

Regenerative Electric Driven Power Cart

Michigan State University

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Sponsors:

Great Lakes Controls and Engineering
Conceptional Innovations

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Executive Summary

The purpose of this project is to develop a control system that will allow a user to operate a 24 VDC motor to move an industrial cart into position to pick up parts, allowing for speed control. This cart will be used in large manufacturing plants with assembly lines, where the parts will need to travel a long distance. The cart will then be tugged accross the plant to a secondary location. During the tug, power is regenerated to charge the batteries. Additionally, we added an object detection sensor to the front of the cart as a safety feature. This system will have two major benefits to the company that purchases them. First, the user will have to exert far less force in moving these heavy loads and second, the company will save money on electricity costs, which would increase revenue and make the company greener.

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Chapter 1: Introduction and Background

1.1 Introduction

Great Lakes Control Systems & Engineering is a Michigan-based engineering company with over 30 combined years of expertise in electrical engineering, control system design, machine building, and robotic integration. They are looking to maximize profit and productivity through quality engineering and service for their customers. Along side them is another company, Conceptual Innovations (CI). CI focuses on engineering, consulting, and custom manufacturing that delivers cost effective, technical solutions. Specializing in development, testing, automation and design, CI provides cutting edge expertise to companies all over the nation. To further their expertise in electrical and control system engineering, Great Lakes Control Systems & Engineering and Conceptual Innovations are proud to be sponsors for this Regenerative Electric Driven Power Cart project at Michigan State University.

At Conceptual Innovations (CI), the Drive Cart is an electric driven cart designed to eliminate risk of overexertion injuries while increasing productivity. The Drive Cart provides a solution for materials transport. Using the Drive Cart to transport parts includes the manual movements of carts from the Tug Train to the production area. This means that the loads must be light enough for operators to manually push without the risk of injury due to overexertion. Due to this problem, safety measures must be placed in order to reduce the risk of injury. With the Drive Cart, the loads can be easily moved to the production area in both forward and reverse direction, however, these carts have no regenerative system. This means that the carts have to be charged during the workday, slowing production significantly. With the introduction of the Regenerative Electric Power Driven Cart, there will be a regenerative feature when moving the carts from the Tug Train to the production area.

1.2 Background

Due to the intensive working conditions, CI and Great Lakes Control Systems & Engineering has designed these power carts to reduce the risk of physical exertion

injury. More specifically, these carts hold loads of up to four tons, which is far more than what the average worker can handle. Previous models of these carts have been implemented, and have successfully worked. These carts can move loads for up to four hours before having to be recharged. This increases efficiency as well as safety of the workers.

CI and Great Lakes Control Systems & Engineering have put in a lot of effort to further their optimization of this design. Having multiple different retro designs and schematics show the different approaches taken to improve their model. With these upgrades, they have made a successful step in modernizing and maximizing efficiency.

According to CI, the Drive Cart is a unique, one of a kind solution for material transport. The Drive Cart is the material handling industries' only motor powered tow-able cart that is able to transport materials from the Tug Train to the designated materials location. In today's industry, Tug Trains pull loads far greater than what an operator can manually push, reducing cart loads and productivity. With the addition of the Drive Cart, operators can carry loads equal to the Tug Train, allowing for maximized cart loads and efficiency, as well as improving customer satisfaction.

As the materials handling industry grows, the room for improvement grows. Taking the necessary steps for adding regenerative capabilities as well as IR sensors for maximizing safety are key steps for maximizing efficiency and customer satisfaction. As the world becomes more technologically advanced, the industry slowly advances as well. Research, design, and development gives the best opportunity to create a product that will guarantee product efficiency, while ensuring customer safety, even if that means straying away from the technology currently being used.

1.3 Objectives

The design team's goal for this project was to provide a solution to design an regenerative power driven cart that can move with up to four tons of equipment on it. The designed system must fulfill the customer's requirements. Currently, the power carts being used today have no regenerative capabilities in it. The Regenerative Electric Power Driven Cart involves inserting a 0.5 horsepower motor with regenerative capabilities. The motor is then programmed using C/C++ languages

and powered by a motor controller, a microcontroller, and charged by a charge controller. This enables the user to have full control of the cart, controlling both speed and direction of the cart. One 12V, 40A battery is used to power the cart. As the Power Cart is being dragged along by the Tug Train, the Power Cart regenerates power from the friction between the motor wheel and the directional wheel. This power is then captured by the charge controller and is used to charge the 24V battery. This allows for workers to use the Power Cart for a full workday before having to recharge the cart overnight. In addition to regenerative feature, an extra safety stop feature was added by the team to ensure that safety is first for the workers. This safety feature involves the installation of two IR sensors that are placed on the front of the cart. These sensors detect any objects within 0.5 meter distance and will automatically stop. This prevents injuries during the work day and improves safety of the workplace. With both the regeneration and safety features installed onto the new cart, CI and Great Lakes Control Systems & Engineering can continue to give customers cutting edge, and efficient products, while ensuring the safety of the workplace.

1.4 Effect on Industry

With the completion of the design, the project became the first of its kind in the materials distribution industry. As discussed in the background section, there is no data showing that any similar project has been done in the industry that is capable of having regenerative features, as well as having sensors to detect objects in front of the cart. This will bring more work efficiency as well as safety in the workplace and create a new standard for future improvements for potential growth.

Chapter 2: Exploring the Solution Space and Selecting a Specific Approach:

2.1 Fast Diagram

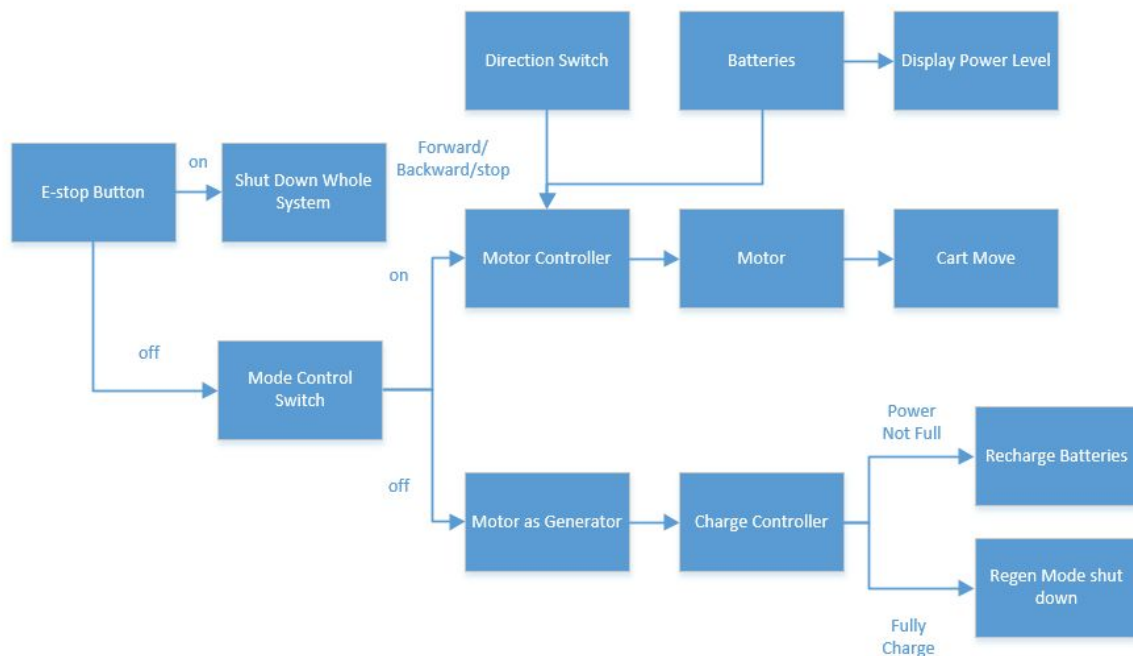


Figure 1: FAST Diagram

The FAST Diagram above in Figure 1 shows the many different subsystems required during the regenerative electric power driven cart project. There are many different functions needed to be completed in order to achieve the project's requirements. The main functions in this system include implementing an emergency stop to turn the system on and off, control the direction of which the motor is moving, and implementing regenerative capabilities. We implemented our FAST diagram through multiple different tests and talking with our facilitator, Bingseng Wang, to help guide us in the right direction. With this, we decided on a single design, which ultimately worked for our project.

