amperes and the rated continuous torque of 19 inch pounds. The optical encoder was an option for the motor chosen and was needed for the positioning system. The batteries were chosen based on the voltage supplied and the durability and longevity of lithium ion batteries. The batteries run in series will supply 24 volts to the motor and will last from six to eight hours of constant operation. Shown below is a diagram of the motor and encoder to be used in the design.



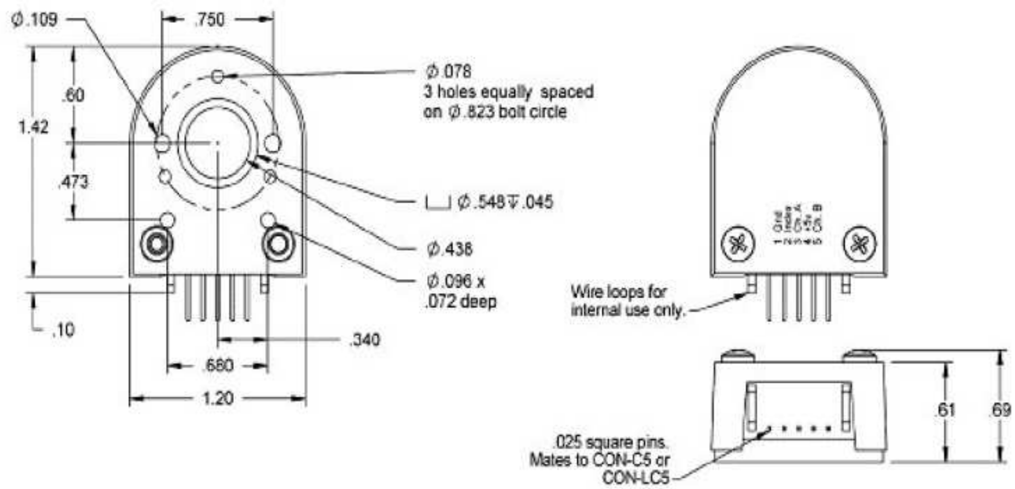


Figure 12 – Midwest Motion Motor (Top) and Encoder (Bottom)

The second subsystem consist of the entire mechanical drive system which moves the carriage forwards and reverse along with the position. A gear will be placed on the shaft of the motor and it will align with the gear rack that will be placed on top of the track via a few strategically located welds. The gear rack and gear was chosen for better control of the carriage along with having a precise positioning system at all times since there will a reading taken every one degree. The gear and gear rack will allow for very low maintenance, installation, and durability over many runs. A photo is shown below on how the gear will come in contact with the gear rack.

Figure 13 – Gear and Gear Rack

The chassis utilizes a lightweight slotted frame that has much versatility along with great strength. The slotted frame has been used many times in the Neptune Technologies plant over the years and has earned a very good reputation for durability, strength, and versatility. The casters used are very inexpensive as well as having more than enough strength to be able to support the 100 pound load with ease. The main casters used are all swivel casters rated at 90 pounds each. Swivel casters were used because of the slight curve the track has as well as being able to not bind up as much if the direction of the cart were reversed. The side casters are fixed casters which will guide the carriage around the track since the casters will be rolling vertically. The casters that will be used on the carriage are shown below. The platform used will be made of an aluminum plate of 0.125” thickness. The aluminum plate was used for the corrosion resistance to the environment as well as having just as much strength as steel but weighing.

Figure 14 – Swivel and Rigid Casters

The platform will carry the motor, electronics, and mast. The platform will have a section under the motor where the platform will be raised and lowered to disengage and engage the motor gear to the gear rack acting as a clutch system. The electronics will be incased in a tower that will have multiple fans to help cool the electronics under a load and high temperatures. The mast will have two parts associated with it. The first part will be the steel pipe that will be welded to a plate that will be bolted to the platform. The second part of the mast will be the PVC pipe that will slide down over the steel pipe and be held in place via nuts and bolts. The figure below shows how small the battery will be that is used in this design.

Figure 15 – 12 Volt Battery Pack

The last subsystem is the data acquisition system that controls the motor and electronics. This system will consist of a motherboard that will control everything on the cart from the velocity to the thermostat controlled fans. The motherboard will be supplied with power from the two lithium ion batteries on board incased in the tower and will communicate with the wireless system that will relay all of the information gathered from the receiver to the base station. The user will be able to evaluate the signal at the precise position and record all of the information gathered and to be analyzed.

