ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

ECE 445

Spring 2013

Design Review

Smart Shopping Cart

February 21, 2013

Di Fan

Ying He

Xuyang Yao

TA: Mustafa Mukadam

Table of Contents

I. Introduction

Statement of Purpose 3

Objectives 3

Goals 3

Benefits 3

Features 3

II. Design

Block Diagrams 4

Block Descriptions 5

Schematics 9

Flowcharts 12

Tracing System 12

Navigation System 13

III. Requirements and Verification

Requirements & Verification 14

Tolerance Analysis 19

IV. Cost and Schedule

Labor Cost 19

Part Cost 20

Schedule 21

V. Ethical Considerations and Safety 22

VI. References 24

I. Introduction

Statement of Purpose:

As technology progressed, lives have been significantly improved due to the emergence of laborsaving and intelligent utilities. However, as we noticed, the shopping carts in major stores have experienced little changes and served only simple purposes ever since they were first manufactured. Pushing these carts around becomes noticeably painful when they carry heavy loads. Even though generally people are not moving fast in stores, there is a risk of collision if obstacles arise out of sight. Moreover, products can be extremely difficult to locate before people get familiar with the store layout. Considering all the disadvantages discussed above, we aim to implement a smart shopping cart that provides great convenience and efficiency to customers.

Objectives

Goals:

- Automatic customer tracing via communication between transceivers
- Avoid collisions with obstacles and detect accessible routes
- Optimize the path required to accommodate custom shopping list
- Alert system to warn customers on condition that carts fall behind

Benefits:

- Self-motion cart aiming to save human labor
- Optimal guiding system to reduce searching time
- Delicate user interface with multiple entering modes
- High-sensitivity sensors to minimize the possibility of collisions

Features:

- Sensors with minimum detection radius of 0.2 m
- Signal transmitters installed in store for precise navigation
- High CPU calculation speed for rapid moving decision
- Enclosed store map and product catalogs intended for searching function

II. Design

Block Diagram

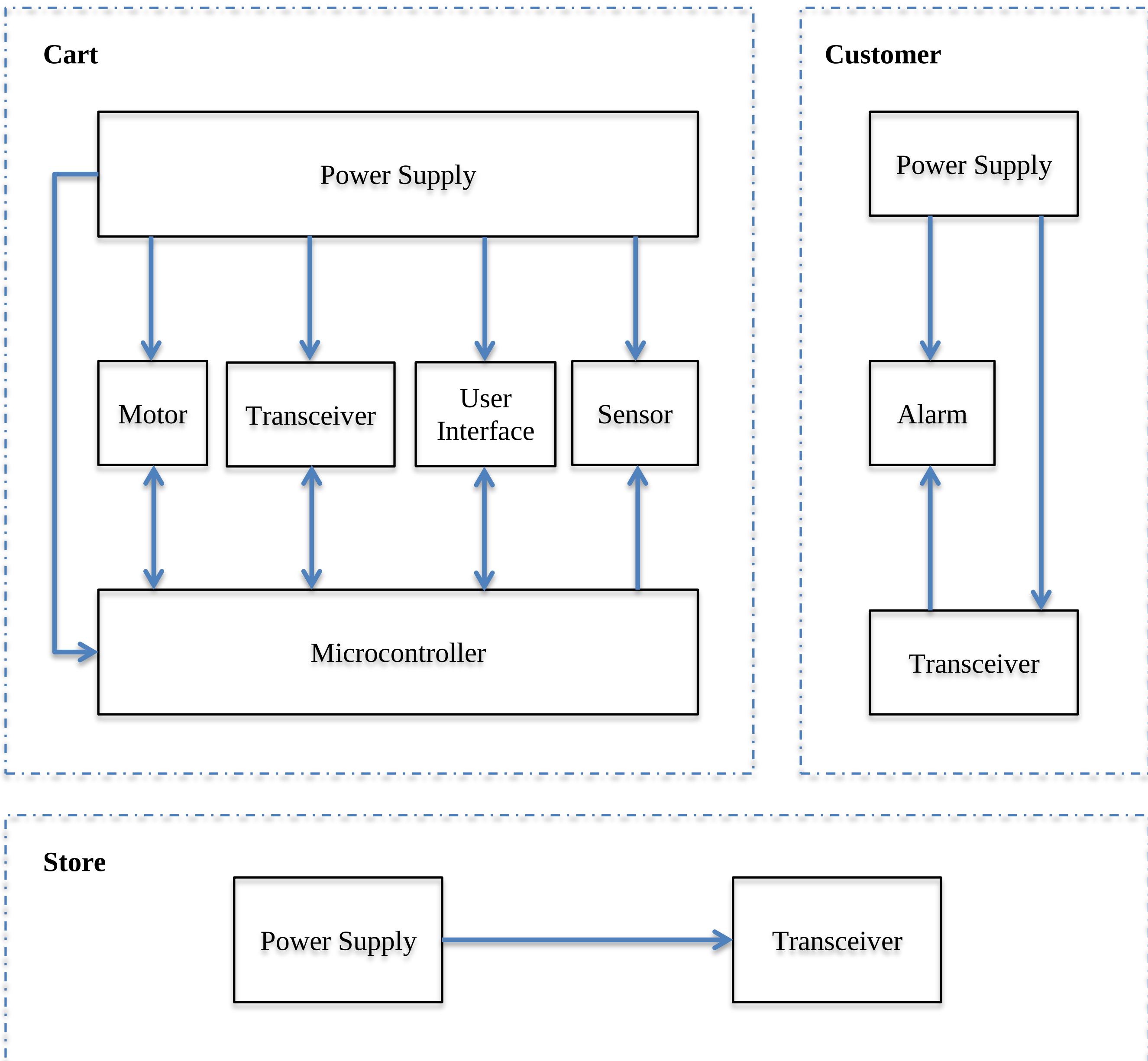

Figure 1 Block diagram

Block Descriptions

Common components:

a. Power supply: Generally, five A23 12 V DC batteries serve as the power supply in this project. Due to the different operating voltages of various components, a 5 V voltage regulator and four 3.3 V voltage regulator will be used to provide appropriate operation environments to the entire circuit. This module is divided into three parts: the cart power supply provides power to two 12 V DC motors, a Arduino microcontroller, a wireless transceiver, a 12-button keypad with LCD screen and four ultrasonic distance sensors; the customer power supply powers a transceiver and an alarm; and the store power supply sustains two transceivers. Total current and power consumed is given by