2.2 Critical Customer Requirements and Selecting a Solution

Solution Selection Matrix						
Engineering Criteria	Importance	Possible Solutions				
		Control the torque limit	Adjust the controller settings	Replace battery	Connections Check	Emergency Break
Brake and Acceleration Speed Error	5	9	9	1	3	9
Cart Overspeed	5	9	9	1	3	9
Cart Moving in wrong direction	5	1	9	1	3	9
Cart cannot Move	3	3	9	3	3	1
Cart cannot Stop	4	3	9	1	3	9
Batteries cannot recharge	4	1	9	9	9	1
Batteries meter indication down	2	1	1	9	3	1
Batteries life exhausted	2	1	1	9	1	1
Batteries overcharge	3	1	9	9	9	1
Total Score		127	265	127	137	185

Figure 2: Solution Selection Matrix

Figure 2 shown above is our solution selection matrix. The matrix has all of the potential problems and concerns that our customer is concerned about. They are all rated, with 9 being a high, and 1 being a low. The most important concern that we needed to address during the project was adjusting the controller settings followed by the emergency stop. We found these to be the most important as the cart needs to be user friendly, and safety is extremely important when handling equipment as heavy as four tons. The team decided to break and rate these five categories down and provide possible solutions for each category. These categories can be seen below.

1. Control the Torque Limit

Controlling the torque on the power cart consists of controlling the instant acceleration and break. It also adjusts the overall cart speed and is essential to prevent over-speeding. In addition, controlling acceleration and break can help manage the equipment on the cart from falling over and causing a safety hazard. This torque limit can be adjusted through the potentiometer that is installed. The potentiometer is a six-speed adjuster that can speed or slow down at any given time. Below is a picture of the 6-speed, multi-turn potentiometer.

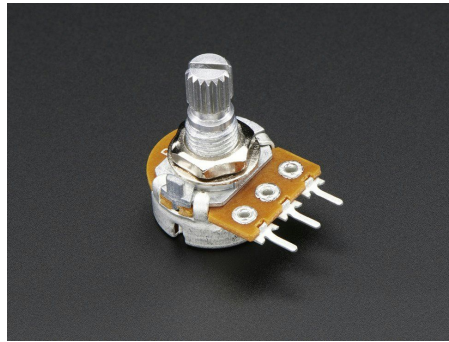


Figure 3: Multi-Turn Potentiometer

2. Adjusting Controller Settings

Adjusting the controller settings is one of the most essential design aspects that our team needed to accomplish. The control settings include, speed adjustment, emergency stop, IR sensor settings, regeneration settings, and forward/reverse settings. These all needed to be preinstalled for the customer so that the product will be as easy as possible to handle.

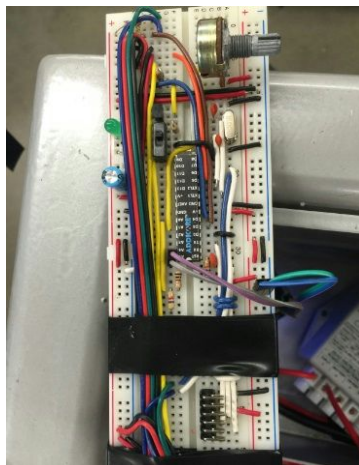


Figure 4: Control Breadboard with all Control Settings

3. Battery Replacement and Charging

The power cart consists of a 12V, 31 Ah battery that lasts for about two hours before needing recharging. With the regenerative capabilities, the battery can last a full work day without having to be recharged. Several precautions needed to be made to prevent any damages to the product. A charge controller with regulation was implemented to prevent overcharging and regulate the voltage and current levels.



Figure 5: 12V Battery used to Power the Power Cart

4. Connections Check

Checking connections for any wiring error was one of our more important objectives. If any wiring error was made, the circuit could have been shorted and potentially burned out. With the schematic seen in section 3.4.1, the wirings were all carefully placed and inserted. After further testing, we made sure that all wiring connections were proper and fixed any mistakes. Below in Figure 6 is a Wien diode wiring connection made through soldering.

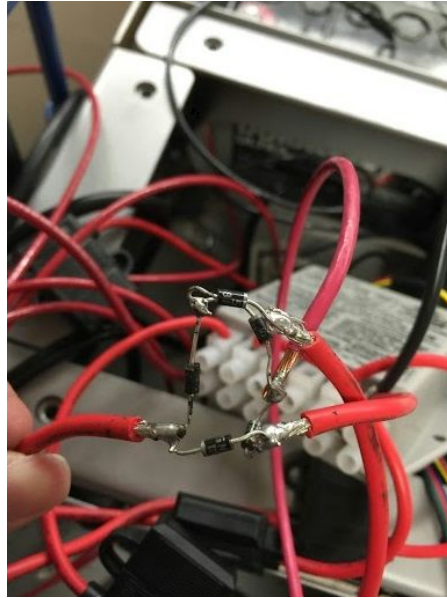


Figure 6: Wien Diode Connection

5. Emergency Break

Emergency breaking is an essential to safety in the workplace. Having emergency breaks prevents carts from trampling over workers or hitting random objects.

Installed is an IR sensor that will detect objects within a 0.5 m distance. If an object is within that distance, the cart will come to an immediate stop. Below in Figure 7 is a picture of the IR sensor.



Figure 7: IR Sensor

2.3 Budget

Number	Manufacturer	Item Name	Quantity	Cost (US\$)
1	SyRen®	50A Regenerative Motor Driver	1	\$119.99
2	Flexcharge®	Charge Controller (NC25A-12)	1	\$90.00
3	Qiorange®	Fuse holder in-line AWG	4	\$2.79
4	Foxnovo®	assorted auto car mini flade fuses.	4	\$0.53
5	Geeetech®	Infrared proximity switch module	2	\$15.98
6	Atmel®	ATmega328P-PU DIP-28 Chip	1	\$4.50
7	UlincoS®	Momentary Push Button Switch U19D1	1	\$8.99
8	Uxcell®	AC ON-OFF-ON 3 Positions Toggle Switch 3PDT	2	\$17.98
9	Uxcell®	PCB Mount Screw Terminal Blocks	20	\$3.98
10	Bay Area Circuits®	PCB Manufacture	1	\$52.50
11	Uxcell®	22pF 50V Low Voltage Radial Ceramic Disc Capacitors	3	\$0.17
12	Uxcell®	Quartz Crystal Oscillator 16MHz	1	\$0.58
13	Arduino®	USB 2 Serial Converter Micro	1	\$19.95
Total				\$337.94

Figure 8: Budget for our Project

During this project, our design team was given \$500 to use on research, parts, prototyping, and testing. One of our goals was to create a low-cost power cart so that the customer can mass-produce these and implement them in the industry. The design team went through several different suggestions and came to a single solution that we thought fit best.

The design team estimated the costs to be roughly \$400 with all prototypes and testing completed. Figure 8 above shows the budget of our team. Our project totaled to \$337.94, with most of the costs going towards the motor controller and PCB board. Most of the materials were already to given to us by our sponsors, which made reaching the budget fairly easy. This made our total cost under our projected budget costs, making this option really effective for our customer.