Figure 16 – Motor Controller 24V (Fully Assembled)

Neptune Technologies will be providing several parts to the data acquisition system including the test antenna, test water meter, mobile receiver as well as the single board computer. The reason the company is supplying all of the parts because they presently use them in the company's testing procedures. The receiver to be used in this design is shown below.

Figure 17 – Signal Hound Receiver

Project Management:

Critical Design Review – Division of Tasks

In order to operate efficiently as a group, the project was divided up into tasks to which teams were assigned. These teams included Carriage and Wheels, Motor and Clutch, Gear and Rack, Motor/Electronics cooling. These teams focus on their tasks and when needed corresponded with other teams to insure a cohesive design. This system of operation allowed the group to work on multiple tasks at one time but still have the design come together without conflict.

Table 3 - Teams and Tasks

Team	Task	Members
Carriage and wheels	chassis/carriage	Grayson/Kyle
	wheel mounting/adju	Grayson/Kyle
	mast	Cody
Motor and Clutch	motor calc.	Ben/Daniel
	clutch	Ben/Daniel/Grayson
	battery	Grayson (Muhamed)
Gear and Rack	bending rack	Daniel/Kyle
	gear size	Daniel/Kyle
Motor/Electonics cooling	HVAC and cooling	Cody/Kyle

This coordinated effort kept us on schedule with the Design Project Schedule formed at the beginning of the semester. As forecasted in the schedule, we generated the working concepts by June 26 and had moved into the embodiment of final design by July 23. On July 8, Corp 4 presented the different feasible designs and the design that was chosen for further development. All along Neptune has been consulted and informed of any changes to the design.

Proposed Second Semester Deliverables

Corp 4's focus at the beginning of next semester is to complete the prototyping process by testing a gear, rack, motor, and battery assembly. This will allow for the best design to be chosen and further development to continue. Next is to work with the Neptune sponsors to purchase the single board computer and wireless transmitter. Once the electronics are purchased a layout plan will be generated that maximizes the operating efficiency of each unit, regarding heat, UV, and precipitation exposure. The electronics must operate within a specific temperature to avoid damage. This will be maintained by an electric fan cooling system, designed for optimal results, which runs off the onboard battery. Also, to ensure consistent operating performance from the cart, Neptune will be consulted about coding the motor controls in Labview.

CONCLUSION:

In conclusion, the final design meets all of Neptune's requirements. It is easy to assemble and requires low maintenance. Also it has been designed to allow for future modifications and/or upgrades in the following years. This automated data collection system will improve Neptune's overall accuracy of test results and dramatically decrease the time it takes to collect data from the test antenna. Neptune will continue to be informed of new developments in the design and components of the design. Corp 4 is currently transitioning from detail design into prototyping and will begin the manufacturing process early in the Fall 2011 semester.

APPENDIX:

1. DESIGN TEAM'S SCHEDULE

Table 4 – Design Schedule

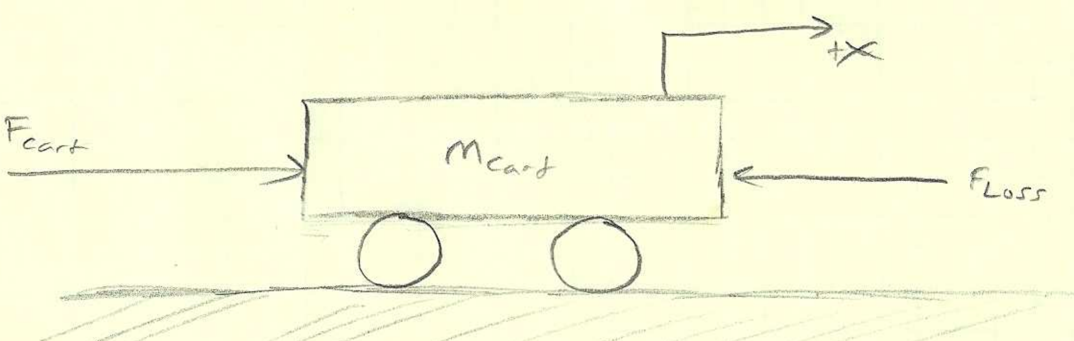
Project Task	Time Required for Task	Start Date	End Date
Define Problem Statement	Day 1	June 5, 2011	June 6, 2011
Identify Users, Needs, Values	Day 1	June 5, 2011	June 6, 2011
Conduct Research, Dom. Knowledge	Week 1	June 5, 2011	June 12, 2011
I.D. Engineering Requirements	Week 2	June 12, 2011	June 19, 2011
Refine Problem Statement	Week 2	June 12, 2011	June 19, 2011
Create Functional Decomposition	Week 2	June 12, 2011	June 19, 2011
Generate Working Concepts	Week 3	June 19, 2011	June 26, 2011
Assess Working Concepts	Week 4, Week 5	June 26, 2011	July 9, 2011
Embodiment of Final Design	Week 6, Week 7	July 10, 2011	July 23, 2011
Develop Manufacturing Plan	Week 8	July 24, 2011	July 31, 2011
Order/ Ship/ Manufacturing Plan	Week 9, Week 10, Week 11, Week 12	July 31, 2011	August 27, 2011
Assemble Working Prototype	Week 13, Week 14, Week 15	August 28, 2011	September 17, 2011
Test and Make Revisions	Week 16, Week 17, Week 18, Week 19	September 18, 2011	October 15, 2011