$$I_{Arduino} = 0.8\ A$$

$$I_{ATmega328} = 3.2\ mA$$

$$I_{motor} = 4\ A$$

$$I_{transceiver} = 17m \times 4 = 68\ mA$$

$$I_{LED} = 0.5\ mA$$

$$I_{tot\_max} = 4.9\ A$$

$$P_{tot\_max} = 58.5\ W$$

b. Transceiver: For instantaneous position update of the customer, a GPS-like positioning system is embedded in the cart. Since commercial GPS may not provide enough precision, we will use four Bluetooth RF RS232 Transceivers to implement accurate navigation, which require 3.3 V DC voltages. Two of them are installed in store and attached to the ceiling for maximum coverage. They will receive signals from the transceivers carried by the cart and customer then reflect these signals back at a data rate at 1.2 kbps. By measuring the time delay compared to the original signals, the microcontroller, which collects information from the cart transceiver and customer transceiver, is able to determine the positions of the cart and customer in a coordinate system based on the signal travelling speed. Detailed calculation strategy is shown as below.

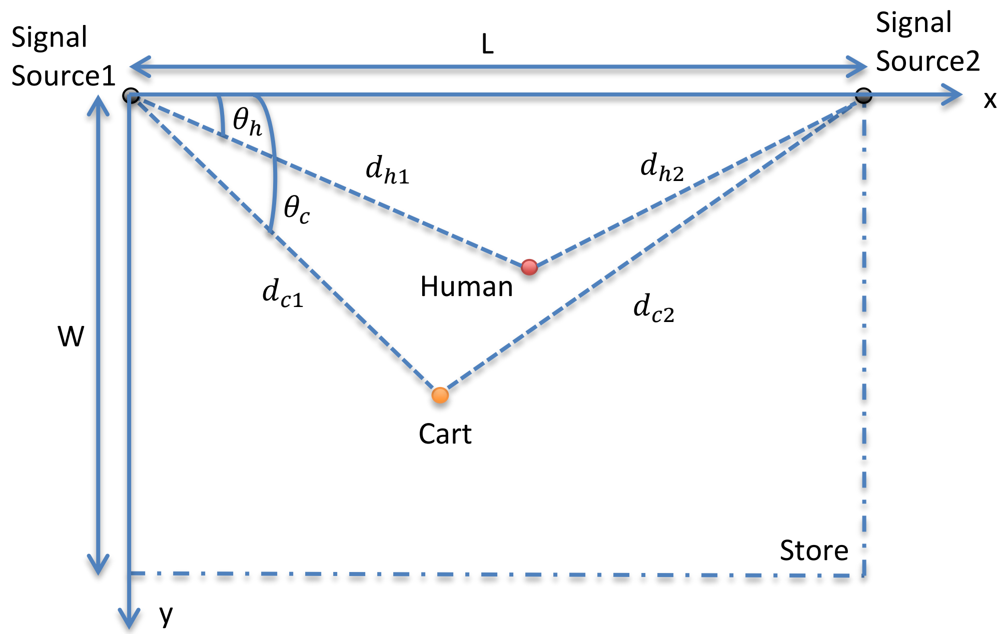

Figure 2 Position determination process

$$d = \frac{\Delta t}{2} v_{signal}$$

$$\cos(\theta_h) = \frac{L^2 + d_{h1}^2 - d_{h2}^2}{2Ld_{h1}}, \qquad \sin(\theta_h) = \sqrt{1 - \cos^2(\theta_h)}$$

$$\cos(\theta_c) = \frac{L^2 + d_{c1}^2 - d_{c2}^2}{2Ld_{c1}}, \qquad \sin(\theta_c) = \sqrt{1 - \cos^2(\theta_c)}$$

$$x_h = d_{h1}\cos(\theta_h), \qquad y_h = d_{h1}\sin(\theta_h)$$

$$x_c = d_{c1}\cos(\theta_c), \qquad y_c = d_{c1}\sin(\theta_c)$$

Cart: We will build a $25 \times 30\ cm^2$ vehicle platform with two 12 V DC motors for the mechanical part of the project. The approximate weight of the finished cart is 2.5 kg.

a. Motor: Two GM9236S025 motors with reduction ratio 65.5:1 are installed in the platform to provide driving force for the shopping cart and directly controls its moving speed. The encoders that are included in the platform are going to encode instructions from the Arduino microcontroller to achieve desired cart speed and turning angle. There are three speed levels in this project: 1.5 m/s for rapid catch-up, 1.4 m/s for intermediate distances and 1.3 m/s for simply following mode.

b. Sensor: Four HC-SR04 ultrasonic distance sensors will be placed to each side of the cart to accomplish our obstacle-avoiding feature. They receive 5 V DC power supply from the 5 V voltage regulator. When any sensor detects an obstacle within its detection radius, it will trigger a voltage signal to the microcontroller in order to adjust the direction of the cart. HC-SR04 sensor covers a range from 2cm to 5m with 0.3cm resolution. Since we are only interested in specific distance intervals in determination of avoidance strategy, the voltage signals corresponding to 0.2 m and 0.5 m are recorded to serve as threshold values. More detailed information is presented in Figure 7.

c. Microcontroller: This is the most critical component in our design. An Arduino and an ATmega328 microcontroller are used to process all the data and calculations. The microcontroller is responsible for determination of the shopping cart's speed and direction when tracing the customer and avoiding obstacles via feedbacks from transceivers and sensors, respectively. It will also generate routes from the current position to places where desired goods are located. To implement this function, we need to enclose the store layout and catalog information within the microcontroller. The Arduino is powered up by 5 V DC voltages, which comes out of the 5 V voltage regulator, and collects all signals from sensors, transceivers and the user interface.

d. User Interface: We aim to provide a convenient and multi-functional user interface, which includes three main subcomponents. A push button on/off switch will be used to enable/disable the user interface. A 16 × 2 LCD screen shield and a 12-button keypad are presented to the customer to enter goods they wish to purchase and display the shopping list for their record. All products are classified into ten general categories so that customers may narrow down the ranges for easier search. Each of the categories is represented by a numerical button. Customers can choose between two modes of navigation: item-by-item entry mode that leads customers to the product immediately after they finish entering the item, or the multiple-item mode that determines the most efficient route covering all items entered. A flow chart that demonstrates the logic determination process is included in Figure 8.