2.4 Design Schedule (GANTT Chart)

		Task Mode ▾	Task Name ▾	Duration ▾	Start ▾	Finish ▾
1			Project	69 days	Mon 1/25/16	Thu 4/28/16
2	✓		Define The Problem	3 days	Mon 1/25/16	Wed 1/27/16
3	✓		Meet with Sponsor	1 day	Thu 1/28/16	Thu 1/28/16
4	✓		Brainstorm	7 days	Tue 2/2/16	Wed 2/10/16
5	✓		Research and generate ideas	9 days	Tue 2/2/16	Fri 2/12/16
6	✓		Pick Motor	3 days	Tue 2/2/16	Thu 2/4/16
7	✓		Pick Motor Controller	3 days	Fri 2/5/16	Tue 2/9/16
8	✓		Pick Charge Controller	3 days	Tue 2/9/16	Thu 2/11/16
9	✓		Identify criteria and constrain	8 days	Wed 2/3/16	Fri 2/12/16
10	✓		Explore possibilities	8 days	Tue 2/2/16	Thu 2/11/16
11	✓		Select the approaches	2 days	Sat 2/20/16	Mon 2/22/16
12	✓		Develop design proposal	2 days	Tue 2/23/16	Wed 2/24/16
13			Model of prototype	21 days	Thu 2/25/16	Thu 3/24/16
14			Coding the motor controller	14 days	Thu 2/25/16	Tue 3/15/16
15			Wiring controllers to motor and batteries	7 days	Tue 3/15/16	Wed 3/23/16
16			Test and evaluate	7 days	Wed 3/23/16	Thu 3/31/16
17			Connect all components to control panel	2 days	Wed 3/23/16	Thu 3/24/16
18			Connect system to cart	3 days	Thu 3/24/16	Mon 3/28/16
19			Refine	3 days	Fri 4/1/16	Tue 4/5/16
20			Create final prototype	10 days	Wed 4/6/16	Tue 4/19/16
21			Communicate result	7 days	Wed 4/20/16	Thu 4/28/16

Figure 9: Gantt Chart of the Project

To help schedule our project so that we met certain deadlines, we created a Gantt chart. This Gantt chart shows all of the objectives and deadlines to be completed. The highlighted areas are those of the critical path, which are the main path to be followed. Everything else are smaller objectives that help lead to the next critical path. Overall this project took 69 days to complete, and this Gantt chart helped the group finish objectives within the designated schedule.

2.4 Final Overall Design

Figure 10

Above in Figure 10 is our final overall design. The motor controller, charge, controller, and microcontroller are all hooked up together and wired onto the control panel. These three components are all placed in a small 24"x 10" x 8" box which powers the entire cart. Below the cart is the motor which powers the entire cart. The motor regenerates power as it is put into regen mode, which charges the battery. The cart is programmed and designed to run a full work day without having to plug into the wall to charge.

Chapter 3 – Technical Description of Work Performed

3.1 Motor Driving System

The primary function of our power cart is to have a functioning motor driving system to power the cart. The motor driving system uses a motor to drive the power cart which can carry up to four tons of equipment.

This system has the following functions:

- Forward and backward directional movement
- Acceleration and deceleration control
- Six setting speed control
- Three operation modes: drive mode/regeneration mode/off mode.
- Emergency stop
- Safety IR sensors to conduct an emergency stop when objects of a certain distance are in front of the cart.

3.1.1 Motor Introduction

The motor used in this project is a PMDC brushed motor shown in the following picture.



Figure 11: PMDC Brushed Motor

Below are the specifications of the motor:

- Rated Voltage: 24V
- Speed: 69rpm
- Rated Torque: 218lb-in

- Amps: 15A
- power: 0.4hp
- Gear Ratio: 36

Figure 12 shows the wire connections of the PMDC motor.

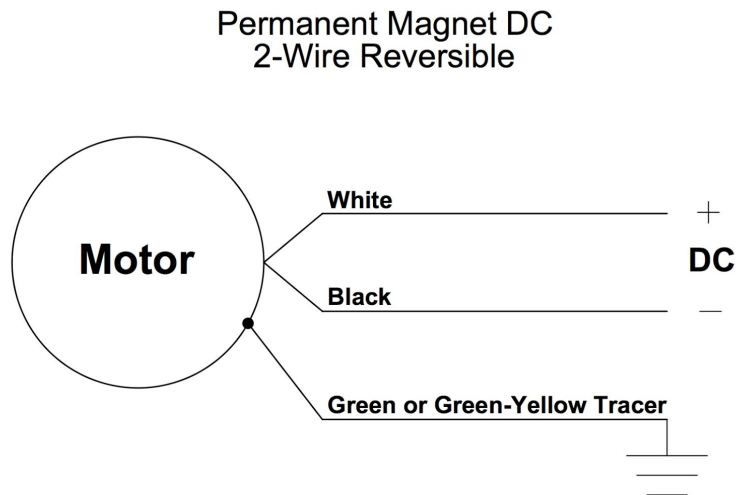


Figure 12: PMDC Motor Connections

These connections show the basic wiring from the motor to the DC battery. the green wire is ignored as it is the ground wire.

3.1.2 Motor Driver

The motor driver used in this project is the SyRen 50A 6V-30V brushed motor driver as the following picture.



Figure 13: SyRen Brushed Motor Driver

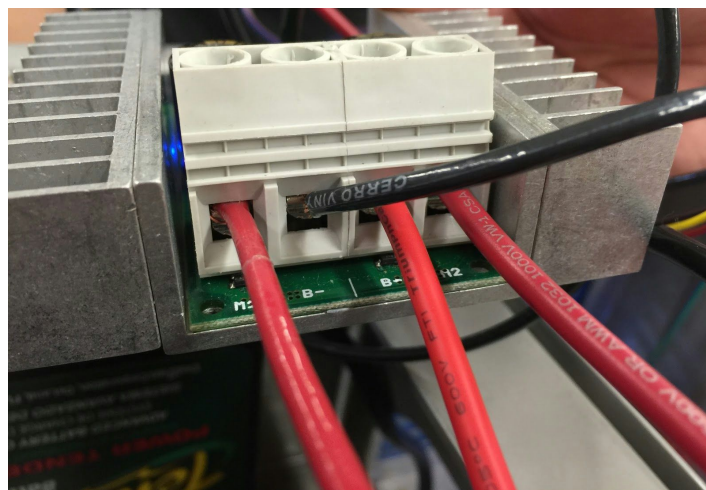


Figure 13: Terminals M1 and M2 of the SyRen Motor Driver

As shown in Figure 13 above, terminals M1 and M2 are the motor terminals which are connected to the positive and negative terminal of the PMDC brushed motor. The terminals B- and B+ are the battery terminals which are connected to the positive and negative terminals of the batteries.

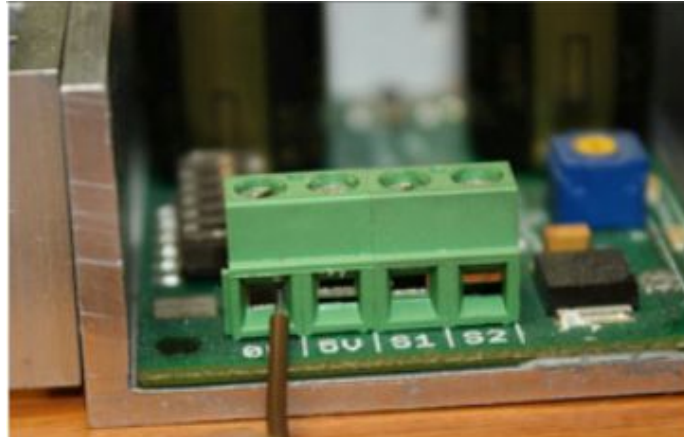


Figure 14: S1 and S2 Terminals of the SyRen Motor Driver

As shown in Figure 14, the terminals S1 and S2 are the signal input terminals which are connected to the microcontroller designed for this project. The terminals 0V and 5V are the power terminals which can provide 5V voltage to power the microcontroller.