2. PRELIMINARY MOTOR TORQUE CALCULATIONS

Comprehensive Design 1 | MECH-4240 | July 25, 2011 | 1/4

Preliminary
Motor
Torque and
Acceleration
Calculations
Prior to Prototype Testing

Cart Motion



$$\overset{+x}{\rightarrow}\sum F = m_{cart}\ddot{x} = F_{cart} - F_{Loss}$$

$$F_{cart} = m_{cart}\ddot{x} + F_{Loss}$$

where:

- F_{cart} is the force supplied at the point of contact between the driving gear, which is rotated by the motor, and the circular track.
- m_{cart} is the mass of the cart. $m_{cart} = 50$ kg
- $\ddot{x}$ is the acceleration of the cart.
- F_{Loss} is the approximate frictional force working against the force propelling the cart.

Note that $F_{Loss} \sim 1$ N $\longrightarrow$ see e-mail in corp_4 folder

Finding acceleration

Case 1

The cart starts from rest

$\dot{x}_0 = 0 \text{ m/s}$

and reaches steady state at

$\dot{x}_{ss} = 0.5 \text{ m/s}$

over a given start-up time

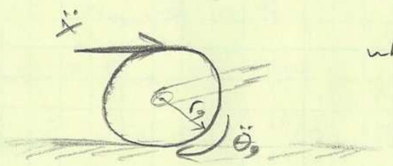
$t_s = 0.1 \text{ s}$

so, acceleration can be found by:

$$\therefore \dot{x}_{ss} = \cancel{\dot{x}_0}^{\,0} + \ddot{x} t_s$$

$$\ddot{x} = \frac{\dot{x}_{ss}}{t_s} = \frac{0.5 \text{ m/s}}{0.1 \text{ s}} = 5 \text{ m/s}^2$$

Finding Motor Torque required for Case 1:



where: r_g is the radius of the driving gear,

$r_g = 1.5 \text{ in} = 0.0381 \text{ m}$

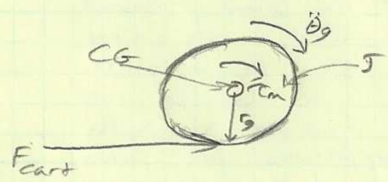
$\ddot{x}$ = cart acceleration $= 5 \text{ m/s}^2$

$\ddot{\theta}_g$ = angular acceleration of driving gear

$$\ddot{x} = \ddot{\theta}_g r_g$$

$$\longrightarrow \ddot{\theta}_g = \frac{\ddot{x}}{r_g} = \frac{5 \text{ m/s}^2}{0.0381 \text{ m}}$$

$$\ddot{\theta}_g = 131.2 \text{ rad/s}^2$$



where: τ_m = required torque from the motor to move the cart.

$$F_{cart} = m_{cart}\ddot{x} + F_{Loss}$$

$$F_{cart} = (50 \text{ kg})(5 \text{ m/s}^2) + 1 \text{ N}$$

$$F_{cart} = 251 \text{ N}$$

$$+\theta\uparrow \sum M_{CG} = J\ddot{\theta}_g = \tau_m - F_{cart} r_g$$

* Continued on next page...

$$J\ddot{\theta}_g = \tau_m - F_{cart} r_g$$

* Note that J is the mass moment of inertia of the geared motor and the driving gear. This will be small compared to the force required to accelerate the cart, so we can assume that it is negligible.