Customer: In our design, the customer will carry a transceiver attached with an alarm system. The transceiver will frequently send signals to the microcontroller to track the position of customer. An alarm will be triggered to remind the customer when the cart falls more than 2 m behind.

a. Alarm: We will connect a red LED light to the transceiver carried by the customer. Once the distance between the cart and customer exceeds 2 m, the transceiver receives a signal from the microcontroller to light the LED. 1.8V-2.2V DC voltages will be applied to the LED in this case.

Store: In order to implement the navigation system of the cart, we need to include the store layout and how products are located into the microcontroller. So a store map is designed as follows.

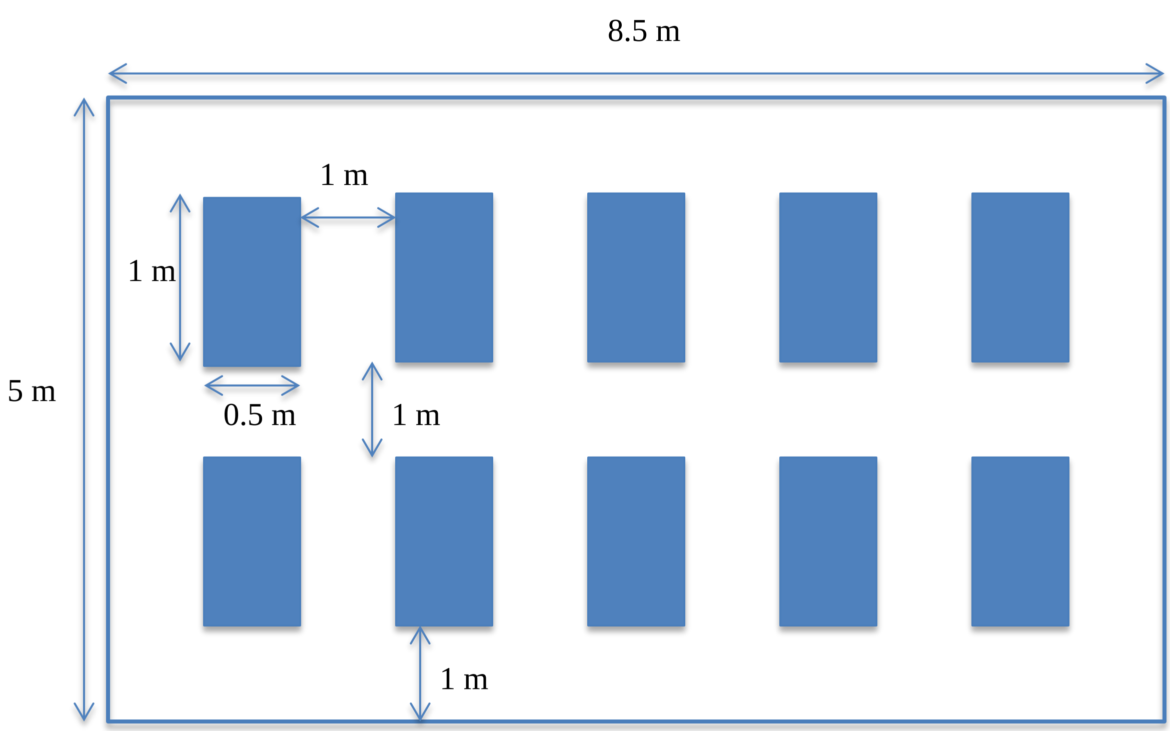

Figure 3 Store layout

Schematics

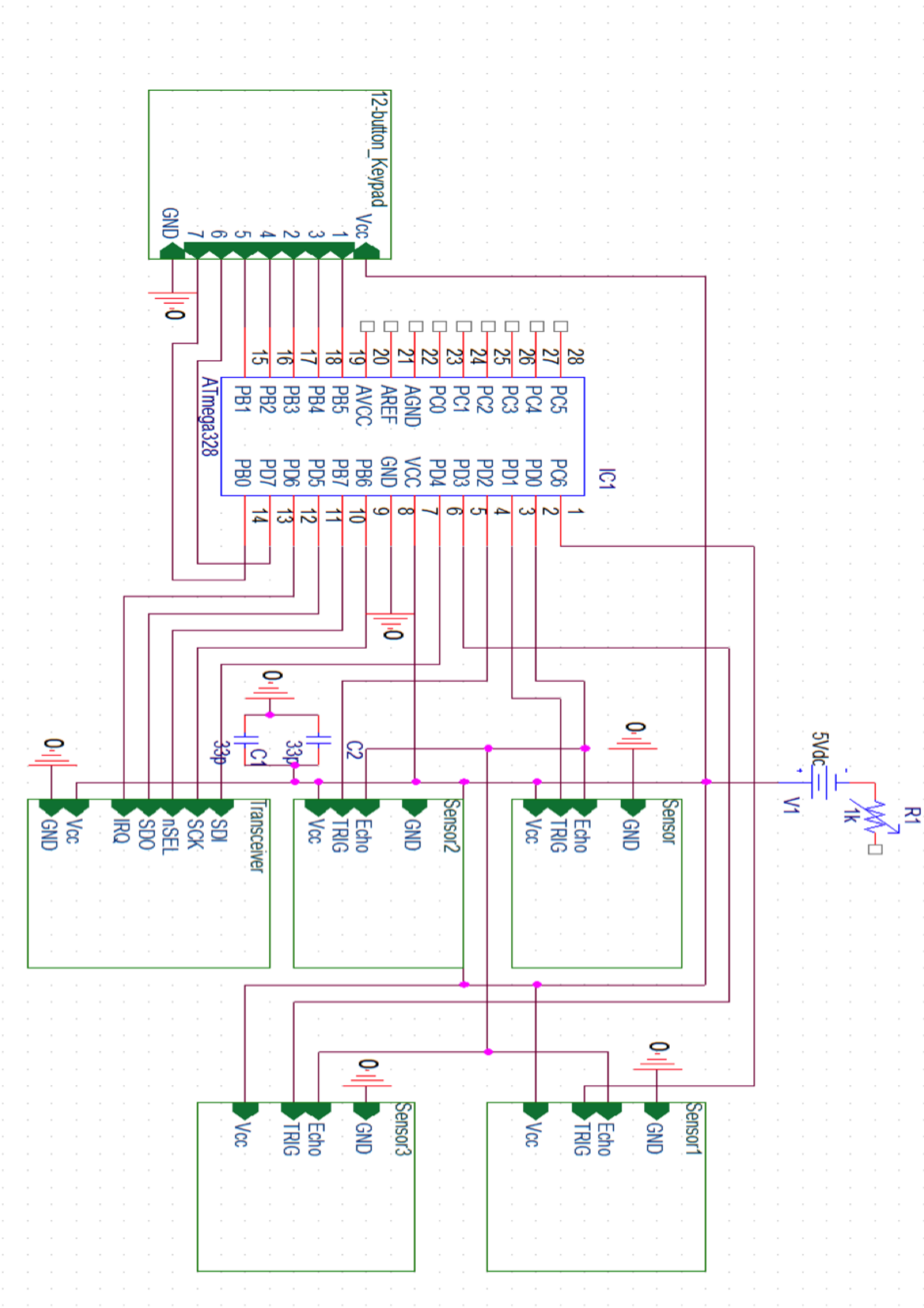

Figure 4 Schematic for microcontroller, sensors, cart transceiver and keypad

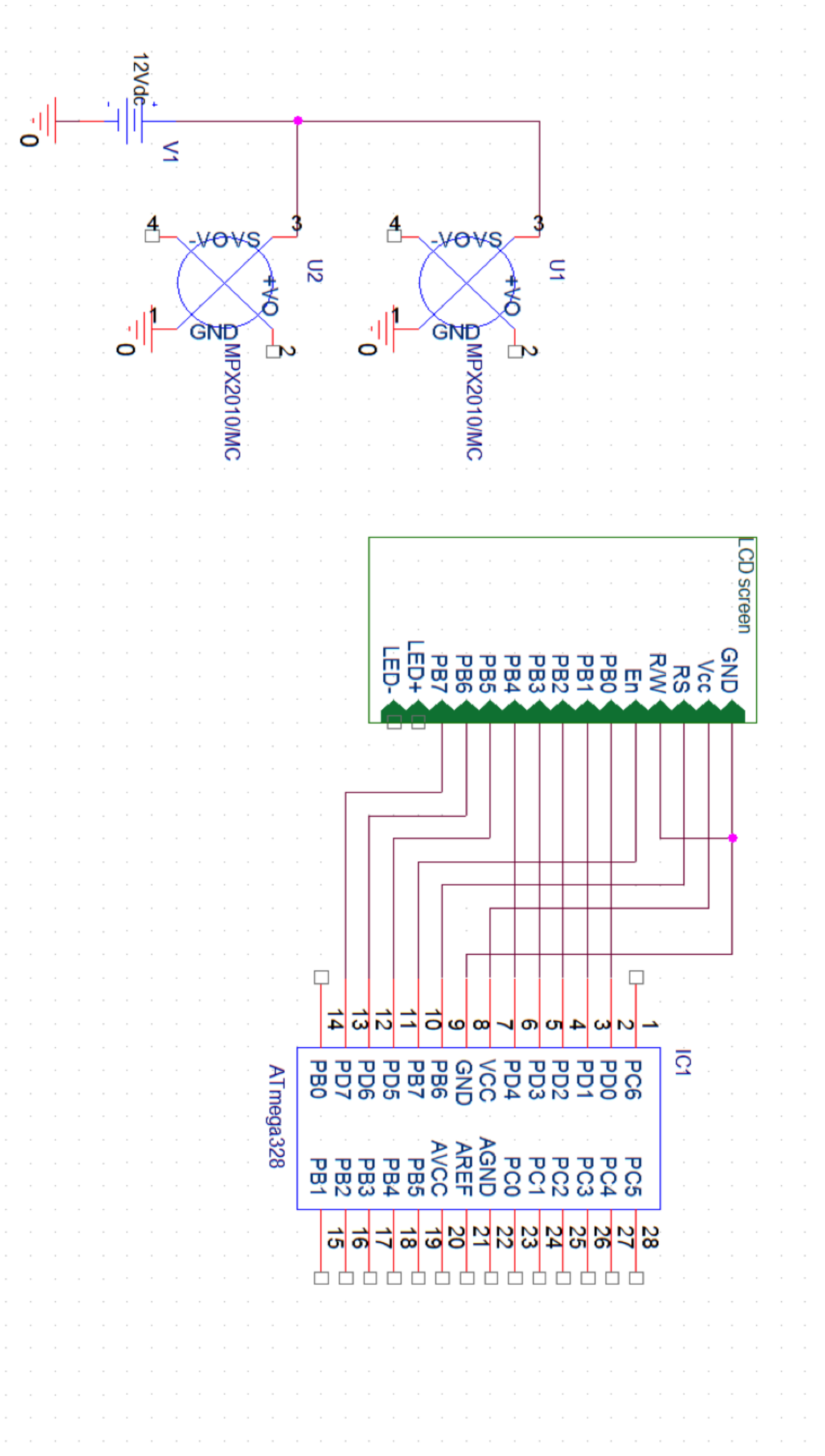

Figure 5 Schematic for LCD screen and motors

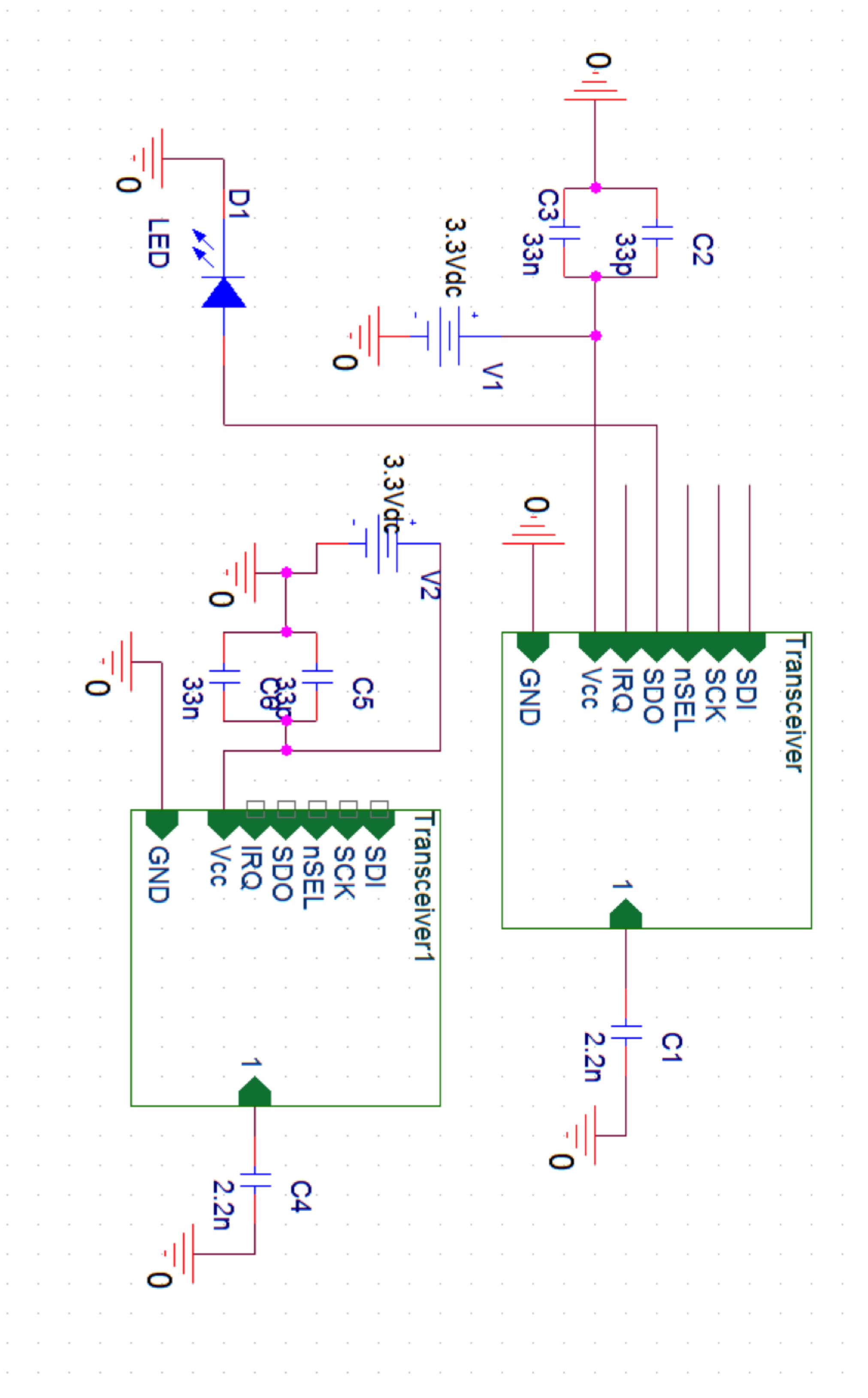

Figure 6 Schematic for customer and store transceivers

Flow Charts

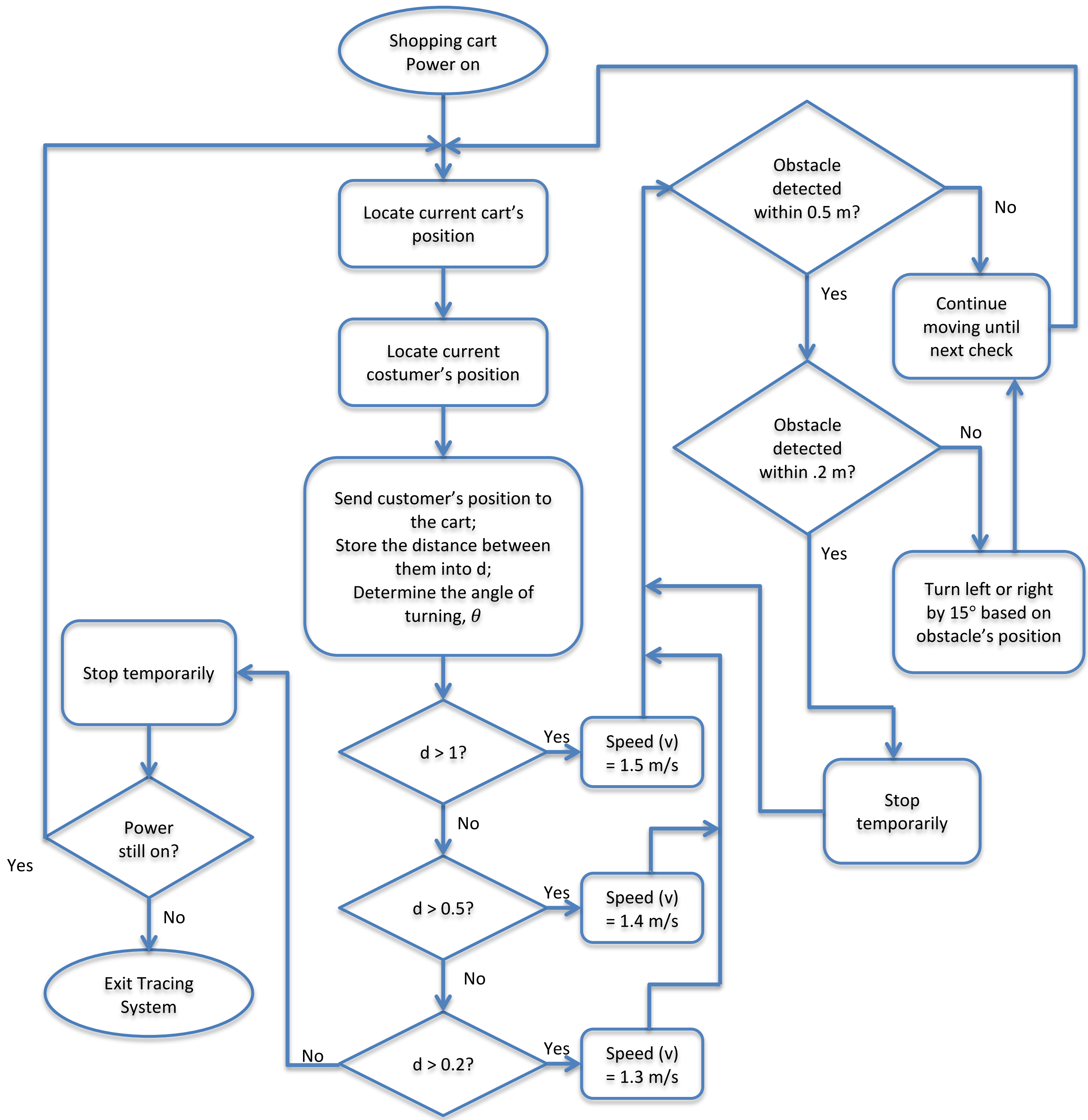

Figure 7 Tracing system flow chart

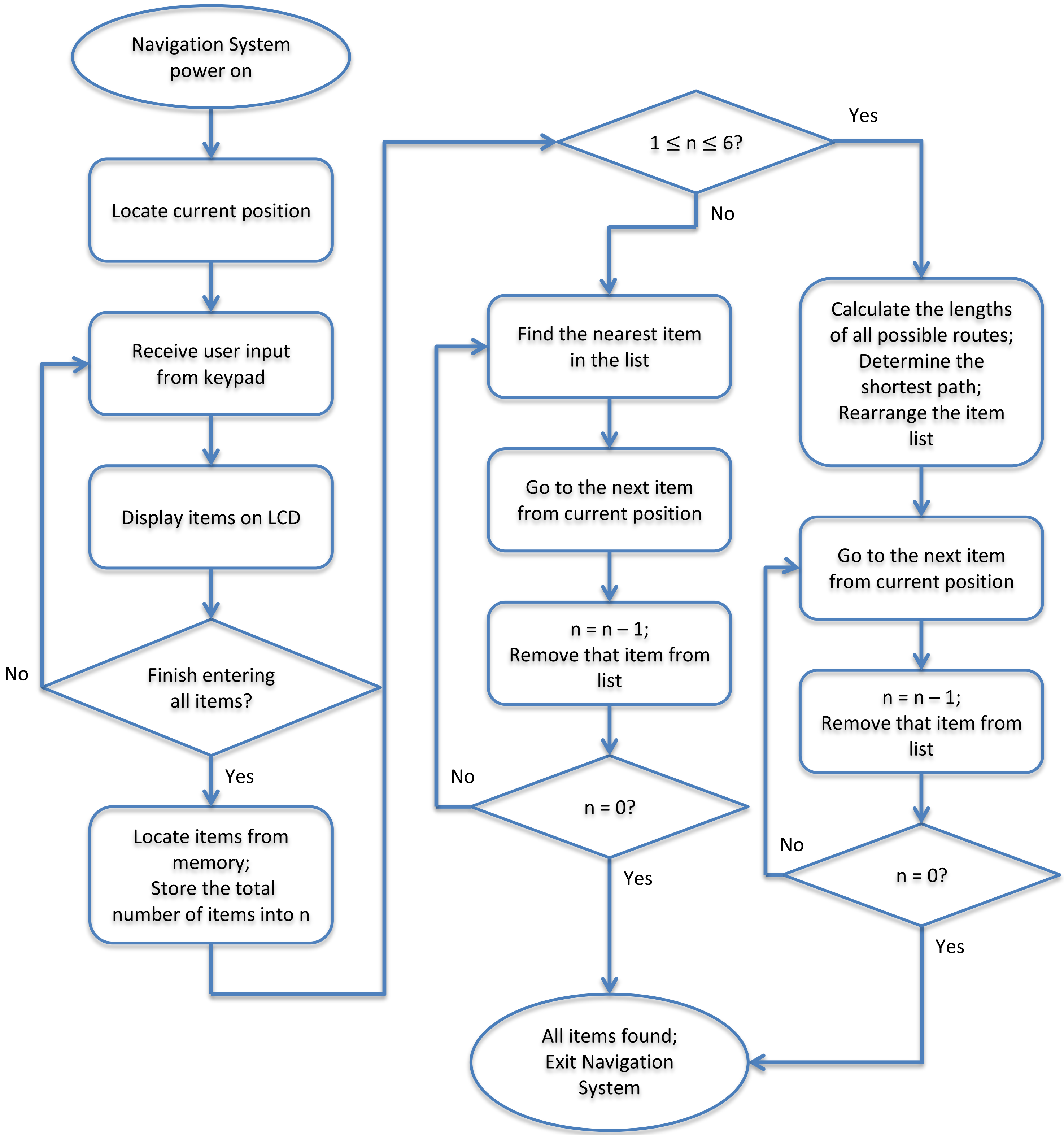

Figure 8 Navigation system flow chart

III. Requirements and Verification

Requirements & Verification

Requirements	Verification