The motor driver has several operation modes based on the settings and the goals. Based on the following specifications we have the ideal design for the power cart :

- Lead-Acid Battery
- Input signal, TTL RS232, serial data using a microcontroller
- Single byte setting for each motor speed command
- Single SyRen driver is controlled

Based on the above, the following mode was chosen and can be seen below in Figure 15:

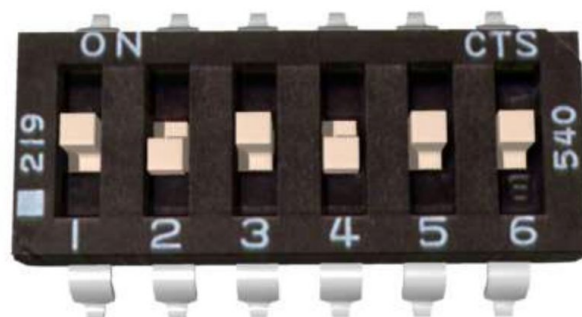
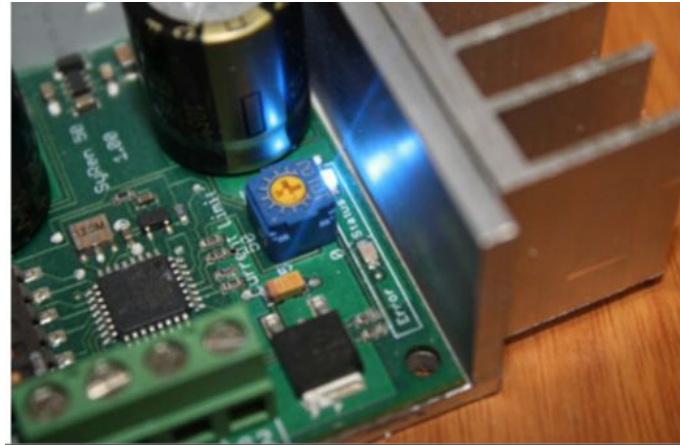


Figure 15: Signal Settings for the SyRen Driver

The driver has a status LED when it is operating in the right way. This status light flashes blue and can be seen below in Figure 16.



Status LED on

Figure 16: Status LED Light On

3.1.3 Motor Driver Control Board (Atmega328p and PCB Board)

The ATmega328 is a single chip micro-controller created by Atmel and belongs to the megaAVR series. This microcontroller combines 32 KB ISP flash memory with read-while-write capabilities, 1 KB EEPROM, 2 KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes.

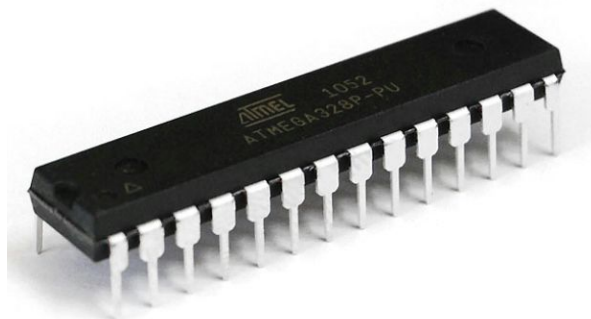


Figure ???. Atmega328p Micro Controller

This is perfect for our design. We use 7 digital Pin and 2 analog Pin to achieve our design functionalities.

```
//Digital Pin
#define eStopButtonPin      3
#define eStopLedPin         4
#define directionSwitchPin  5
#define IRSensorPin_1       6
#define IRSensorPin_2       7
#define ObstacleDetectionEnablePin 8
#define motorOutput         9

//Analog Pin
#define batteryPin          A0
#define speedPin            A1
```

We use the library that SyRen provided to drive the SyRen Motor Driver.

```
#include <SyRenSimplified.h>
```

The SyRen Motor Driver can take the serial signal as its input, so in order to communicate the Motor Driver and the Atmega328p, we use baud rate of 9600 for the soft serial output.

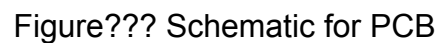
```
//Motor Driver
SoftwareSerial SWSerial(NOT_A_PIN, motorOutput);
SyRenSimplified SR(SWSerial);
SWSerial.begin(9600);
```

Then, we can use `SR.motor(power);` to drive this motor driver. For the direction controll, we can set the `power` to be a negetive number, this will tell the motor driver to run opposite direction. In real life, we cannot just stop the motor or drive the motor immediately, so we need write an algorithm to solve this problem and provide the acceleration and the deceleration. We create a function as below.

```
void runMotor(int speedInput, float accelerationDelay) {
    if (abs(speedInputPre - speedInput) > 50) {
        if ((speedInputPre <= 0) && (speedInput >= 0)) {
            for (int power = speedInputPre; power <= speedInput; power++) {
                SR.motor(power);
                delay(accelerationDelay);
            }
        }
        else if ((speedInputPre >= 0) && (speedInput <= 0)) {
            for (int power = speedInputPre; power >= speedInput; power--) {
                SR.motor(power);
                delay(accelerationDelay);
            }
        }
    }
    else {

```

A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. After the breadboard works perfectly, we design the PCB. The schematic(Figure???) and PCB design(Figure ???) is shown below.



A bonus feature that our team included was the infrared (IR) sensors. The sensor are used to ensure safety in the workplace. The sensors were installed on the front of the cart to sense any unexpected obstacles or people, and then performing an emergency stop. The IR sensor is programmed to stop when it detects objects

within 0.5 m. Below in Figure 18 is a picture of the IR sensor installed on the front of the cart.



Figure 18: IR Sensor Installed in the Front of the Cart

The IR sensor we chose was the Geeetech Infrared Proximity Switch Module, which is fully compatible with Atmega328p micro controller seen in the picture below.

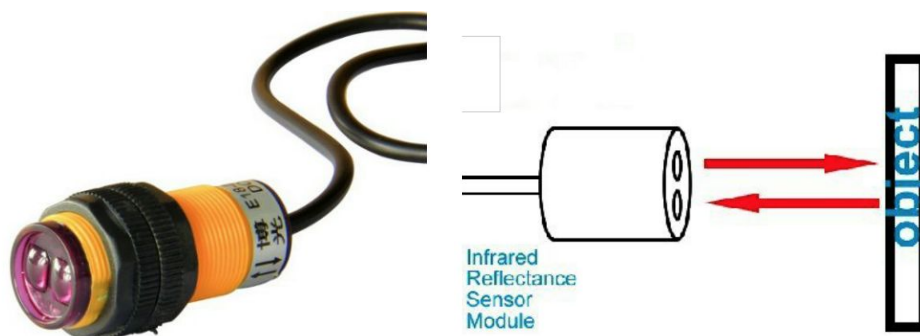


Figure 19: Geeetech IR Proximity Switch Module Connection

The Geeetech Infrared Proximity Switch Module has three wires (VCC, GND and OUTPUT). It is connected to the OUTPUTs, D6 and D7, which located on Pin 12 and Pin 13. We then used the code, `digitalRead(IRSensorPin)`, to show the IR sensor output.

```

void detectObstacle() {
  if (digitalRead(ObstacleDetectionEnablePin)) {
    //IR Sensor
    if ((digitalRead(IRSensorPin_1) == LOW) || (digitalRead(IRSensorPin_2) == LOW)) {
      ObstacleDetected = 1;
    }
    else {
      ObstacleDetected = 0;
    }
  }
  else {
    ObstacleDetected = 0;
  }
}

```

3.2 Regeneration System and Power Supply

The regeneration system is able to charge the batteries when the cart is not in use and is toggled to regeneration mode. The power comes from the rotation of the motor which enables regeneration mode and being wired to the batteries by a charge controller with a voltage regulator in it. The charge controller should be able to output steady voltage because the voltage produced by the motor is not. The other circuit components needed in this system are fuses and diodes. The fuses are implemented for safety purposes so that when the current through the regeneration system over 3A, the circuit will open. The diodes direct the current flow so that the current always flow to the battery.