So....

$$J\ddot{\theta}_g \rightarrow 0 = \tau_m - F_{cart} r_g \quad \text{and}$$

$$\tau_m = F_{cart} r_g$$

$$\tau_m = (251\ N)(0.0381\ m) = 9.56\ Nm$$

or for case 1

$$\tau_{m,1} = 84.6\ \text{in-lbs.}$$

For Case 2:

acceleration is zero at the steady state case, so $\ddot{x} = 0$ and

$$F_{cart} = m_{cart}\ddot{x} \rightarrow 0 + F_{LOSS}$$

$$\longrightarrow F_{cart} = F_{LOSS} = \sim 1\ N$$

$$\tau_{m,2} = F_{cart} r_g = (1\ N)(0.0381\ m) = 0.0381\ Nm$$

$$\tau_{m,2} = 0.34\ \text{in-lbs.}$$

- The motor we have selected provides 19 in-lbs of continuous torque and 212 in-lbs peak torque, so we have plenty of torque for both the start-up case and the steady state case. If our approximations for F_{LOSS} are correct and we need less torque, Midwest Motion will let us return the motor and get something more efficient. If it turns out that F_{LOSS} will be higher than 1 N, then our motor will still be able to accomodate the needs of our system.

3. PRELIMINARY POWER AND BATTERY LIFE CALCULATIONS

Comprehensive Design 1	MECH-4240	August 1, 2011	1/2

Preliminary Power
and Battery Life
Calculations

- The selected motor for the final design provides 19 in-lbs continuous torque at a rated current of 1.7 A. In preliminary test runs using a dynamometer, the steady state force required to move the carriage under a 100 lbs load is 7 lbf. Since the driving gear, which is connected to the motor shaft is ~3 in in diameter, the required motor torque at steady state would be:

$$\tau = Fr \approx (7\ \text{lbf})(1.5\ \text{in}) = 10.5\ \text{in-lbs}$$

so the motor should have enough torque to move the carriage at steady state velocity and will probably use approximately 1.7 A of current or slightly less.

For a conservative estimate, let's assume that the power draw on the battery by the motor is ~1.7 A.

- The selected power source is two 12 V Lithium-ion batteries wired in series to provide a battery life between recharges of 22 amp-hours at 24 VDC.

Typically, batteries should not be completely drained between recharges as this diminishes the life of the battery. For these calculations let's drain the battery 65% of its life between recharges. Then:

$$(22\ \text{amph})(0.65) = 14.3\ \text{amp-hours of}$$

battery life between recharges.

Since the motor is drawing 1.7 A continuous current, this yields:

$$\frac{(14.3\ \text{amp-hours})}{(1.7\ \text{amps})} \approx 8.41\ \text{hours}$$

of battery life in between recharges.

4. COMPONENT SPECIFICATION SHEETS

DEBEN 12 VOLT LITHIUM ION BATTERY SPECIFICATIONS

Lithium battery packs offer tremendous advantagesover traditional sealed lead acid SLA batteries.

The Lithium Ion Power Packs from Deben will make you wonder how you managed to carry large and heavy sealed lead acidbattery packs. Lithium battery packs have improved power delivery as well as beingone third of the weight when compared to the sealed lead acidequivalent.The lightweight battery pack is enclosed in an attractive greenand black shock absorbing case, designed to slip easily into a largepocket or into the included outer canvas case.

Fuel Gauge

The built in fuel gauge lets you know how much power is left in yourbattery. Simply press the button to illuminate the display giving anaccurate indication. Intelligent fuel gauge let's you know the power status of your Tracer battery.