Power Supply: 1. Output voltage of A23 batteries should be 12 ± 1 V in order to provide steady power supply to motors. 2. 5 V voltage regulator (connected to Arduino and sensors) should output voltage of 5 ± 0.3 V with maximum current 1.5 A. 3. 3.3 V voltage regulator should supply 2.2 – 3.8 V to transceivers while current maintained within 17 ± 2 mA. 4. Output voltage of the 1K Ohm potentiometer needs to be restricted within 1.8 – 2.2 V, which provides the working current of the LED.	1. Connect the probes of a multimeter to the ends of each battery to measure the output voltage. The multimeter should read 12 ± 1 V. 2. After wiring the 5 V voltage regulator to an A23 battery, measure the output voltage with a multimeter. Expected value is 5 ± 0.5 V. Connect a 3.5 ohms resistor as load, measure the current through the load to test if the regulator can sustain a 1.5 A current. 3. Connect the 3.3 V voltage regulator to an A23 battery, use a multimeter to measure the terminal voltage of the regulator. Make sure the voltage falls in the 2.2 – 3.8 V range. Use a 200 ohms resistor as load and test if the regulator functions properly with 17 ± 2 mA current. 4. Connect the potentiometer to the SDO pin of a transceiver and adjust the resistor value. Use a multimeter to measure its output voltage when SDO is set to high. The multimeter should read 1.8 – 2.2 V.
Transceiver: 1. Transceivers should cover an effective	1. Place two transceivers 10 m apart and make one serves as receiver and the