3.2.1 Battery Introduction

The battery used in this project is the 12V, 31Ah Lead-Acid battery. This battery can be seen below in Figure 20.



Figure 20: 12 V, 31Ah Lead-Acid Battery

The battery state of charge versus voltage can be seen below in Figure 21 C/5 curve. The voltage of battery vary between 10.2V to roughly 12.2V, relating to the battery level. When we design and program the battery level indicator (show percentage in digital display) controlled by Atmega328p microcontroller, we added a voltage divider to reduce battery voltage to certain value that is acceptable to Atmega328p microcontroller. The Atmega328p microcontroller will detect that reduced voltage and calculate the percentage level based on this formular $(0.2305x^4 - 19.53x^3 + 622.01x^2 - 8811.5x + 46779)$. The algorithm used in programming code is shown below.

```
String ReadBatteryLevel(bool force) {
    if (eStopLedState || force) {
        double voltage = analogRead(batteryPin) / (1023.00 / 28.00);
        BatteryLevel = 0.2305 * pow(voltage, 4) - 19.53 * pow(voltage, 3) + 622.01 * pow(voltage, 2) - 8811.5 * voltage + 46779;
        if (BatteryLevel < 0) {
            BatteryLevel = 0;
        }
        if (BatteryLevel > 100) {
            BatteryLevel = 100;
        }
    }
    return String(BatteryLevel) + "%";
}
```

Batteries

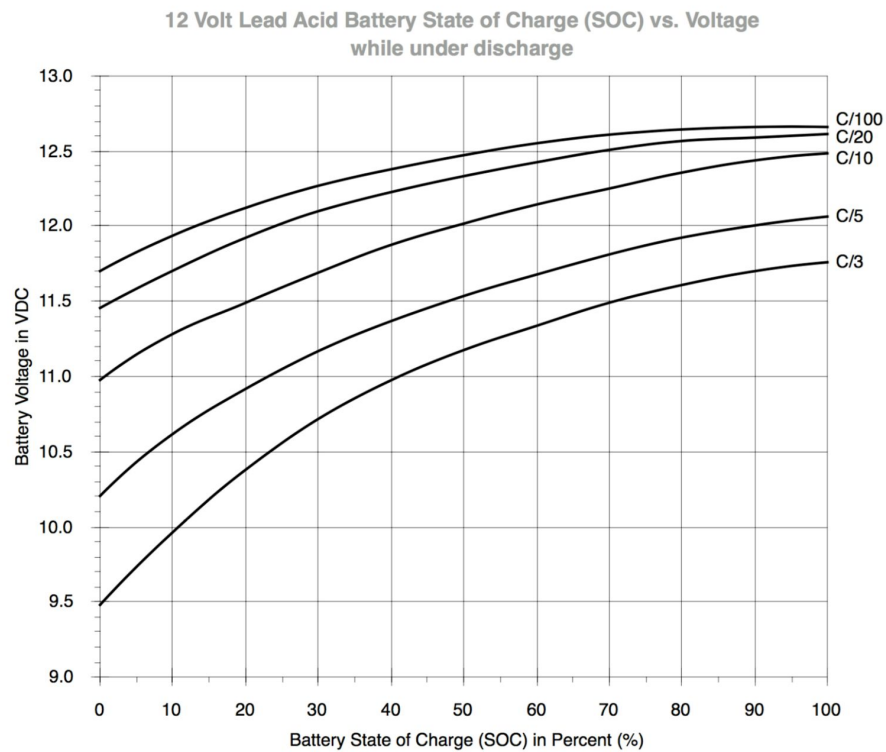


Figure 21: Lead-Acid Battery State of Charge vs Voltage under Discharge

3.2.2 Charge Controller

The charge controller our team used in this project was the Flexcharge NC25A Ultra High Efficiency Charge controller. This can be seen below in Figure 22.

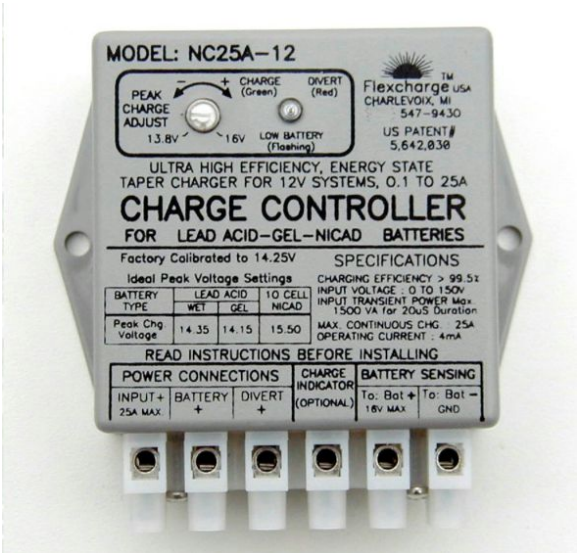


Figure 22: Charge Controller

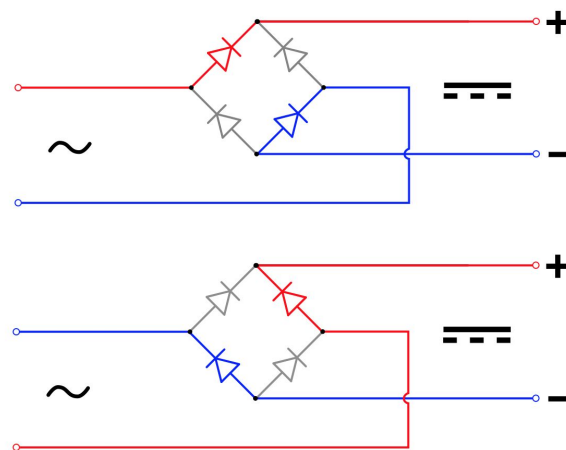
Multiple connections were made to each terminal to ensure charging of the charge controller. The input terminal was connected to the positive terminal of the motor. The battery+ terminal was connected to the positive terminal of the battery. The to bat+ terminal was connected to the positive terminal of the battery. The to bat- terminal was connected to the negative terminal of the battery and the negative terminal of the motor.

The specifications of the charge controller are as follows:

- A status LED flashing when the battery is not fully charged.
- Overcharge protection.
- Ultra high charging efficiency 98.9% to 99.8%.
- Output steady voltage for battery charging.

3.2.3 Diode Bridge

A diode bridge was added between the connection of the motor and the battery to make sure that no matter which direction the motor rotates, the current can flow to the battery. This will increase the recharging efficiency by both toggled directions making the batteries charge.



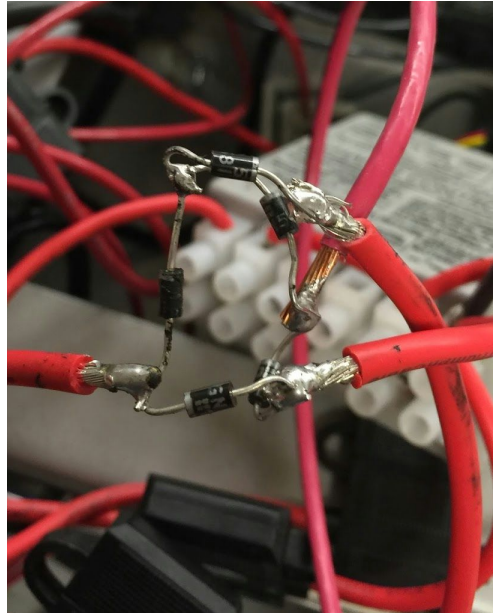


Figure 23: Diode Bridge

The diodes used are 1N4148 diodes. The specifications of 1N4148 include:

- Forward current: 300mA - 500mA.
- Forward voltage: 0.62V - 0.72V.
- Peak reverse voltage: 100V.