Simply press the button to display the lights

3 green and 2 red	75 -100% capacity
2 green and 2 red	50 -75% capacity
1 green and 2 red	20 - 50% capacity
2 Red	10 - 20% capacity - Recharge as soon as possible
1 Red	Less than 10% - battery about to electronically
No Lights	Empty - recharge within 12 hours

OVERCHARGE	✔
OVER TEMPERATURE	✔
OVER CURRENT	✔
DEEP DISCHARGE	✔
SHORT CIRCUIT	✔

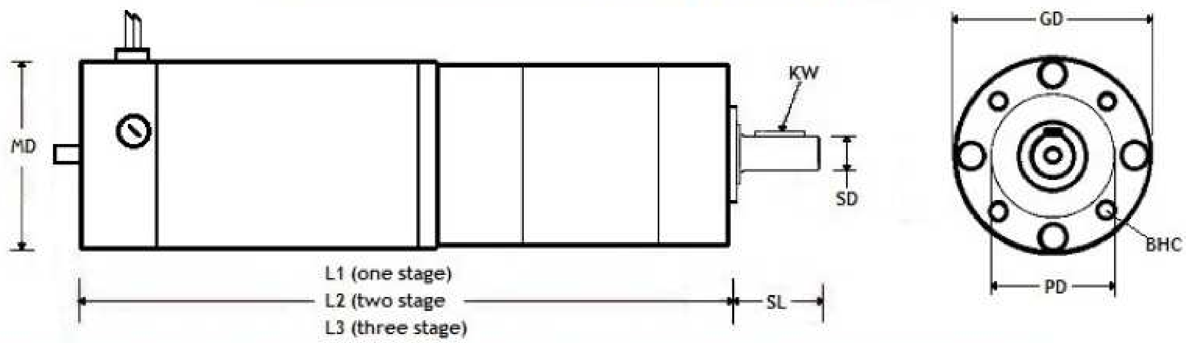
This battery pack is supplied with a purpose designed mains charger, a12V DC vehicle charger and cigar connector for 12V lights.

- Suitable for many uses in addition to high power 12V lighting.
- Purpose made adaptors supplied to customers requirement (ring for details).

Lithium Rating	Weight		Light Duration 100W Bulb		Light Duration 50W Bulb	
	SLA	Lithium	SLA	Lithium	SLA	Lithium
22Ah	6300g	1250g	90 min	2 hrs 10mins	2 hrs 50mins	4 hrs 20mins

MIDWEST MOTOR SPECIFICATIONS

Date: 08 Feb, 2010 Prepared for: Production
Model Number: MMP D22-376H-24V GP52-016



INTEGRAL BRAKES AND OPTICAL ENCODER OPTIONS AVAILABLE – SEE PAGES 2 AND 3 FOR DETAILS

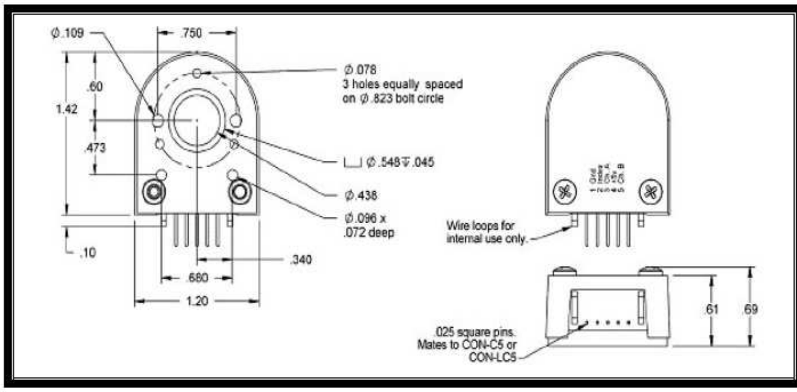
DIMENSIONS:	(Note: Center of output shaft contains an M-4 threaded hole)
MD = 2.25" (57mm)	SL = 25mm (21mm usable)
L2 = 7.20" (183mm)	GD = 2.047 (52mm)
KW = 4 x 4 x 16mm long	PD = 32mm, pilot length = 3mm
SD = 12mm; +0, -21µm	BHC (dia) = M5 x 10mm deep (4 ea) on a 40mmØ BC