range of 10 ± 0.5 m with no more than 5% distortion. 2. Working at 433 MHz band, receiver bandwidth is fixed at 67 ± 5 kHz, while transmitter frequency deviates from the carrier frequency at 45 ± 3 kHz. 3. Data rate should be maintained at 1.2 ± 0.2 kbps.	other as transmitter. Use two oscilloscopes to monitor the waveforms sent and received by the transceivers, respectively. The received signal should differ from the origin one by less than 5%. 2. Set all transceivers and a spectrum analyzer to operate at 433 MHz. The analyzer is expected to receive the signal at frequency within ± 36 kHz after one transceiver sends a signal at 433 MHz. Then retrieve the signals received by other transceivers using the microcontroller to check if they deviate from 433 MHz by 45 ± 3 kHz. 3. Under transmitter operation, measure the interval between signals sent by a transceiver using an oscilloscope. Desired interval should be 0.71 – 1 ms.
Motor: 1. The cart should move at 1.5 ± 0.1 m/s, 1.4 ± 0.1 m/s and 1.3 ± 0.05 m/s for the three speed levels. 2. Percentage error of the actual turning angle of the front ball wheel cannot exceed 10%.	1. For each of the three levels, let the cart move for 5 s in open area. Measure the distance that the cart goes by a metric ruler and divide the result by 5. The expected results should be 1.5 ± 0.1 m, 1.4 ± 0.1 m and 1.3 ± 0.05 m, respectively. If test fails: Use a stroboscope to measure the rotation speed of the motor. The stroboscope should read 1±0.02 Hz for 1.5 m/s level, 0.93±0.02 Hz for 1.4 m/s

	and 0.87±0.02 Hz for 1.3 m/s. 2. Mark the start position of the cart and set the turning angle from 0 to 90° with 5° increment each time. Let the cart move for 5 s in open area. Measure the angle between the cart's path and the direction it originally faced by a protractor. The calculated error percentage should be less than 10%.
Sensor: 1. Under 5 V DC voltages, sensor will operate at a current of 15 ± 2 mA. 2. Sensor should be able to detect objects 0.5 ± 0.05 m and 0.2 ± 0.02 m away and differentiate these two distances by triggering voltage signals of different magnitudes. 3. Working frequency of the sensor should be 40 ± 4 Hz to provide updated information of obstacles.	1. Apply 5 V DC voltages to each sensor, measure the passing current by a multimeter. The multimeter should read 15 ± 2 mA. 2. Place an object at 0.5 ± 0.05 m in front of a sensor and measure the voltage response using an oscilloscope. Repeat the same process after moving the object to 0.2 ± 0.02 m. The sensor is expected to trigger steady voltages in both cases, as long as the distance is constant. Furthermore, the former voltage should be smaller than the latter one by more than 0.2 V. These two voltages will be recorded as threshold values. 3. Set the rotation frequency of a rotor with only one tooth to 36 – 44 Hz and fix the sensor at any point that could detect the tooth. Use an oscilloscope to monitor the output voltage of the sensor. If the voltage signal is steady

	and constant, the sensor frequency is the same as the rotor, which means the specification is satisfied.
Microcontroller: 1. Microcontroller needs to calculate the positions of the cart and customer based on information collected from transceivers, and output speed and turning angle of the cart. The calculated positions should not deviate from the real positions by more than 5 cm. 2. If an obstacle is detected within 0.2 m in front or the left, the microcontroller should modify the turning angle by 15° to the right until all obstacles are cleared; if something is found in the right, increase the angle to the left by 15°. 3. Microcontroller should be able to determine which button is pressed on the keypad and correctly reflected that information on the LCD screen. 4. If the number of items entered is less than 6, the microcontroller should determine the optimal solution in 3 s; if the number is between 7 and 10, the processing time is restricted in 5 s. 5. When the distance between the cart and customer exceeds 2 m, the microcontroller will send a 'high' signal through cart's transceiver to	1. Pick arbitrary positions for the cart and customer and record their coordinates. Export the positions determined by the microcontroller to a computer and check if they are within 5 cm of the real locations. Distances are measured based on geometric centers. 2. Place an object at a distance of less than 0.2 m from the cart in each of the three sides. Check if the microcontroller makes correct turning instructions by exporting data to a computer. If test fails: Measure the output voltage of the corresponding pins by a multimeter, which should read $\pm(0.83\pm0.05)$ V. Positive voltages indicate right-turning and negative voltages are for left-turning. 3. Press each button on the keypad and write Arduino codes to test if the microcontroller correctly decodes which button is pressed. Display the corresponding product names stored in the microcontroller on LCD. Make sure they match the names assigned to each button. If test fails:

customer's transceiver, which provides voltage to light the red LED.	Measure the voltage of the pins connected to the LCD by a multimeter. They should be properly turned on and off according to the programming codes of Arduino, which display correct product names. 4. Test the case of n = 6 and n = 10. Trace the 'ready' signal of Arduino using an oscilloscope. Time delay should be within 3 s and 5 s, respectively. 5. Set the distance between the cart and customer to be larger than 2 m. Measure the output voltage of the corresponding pin of Arduino and check if it is set to high.
User Interface: 1. LCD display needs be refreshed in 0.5 s after a new item is entered by keypad. And the information displayed should be the same as what the microcontroller outputs. 2. All output pins of the keypad should produce correct low/high signals in order to properly reflex which button is pressed.	1. Connect the LCD display to the microcontroller. Use an oscilloscope to measure the time delay for the LCD to output a high signal after one button is pressed on the keypad. That time interval needs to be less than 0.5 s. 2. For each button on the keypad, connect the corresponding two pins that should be set to high if that button is pressed to a multimeter. If both of them are 'on' and the remaining five are 'off', the keypad is working properly.
Alarm: 1. The red LED is expected to light when the distance between the cart and customer exceeds 2 m.	1. Set the distance between the cart and customer to be larger than 2 m. Measure the output voltage of the potentiometer that is connected to the

	customer transceiver. The expected value is 1.8 – 2.2 V.