3.2.4 Charging Efficiency

There are limitations of the charging efficiency. The sponsor did not provide a proper motor for the project that can both drive the cart and regenerate power. Also, the sponsor provided us two motors, one with 0.06 horsepower with regeneration mode and one with 0.4 horsepower to drive the cart.

Unfortunately, the 0.4 horsepower motor does not have regeneration mode to recharge the battery, so our team had to use the 0.06 horsepower motor to test the charge efficiency. The data measured can be seen in the table in chapter 4.2.

From the data tested from the regeneration mode we came to the following conclusions:

- The cart moves at 1.1m/s (average person walking speed).
- Average voltage change: 0.034V (approximately 2% to 3% of the battery capacity).

- The output voltage from the charge controller is around 4.5V.
- The actual charge efficiency of this charge controller is about 70%.

3.3 Control Panel

3.3.1 Control Panel Design

The design of the control panel is aimed to be user friendly. The E-stop button must be able to catch the eye and easy to use to make sure safety. Below is the design of the cover of the control panel:

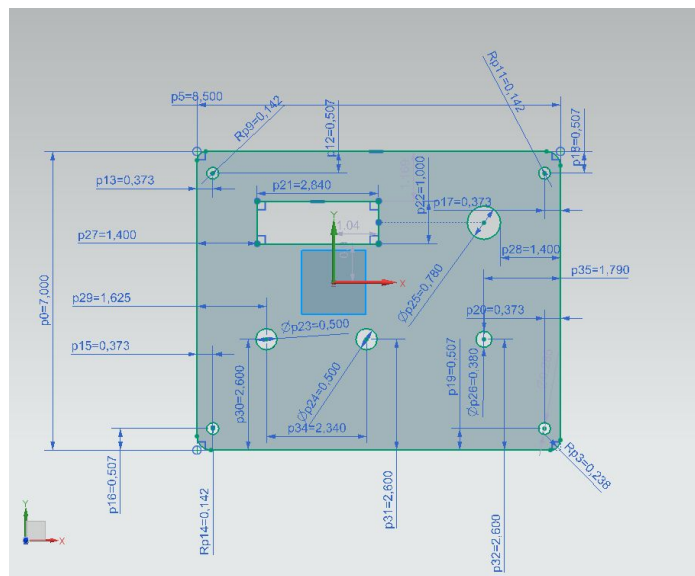


Figure 24: Control Panel Design

The components of the control panel include:

- On/Off/Regeneration Switch
- Forward/Reverse Switch
- E-stop Button
- A Display to show Operation Information.
- Speed Control Switch

3.3.2 3PDT Toggle Switch

We decided to use the 3 Position, 9 Pin Latching Toggle Switch 3PDT as our mode switch. It has 3 positions (Driving mode/OFF/Regeneration mode). By using

this 3PDT switch, we can isolate the motor and battery from driving mode and regeneration mode. Below is an image of the toggle switch that we used.



Figure 25: 3 Position, 9 Pin Latching Toggle Switch (3PDT)

3.4 The Final Design

3.4.1 The Schematic for Control System

The final schematic is shown in Figure.26. The 3PDT switch in top-left side is the main control switch, which isolates motor driver controller and charge controller . When it flip to top side, the motor driving system (Bottom-middle part) works. When it flip to bottom side, the charging system (Top-right part) works. The motor driver is SyRen 50A 6V-30V brushed motor driver discussed in 3.1.2. The microcontroller part is a PCB Board which contains or connects to IR sensors, Forward/Reverse switch, E-stop botton, digital display, speed control button and ATmega328. Details of each part is introduced in previous sections in this chapter.

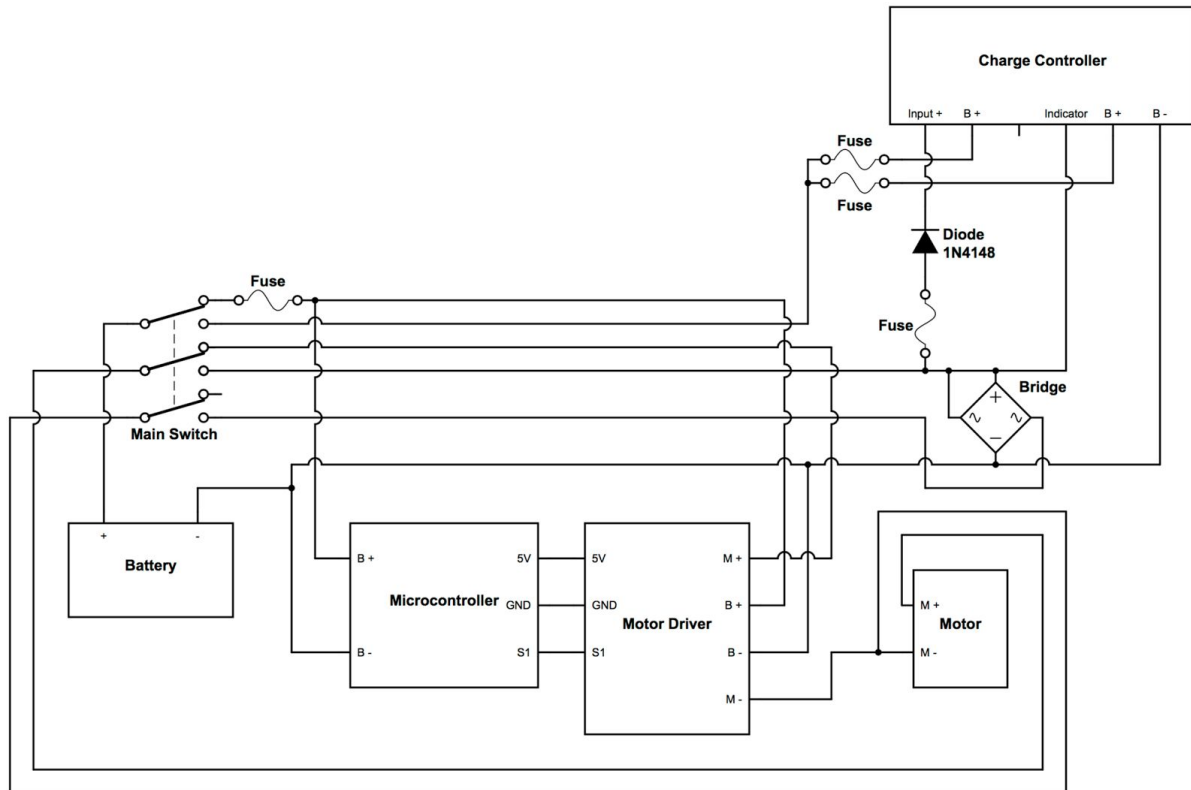


Figure 26: Circuit Schematic

3.4.2 The Final Design

Chapter 4 –Test data with Proof of Functional Design

4.1 Test Data of Driving System

The data below is running with the ½ horse power motor supplied by a fully charged 12V battery.

Speed 5 (Highest Speed): Average Speed (0.322 m/s)

time (s)	distance (m)	speed (m/s)	acceleration time (s)	deceleration time (s)
9.71	3.14	0.323	1	1
6.43	2.35	0.365	1	1

10.99	3.30	0.3002	1	1
18.90	6.11	0.323	1	1
10.60	3.5	0.3301	1	1

Speed 1 (Lowest Speed): Average Speed (0.08m/s)

time (s)	distance (m)	speed (m/s)	acceleration time (s)	deceleration time (s)
19.6	1.57	0.08	1	1
22.8	1.755	0.077	1	1
28.72	2.355	0.082	1	1
29.43	2.355	0.08	1	1
38.765	3.14	0.081	1	1

4.2 Test Data of Regeneration System

The data in this table is based on the normal walking speed of human which is about 1.1 meters/second. Under this condition, the input voltage to the battery is about 4.5V. When the battery is nearly drained, the change in voltage is larger. When the battery is close to fully charged, the change in voltage is smaller. The average voltage change is about 0.034V (about 2% to 3% of the battery capacity).