DC MOTOR PERFORMANCE PARAMETERS:	VALUE	UNITS	TOLERANCE
Rated DC Voltage	24.0	DC VOLTS	-----
Rated Continuous Current	1.7	AMPERES	-----
No-Load Speed	2200	RPM	MAX
Rated Speed	1900	RPM	+/- 15%
Rated Continuous Power out	35	WATTS	+/- 15%
Rated Continuous Torque	25.0	OZ-IN	-----
Peak Torque (motor only)	150	OZ-IN	-----
No-Load Current	0.27	AMPERES	MAX
Back EMF Constant (Ke)	10.8	V/KRPM	+/- 10%
Torque Constant (Kt)	14.6	OZ-IN/AMP	+/- 10%
DC Armature Resistance (@1.5 amps)	3.8	OHMS	+/- 15%
Armature temperature	155	DEG. C	MAX
PLANETARY GEARMOTOR OUTPUT PARAMETERS:	**VALUE**	**UNITS**	**TOLERANCE**
Gearhead Ratio (exact)	15.88 : 1		
Gearmotor Rated Continuous Torque	19	IN-LBS	MAX
Gearmotor Rated Peak Torque	212++	IN-LBS	MAX
Gearhead Shaft Output Speed (at full-load)	120	RPM	-----
Gearhead Standard Backlash	45	ARC MINUTES	MAX
Gearhead Efficiency	75%	-----	-----
Gearmotor Total Weight	58	OZ	MAX

++ All Peak Torque Values are dependent upon duty. Consult our Sales Offices for details.

MIDWEST MOTION ENCODER SPECIFICATIONS

Option 1: Optical Encoder **Consult our Sales Office for Pricing**



Interconnects / Functions

Pin Number	Function	Color
Pin 1	Ground	Brown
Pin 2	Index	Violet
Pin 3	Channel A	Blue
Pin 4	+ 5 Volts	Orange
Pin 5	Channel B	Yellow

****Encoder resolutions available: 32 PPR, 100 PPR, 250 PPR, 500 PPR, 1024 PPR**

(Use suffix "EU-xxx" after model # to designate the encoder and its resolution)

The standard modular encoder option, mounted integrally to the back of the motor,
includes an index pulse, and 12" long flying leads with connector - mounted and tested before shipping.

POLOLU MOTOR CONTROLLER

Simple High-Power Motor Controller 18v15 or 24v12, fully assembled.

Key Features

- Simple bidirectional control of one DC brush motor.
- 5.5 V to 30 V (18v7, 18v15, and 18v25) or 40 V (24v12 and 24v23) operating supply range.
- 7 A to 25 A maximum continuous current output without a heat sink, depending on controller model
- Four communication or control options:
- USB interface for direct connection to a PC.
- Logic-level (TTL) serial interface for direct connection to microcontrollers or other embedded controllers.
- Hobby radio control (RC) pulse width interface for direct connection to an RC receiver or RC servo controller.
- 0–3.3 V analog voltage interface for direct connection to potentiometers and analog joysticks.
- Simple configuration and calibration over USB with free configuration program (Windows 7, Vista, Windows XP, and Linux compatible).

Additional Features

- Adjustable maximum acceleration and deceleration to limit electrical and mechanical stress on the system.
- Adjustable starting speed, maximum speed, and amount of braking when speed is zero.
- Optional safety controls to avoid unexpectedly powering the motor.
- Input calibration (learning) and adjustable scaling degree for analog and RC signals.
- Under-voltage shutoff with hysteresis for use with batteries vulnerable to over-discharging (e.g. LiPo cells).
- Adjustable over-temperature threshold and response.
- Adjustable PWM frequency from 1 kHz to 22 kHz (maximum frequency is ultrasonic, eliminating switching-induced audible motor shaft vibration).
- Error LED linked to a digital ERR output, and connecting the error outputs of multiple controllers together optionally causes all connected controllers to shut down when any one of them experiences an error.
- Field-upgradeable firmware.

USB/Serial features:

- Controllable from a computer with native USB, via serial commands sent to the device's virtual serial (COM) port, or via TTL serial through the device's RX/TX pins.
- Example code in C#, Visual Basic .NET, and Visual C++ is available in the Pololu USB Software Development Kit
- Optional CRC error detection to eliminate communication errors caused by noise or software faults.
- Optional command timeout (shut off motors if communication ceases).
- Supports automatic baud rate detection from 1200 bps to 500 kbps, or can be configured to run at a fixed baud rate.
- Supports standard compact and Pololu protocols as well as the Scott Edwards Mini SSC protocol and an ASCII protocol for simple serial control from a terminal program.
- Optional serial response delay for communicating with half-duplex controllers such as the Basic Stamp.
- Controllers can be easily chained together and to other Pololu serial motor and servo controllers to control hundreds of motors using a single serial line.