Tolerance Analysis

In this project, the microcontroller processes a larger amount of information than any other part of the cart and it communicates with all the rest components. Consequently, the microcontroller critically affects the performance of the entire project. A minor mistake in calculating the cart's speed and direction may result in significant inefficiency when trying to avoid an obstacle. And the cart fails to perform functionally if the microcontroller is not able to figure out the best route in GPS mode. Therefore, the moving decisions of the microcontroller demands great accuracy and its connections with the transceiver, sensors and motors should be fast and reliable. The cart is expected to turn from 0 to 180 degrees both clockwise and counterclockwise and have a speed to sweep from 0 to 1.5 m/s. The turning angle is especially important so its tolerance is within $\pm$10%. Additionally, the store layout and product locations need to be properly stored in the microcontroller.

IV. Cost and Schedule

Labor Cost

Member	$/hour	Hours/week	Total hours	Subtotal	Subtotal * 2.5
Ying He	40	12	144	5760	14400
Di Fan	40	12	144	5760	14400
Xuyang Yao	40	12	144	5760	14400
				Total	43200

Parts Cost

Name	Part Number	Unit Price	Quantity	Total Price
Power Supply				
12 V DC Battery	Energizer A23	$1.15	5	$5.75
Voltage Regulator 5V	COM-00107	$1.25	1	$1.25
Battery Storage Clip Holder	YS320925515181	$0.996	5	$4.98
Microcontroller				
Arduino Uno	DEV-1102	$29.95	1	$29.95
Atmega328	DEV-10524	$5.50	1	$5.50
Voltage Regulator 3.3V	COM-00526	$1.95	4	$7.8
User Interface				
Keypad 12-button	COM-08653	$3.95	1	$3.95
LCD Keypad Shield	SainSmart 1602	$9.99	1	$9.99
Push Button Switch	COM-09177	$0.99	2	$1.98
Motor				
12V DC Gearmotor/Encoders	GM9236S025	$37.95	2	$75.9
Transceiver				
RFM12B-S2 Wireless Transceiver	WRL-09582	$6.95	4	$27.8
Red LED	COM-09590	$0.35	2	$0.7
1K Ohm Potentiometer	023-510	$1.79	1	$1.79
Sensor				
Ultrasonic Distance Sensor	HC-SR04	$5.59	4	$22.36
Miscellaneous				
Resistors, capacitors, inductors, transistors, wires, PCB and etc.			20	$15
Total				$214.7

Grand Total = $43200 + $214.7= $43414.7

Schedule

Week		Tasks	Assigned to
1	2/4/13	Finish primary proposal and mock DR sign-up	Ying He
		Order vehicle frame, install motors	Di Fan
		Assemble the vehicle	Xuyang Yao
2	2/11/13	Learn Arduino software and design store map	Di Fan
		Learn Arduino software, install receiver and sensors to the vehicle	Xuyang Yao
		Record the map into the memory of the controller	Ying He
3	2/18/13	Finish the customer tracking unit	Xuyang Yao
		Prepare for the Design Review: requirement and verification & flow chart	Di Fan
		Prepare for the Design Review: block description & schematics	Ying He
4	2/25/13	Finish the detection & decision unit for stationary obstacles	Di Fan
		Order the rest parts we need to use	Xuyang Yao
		Test the parts we order	Ying He
5	3/4/13	Detection & decision unit algorithm & write individual progress report	Ying He
		Assemble detection & decision unit parts & write individual progress report	Di Fan
		Debug detection & decision parts algorithm & write individual progress report	Xuyang Yao
6	3/11/13	Design the position system	Ying He
		Create circuit board and order PCB	Di Fan
		LCD display and store catalog	Xuyang Yao
7	3/18/13	Spring Break	

8	3/25/13	Set up user interface	Ying He
		Design one-by-one searching scheme	Di Fan
		Check and test LCD screen & keypad	Xuyang Yao
9	4/1/13	Design multiple-item searching scheme	Ying He
		Finish the most-efficient-path determination unit	Di Fan
		Debug algorithm and test all components before assemble	Xuyang Yao
10	4/8/13	Assemble all components	Ying He
		Finish attach components to PCB	Di Fan
		Debug and test	Xuyang Yao
11	4/15/13	Prepare for demo and presentation & write final report	Ying He
12	4/22/13	Demo and presentation	Di Fan
13	4/29/13	Final paper and lab notebook due	Xuyang Yao
		Check out	

V. Ethical Considerations and Safety

Ethical Considerations

Our project aims to build a shopping cart that provides great convenience and efficiency to customers in store. Thus, we need to address several items in the IEEE Code of Ethics.

IEEE Code of Ethics	Our concerns
1. to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;	We need to ensure that the future use of our project in stores will not contain any potential danger.
2. to avoid real or perceived conflicts of	Our interest of shopping cart project has no

interest whenever possible, and to disclose them to affected parties when they do exist;	conflict with any other existing object by research.
3. to be honest and realistic in stating claims or estimates based on available data;	We will be honest and realistic with TA and Instructor while giving explanation and presentation of our project.
4. to reject bribery in all its forms;	Bribery should not be a problem in the project.
5. to improve the understanding of technology; it’s appropriate application, and potential consequences;	We will learn and improve our understanding of any project related knowledge.
6. to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;	We will try our best to make the project perfect by using the knowledge we have obtained by far.
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;	We promise to guarantee that all the technical works are honest, and will admit the error if there is any. We will not take credits from other people’s work.
8. to treat fairly all persons regardless of such factors as race, religion, gender, disability, age, or national origin;	We will treat all people fairly regardless of their race, religion, gender, disability, age, or national origin.

Safety

In this project, safety issues are emphasized by restricting the maximum cart moving speed to be 1.5 m/s, which is slightly higher than average walking speed. Additionally, the obstacles-avoidance feature eliminates all potential collisions between carts and human or among carts. Ultimately, our design aims to provide safe and enjoyable shopping experience to customers.

VI. References

1. “Arduino Uno”. <http://arduino.cc/en/Main/arduinoBoardUno>.
2. “Pittman Express – GM9236S025 Datasheet”. <http://www.servo2go.com/support/downloads/GM9236S025.pdf>.
3. “Keypad – 12 Button Datasheet”. <https://www.sparkfun.com/products/8653>.
4. “RFM12B-S2 Wireless Transceiver Datasheet”. <https://www.sparkfun.com/products/9582>.
5. “Tutorial testando o transceptor RFM12B-S2 Wireless Transceiver com Arduino” <http://labdegaragem.com/profiles/blogs/tutorial-testando-o-transceptor-rfm12b-s2-wireless-transceiver >.