In the table below are the data of the regeneration system.

Time duration (minutes)	before charge (V)	after charge (V)	volt change (V)	input voltage (V)
10	10.45	10.50	0.05	4.5
10	11.90	11.92	0.02	4.5
10	11.00	11.03	0.03	4.5
10	12.40	12.41	0.01	4.5
10	10.30	10.34	0.04	4.5
10	11.01	11.04	0.03	4.5
10	10.04	10.09	0.05	4.5

10	11.13	11.16	0.03	4.5
10	11.99	12.01	0.02	4.5
10	10.05	10.11	0.06	4.5

The diameter of the wheels of the cart is 0.204 meters. The diameter of the wheel on the 1/16 horse power motor is 0.08 meters. When the cart was moving at 1.1 m/s, the rotation speed of the small motor was about 4.383 rotation/s. When the motor was rotated by this speed, it was measured that the directly output voltage was from 5.4 V to 7.5 V. The output voltage of the charge controller came to be about 4.5 V. The current outputs measured were very close from the motor and the charge controller. From the above data we can conclude that the actual charge efficiency of this charge system is about 70%.

4.3 Final Prototype Performance

The final prototype achieved its design goal and performed as expected. There are two motors supplied by sponsors, one is ½ horse power without regen ability and another is 1/16 horse power with regen ability. Due to the lack of regen caster for ½ horse power motor, cart can be only driven by motor and cannot regenerate power. In this case, two motors were build and teseted seperately. The first ½ horse power motor was to test driving mode, it has a speed of 0.08m/s to 0.322m/s, speed adjust, E-stop, switchs and sensors were teseted in normal driving mode, the results were as expected. Due to the low horse power of second motor, cart cannot be driven. But, with regen caster wheel, charging system can be tested in this case. The second 1/16 horse power motor can generate 5mA current in normal driving speed(1.1m/s). It would take 7 hours to fully charge the battery.

For future improvement, a motor has regen caster wheel and additional 12V battery supply integrated might lead to a better performance which both Driving and Regen mode work perfectly. Charging efficiency could also be improved with larger horse power motor.

Chapter 5- Design Issues

5.1 Safety Issues

Safety protection is a key issue in our design project. Workers's safety in factory is our priority concern. The cart can carry a load is up to 8000lb making the cart too dangerous if the cart hits people. To prevent the cart hitting any object or people when the cart is moving, an IR sensor will be installed in front of the cart. When the sensor detects an object within 0.5 meter, the cart will go from start to stop automatically with deceleration. With the heavy load and high inertia, instantaneous stops or starts might lead to falling of heavy products or collision with the worker. In the final design, the acceleration and deceleration setting is added to motor controller through adding certain delay in final code. When the cart starts, stops, or changes moving direction, there is a one second acceleration or deceleration time.

5.2 Charging compatibility

The current charging circuit was designed for charging by one battery. Also, because the cart already had an LED display showing the battery status, the charge indicator on charge controller was left unused, but LED display is only on when cart is in driving mode, so the user will not be able to see whether battery is fully charged when in regen mode. For future improvement, microcontroller programming should be able to show the battery status during the recharging phase. Also, circuit needs to have improved ability to support multiple batteries, which can be done by following the User Manual of the Charging Controller. The User Manual provides many different kinds of circuit layout for different batteries and motor set up.

5.3 Motor Issues

Our sponsors had given us a motor to test and design the power cart with. This lead to our team designing an entire code around a certain motor. When we tested our design at the sponsor's factory, it successfully ran with flawless results. We then asked for the sponsor to deliver the motor and cart, and when we received the parts, we were given an entirely new motor. This became a significant problem because the motor specifications did not match what the our specifications that was

designed. This led to a motor that did not run properly, resulting in conflict. We notified the sponsors and he gave us a different motor without any regeneration capabilities. This resulted in us using two different motors, one for testing regeneration, and the other to test movement, speed control, and safety features of the cart.

Chapter 6 – Final Cost, Summary, Schedule, and Future Design

6.1 Final Summary and Costs

As we worked throughout the semester on our project we stayed on schedule the entire time until we ran into some issues towards the end of the project. The preparing, designing, and prototyping portions of the development of the project went smoothly and when we originally tested the cart at our sponsors location that portion also went as planned. The cart moved with the current motor which was $\frac{1}{2}$ horsepower, but this motor did not have regeneration capabilities as it would lock up if it wasn't running. When the cart was shipped to the ECE Lab for testing, it was equipped with a 1/16 horsepower motor with regeneration capabilities. Our sponsor informed us that the cart should run with this motor but will be slower. In reality, the new motor was not powerful enough to get the cart to move. We took regeneration and drive data from both motors and if we had a higher budget or if our sponsor was

able to provide us with the correct motor we would be able to combine the drive feature and regeneration feature into the same motor.

The total cost in constructing our project was \$337.94. This amount includes what we had to purchase as a group to create our regenerative system and can be seen in the budget section in 2.3. Additional items, including the more expensive items, were provided by our sponsor, including: The motor (\$2,000), the cart (\$2,500), the regeneration caster (\$200), and the 12V battery (\$20).

Item Name	Quantity	Cost (US\$)
50A Regenerative Motor Driver	1	\$119.99
Charge Controller (NC25A-12)	1	\$90.00
Fuse holder in-line AWG	4	\$2.79
assorted auto car mini flade fuses.	4	\$0.53
Infrared proximity switch module	2	\$15.98
ATmega328P-PU DIP-28 Chip	1	\$4.50
Momentary Push Button Switch U19D1	1	\$8.99
AC ON-OFF-ON 3 Positions Toggle Switch 3PDT	2	\$17.98
PCB Mount Screw Terminal Blocks	20	\$3.98
PCB Manufacture	1	\$52.50
22pF 50V Low Voltage Radial Ceramic Disc Capacitors	3	\$0.17
Quartz Crystal Oscillator 16MHz	1	\$0.58
USB 2 Serial Converter Micro	1	\$19.95
		\$337.94

Figure 27: Budget for the Project

6.2 Bonus Features and Future Design

When we orginally visited our sponsors location to get a better scope of the project they informed us that if we had the time and if we wanted to we could add an additional object detection sensor. We decided to move forward with that since we thought it would be crucial component for the safety of the users and parts it would be carrying. Looking back to section 3.1.4 of this report, you can learn more about the infrared sensor that we added. Furthermore, we added a very clean, user friendly

control panel that has a matching blue color and labels to describe what each switch or dial does. More on this can be seen in section 3.3 of this report.

Our regenerative electric driven power cart has very many possibilities and uses in the future. The design can grow in many ways and can be implemented in many different situations as well. As far as the design goes, the motor can be improved to increase the power efficiency and speed, the control panel can be edited to have more features, the physical size of the cart can be resized or changed, the regeneration system can be improved to make the battery last even longer, and more. Most of these design improvements would have been worked on in more depth if we were given a longer timeframe for this project. Not only can the design be improved but this cart could be implemented in other situations such as at a grocery store to help elderly or handicapped people, in the inventory departments of stores to help move heavy loads, in schools to help move heavy equipment around, and much more.

Appendix 1 – Technical Roles, Responsibilities, and Work Accomplished

Each team member had specific technical roles, responsibilities and work that was accomplished. Below is a detailed description of each person's role on the team and their work accomplished.

Daniel Jarratt - Lead Manager

Daniel Jarratt was the team's lead manager for this project. He set up all meetings with sponsors and the facilitator, as well as assigned roles for everyone on the team. He scheduled appointments on when the team should meet and work on the project, and kept track of the progress being made.

Daniel's responsibilities within the project include designing the control panel, collecting test data, and editing the final report. When designing the control panel, Daniel used CAD to print the schematic for the panel plate. This panel plate design can be seen in 3.3.1 Control Panel Design. Daniel also collected test data for the power cart. He ran several tests to determine the rate at which the battery drains,

recharges, and the walking speed for the average worker. These tests were ran multiple times to ensure that the data was accurate.

Ning Zheng

Ning Zheng is the team's website developer. He developed the website and created all of the links to ensure that they were working properly. He also created the design for the prototype as well as designed it. Ning chose the motor controller and microcontrollers to use for the project.

Rui Zhang

Rui Zhang was the team's presentation developer and coordinator. He had a big part in creating the presentations, deciding who was going to say what, and also creating the poster. Rui also helped with writing the report, as he worked mainly on the Technical Description section.

Rui's responsibilities in creating the project consisted of working on the charging circuit, soldering the Wein bridge and other components, designing the control panel, and testing the cart. Rui contributed largely in choosing the right motor driver and microcontroller for the charging circuit. Rui used the soldering stations provided in the ECE lab to solder a majority of our connections that needed it. He also played a large role in creating the design for the control panel.

Zhongyang Wang

Zhongyang was the team's lab coordinator. In this position, he kept track of all our parts and devices. He also made sure our laptop was safe along with our cart. Zhongyang was also primarily in charge of all the part orders and deciding what parts were the most cost efficient to purchase. He also worked on the poster, presentation, and final report.

On the technical side, Zhongyang consistently helped in the creating of the charging system of the prototype, helped hook up the motor driver, and contributed greatly to the overall design of the protoboard. Zhongyang assisted in choosing the most efficient motor driver as well as hooking it up. He helped in securing the actual

motor to the cart and hooking it up as well. Lastly, Zhongyang assisted in the final hookup of the outputs to the control panel.

Appendix 2 – Literature and Website References

Appendix 3 – Detailed Technical Attachments

Code for Atmega328p Programming

```
#include <NewPing.h>
#include "TimerOne.h"
#include <SoftwareSerial.h>
#include <SyRenSimplified.h>
#include <LiquidCrystal_I2C.h>
```

//Digital Pin

```
#define eStopButtonPin      3
#define eStopLedPin        4
#define directionSwitchPin  5
#define IRSensorPin_1      6
#define IRSensorPin_2      7
#define ObstacleDetectionEnablePin  8
#define motorOutput        9
```

//Analog Pin

```

#define batteryPin A0
#define speedPin A1

//Motor Driver
SoftwareSerial SWSerial(NOT_A_PIN, motorOutput);
SyRenSimplified SR(SWSerial);

//LCD Display
LiquidCrystal_I2C LCD(0x27, 16, 2);

//Default Parameter
int eStopLedState          = LOW;
int eStopButtonState       = LOW;
int lasteStopButtonState   = HIGH;
int ObstacleDetected       = 0;
int motorSpeed              = 0;
int directionState         = 0;
int lastDebounceTime       = 0;
int debounceDelay          = 50;
int stableReadingOutput    = 0;
int stableReadingRaw       = 0;
int BatteryLevel           = 0;
int speedInputPre          = 0;

void setup() {
    //Set Pin Mode
    pinMode(eStopLedPin, OUTPUT);
    pinMode(eStopButtonPin, INPUT);
    pinMode(directionSwitchPin, INPUT);
    pinMode(motorOutput, OUTPUT);
    pinMode(batteryPin, INPUT);
    pinMode(speedPin, INPUT);

    //Initialization
    LCD.init();
    LCD.backlight();
    Serial.begin(9600);
    SWSerial.begin(9600);
    ReadBatteryLevel(true);
    Timer1.initialize(500000);
    digitalWrite(eStopLedPin, eStopLedState);
}

```

```

void loop() {
    detectObstacle();
    int StopButtonReading = digitalRead(eStopButtonPin);
    directionState = digitalRead(directionSwitchPin);
    if (StopButtonReading != lasteStopButtonState) {
        lastDebounceTime = millis();
    }
    if ((millis() - lastDebounceTime) > debounceDelay) {
        if (StopButtonReading != eStopButtonState) {
            eStopButtonState = StopButtonReading;
            if (eStopButtonState == HIGH) {
                eStopLedState = !eStopLedState;
            }
        }
    }
    if (eStopLedState == HIGH || (ObstacleDetected && (directionState==HIGH)))
    {
        runMotor(0, 2);
        eStopLedState = HIGH;
        lasteStopButtonState = LOW;
        digitalWrite(eStopLedPin, eStopLedState);
        if (ObstacleDetected) {
            DispalyLCD(0, "MODE: STOP");
            DispalyLCD(1, "OBSTACLE DETECT");
        }
        else {
            DispalyLCD(0, "MODE: STOP");
            DispalyLCD(1, "SPEED: 0");
        }
    }
    else {
        if (directionState == HIGH) {
            motorSpeed = map(analogRead(speedPin), 0, 1023, 127, 0);
            int motorSpeedDisplay = map(abs(motorSpeed), 0, 127, 0, 6);
            DispalyLCD(0, "MODE: D");
            DispalyLCD(1, "SPEED: " +
String(getStableReading(motorSpeedDisplay)));
        }
        else {
            motorSpeed = map(analogRead(speedPin), 0, 1023, -127, 0);
            int motorSpeedDisplay = map(abs(motorSpeed), 0, 127, 0, 6);

```

```

        DispalyLCD(0, "MODE: R");
        DispalyLCD(1, "SPEED: " +
String(getStableReading(motorSpeedDisplay)));
    }
    runMotor(motorSpeed, 2);
}
digitalWrite(eStopLedPin, eStopLedState);
lasteStopButtonState = StopButtonReading;
}

```

```

void DispalyLCD(int line, String text) {
    LCD.setCursor(0, line);
    if (line == 0) {
        int space = 16 - text.length() - ReadBatteryLevel(false).length();
        for (int i = 0; i < space; i++) {
            text += " ";
        }
        text += ReadBatteryLevel(false);
    }
    int space = 16 - text.length();
    for (int i = 0; i < space; i++) {
        text += " ";
    }
    LCD.print(text);
}

```

```

String ReadBatteryLevel(bool force) {
    if (eStopLedState || force) {
        double voltage = analogRead(batteryPin) / (1023.00 / 28.00);
        BatteryLevel = 0.2305 * pow(voltage, 4) - 19.53 * pow(voltage, 3) + 622.01 *
pow(voltage, 2) - 8811.5 * voltage + 46779;
        if (BatteryLevel < 0) {
            BatteryLevel = 0;
        }
        if (BatteryLevel > 100) {
            BatteryLevel = 100;
        }
    }
    return String(BatteryLevel) + "%";
}

```

```

void detectObstacle() {
    if (digitalRead(ObstacleDetectionEnablePin)) {
        //IR Sensor
        if ((digitalRead(IRSensorPin_1) == LOW) || (digitalRead(IRSensorPin_2) ==
LOW)) {
            ObstacleDetected = 1;
        }
        else {
            ObstacleDetected = 0;
        }
    }
    else {
        ObstacleDetected = 0;
    }
}

int getStableReading(int value_input) {
    stableReadingRaw = value_input;
    Timer1.attachInterrupt(getStableReadingCallback);
    return stableReadingOutput;
}

void getStableReadingCallback() {
    stableReadingOutput = stableReadingRaw;
}

void runMotor(int speedInput, float accelerationDelay) {
    if (abs(speedInputPre - speedInput) > 50) {
        if ((speedInputPre <= 0) && (speedInput >= 0)) {
            for (int power = speedInputPre; power <= speedInput; power ++ ) {
                SR.motor(power);
                delay(accelerationDelay);
            }
        }
        else if ((speedInputPre >= 0) && (speedInput <= 0)) {
            for (int power = speedInputPre; power >= speedInput; power -- ) {
                SR.motor(power);
                delay(accelerationDelay);
            }
        }
    }
}

```

```
else {  
    SR.motor(speedInput);  
}  
speedInputPre = speedInput;  
}
```