Nov 12, 2015

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC V5A 1S6

Re: ENSC 440/305 Design Specification – Shop Smart

Dear Dr. Rawicz,

The following document contains the design specifications for our Shop Smart project. The idea behind this project is to enhance the shopping experience of an everyday customer by creating an embedded system that can be attached to a shopping cart. This system will not only keep track of the items inside the cart, but will also cut down the time an average shopper spends in the store.

This document entails an overview of all aspects of the project, particularly focusing on our vision, design and technical specifications. Additionally, it discusses the design aspects of the individual components that make up our product and how they are incorporated into the design solution and functionality. The purpose of this document is to specify the stages in which the product is taken from a proof of concept to a final marketable product.

Shop Smart is composed of five highly motivated engineering students, coming from different backgrounds – Zargham Amer, Manpreet Singh, Yasamin Houshmand, Shaihryar Khan, and Jashan Dhaliwal. Our aim is to successfully complete this project with the highest possible quality and efficiency.

If you have any concerns or inquiries regarding this documentation, please do not hesitate to contact any of our team members.

Kindest Regards,

Zargham Amer
Chief Executive Officer
Shop Smart

Design Specification for *Shop Smart*

'The Self-Checkout on Wheels'

Project Team

Zargham Amer
Manpreet Singh
Yasamin Houshmand
Shaihryar Khan
Jashan Dhaliwal

Contact Person

Yasamin Houshmand
yhoushma@sfu.ca

Submitted to

Dr. Andrew Rawicz
Steve Whitmore
School of Engineering Science
Simon Fraser University

Issued on: November 12, 2015

Abstract

This document contains a detailed design specification for the hardware and software components of the Shop Smart system. It includes the high level architecture and the software algorithms involved within this process. Please note that these specifications only apply to the proof of concept and the prototype model described in the functional specification document [1].

Shop Smart is providing a solution that comes with an embedded system (the BeagleBone Black), an RFID reader and a smartphone application. This document not only describes the objectives of our device, but also clearly justifies the decisions taken in the implementation of the product.

The software side consists of a GUI application that will be incorporated on an embedded system with which users will interact. More precisely, the GUI will assist the user in keeping track of the items present in the shopping cart and will maintain the item information on a list as the user proceeds to add and/or remove items. Simultaneously, with the help of a smartphone application, a user can also generate a shopping list that can be transferred onto the main GUI application. The software section involves algorithms that play a pivotal role in the proper functionality of the overall system, as the algorithms are responsible for displaying item's information scanned through the RFID reader, communication between the smartphone application as well as with the database of the items available in the store.

The hardware section consists of an RFID reader, communication of the RFID reader-embedded system and an efficient portable battery to power up the whole thing up.

A detailed test plan is also outlined in this document, and will play an essential role in determining whether the system meets our expectations. At this moment there are no major delays anticipated, thus making the final date for the release the same as was originally planned: December 8th, 2015.

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Glossary

9600 Baud Rate	Standard baud rate (or more commonly used baud rate) [26]
Baud Rate	Rate at which data or information is transferred between communication channels. [26]
BJT	Bipolar Junction Transistor
Cradle-to-Cradle Design	A design technique that has zero waste. This design method incorporates the reuse of all components and materials incorporated in the design of a product, eliminating all waste.
CVV	Card Verification Value. It is a 3 digit number to prevent fraud and authorize fair method of payment.
EEPROM	Electrically Erasable Programmable Read-Only Memory
Flow Control	Control through which flow of data can be managed between computers or devices [2]
GUI	Graphical User Interface
IC	Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
MMC	Multimedia Card
NFC	Near Field Communication
PC	Personal Computer
PCB	Printed Circuit Board
PMIC	Power Management Integrated Circuit
RF	Radio Frequency
RFID	Radio Frequency Identification
RFID Tags	Radio Frequency Identification tags with unique ids
RX	Receiving (data/packets) into the interface [26]
Serial	Interface that streams its data at a rate of one single bit at a time [26].
TX	Transmitting of (data/packets) out of the interface [26]
UART	Universal asynchronous receiver or transmitter, responsible for implantation of serial communication [26]
USB	Universal Serial Bus

1 Introduction

Shop Smart is introducing a "Self-Checkout on Wheels" that is designed to assist consumers with their everyday shopping needs. Our device consists of three design areas: electronics, software, and RFID tags.

The main electronic component of our device is an embedded system called the BeagleBone Black board. This embedded system runs the software application which enables users to find information on various items that are in the store. The RFID reader will be used to scan each item into the system, and the touchscreen module is implemented for user interaction, and particularly to display the items present in the cart that needs to be processed and checked out.

The software section consists of an easy to use GUI application that will have multiple functionalities that a user may access. More details of this can be found below in Section 4. One of the main components of the software design is a smartphone application that allows the customer to bring a pre-planned shopping list and simply import it to the device on the shopping cart.

Lastly, each item will have a unique the RFID tags before they are placed in the store. This will enable users to scan items with the RFID reader and simply place them in the cart.

Our main goal in creating the Shop Smart system is to provide a solution that will enhance the shopping experience of customers all while reducing the required manpower to manage a store.

1.1 Scope

This document entails the design of the Shop Smart solution. The design report is coordinated with the requirements from the previous Functional Specification documentation [1]. A number of priorities for the requirements will be discussed in detail. Additionally, component drawings, high-level and low-level flow diagrams, as well as hardware schematics will be used to describe the system.

1.2 Audience

This document is intended to be used by the members of the Shop Smart team in order to help with the overall development and design of our product. It will provide a basis for the engineers during every step of design process of the device, and will be used to confirm that the intended requirements are met. The document will also assist with the creation of a test plan, which will ensure that the delivered product functions as proposed by the design.

2 System Overview

Shop Smart contains an embedded system, the BeagleBone Black, an LCD screen, a single RFID reader, numerous RFID tags and a Wi-Fi module. These five major hardware components, when combined with the GUI and smartphone application, are what create our product. By enabling the user to transfer their shopping list from the mobile application onto the embedded system and by interacting with the GUI, we help them keep track of their shopping expenditures and avoid checkout lines.

By placing RFID tags onto each item we are able to track any objects placed inside the shopping cart, and concurrently update the shopping list. This basic concept of tracking everything is how we plan to enable our entire system and is further illustrated in Figure 1 below.

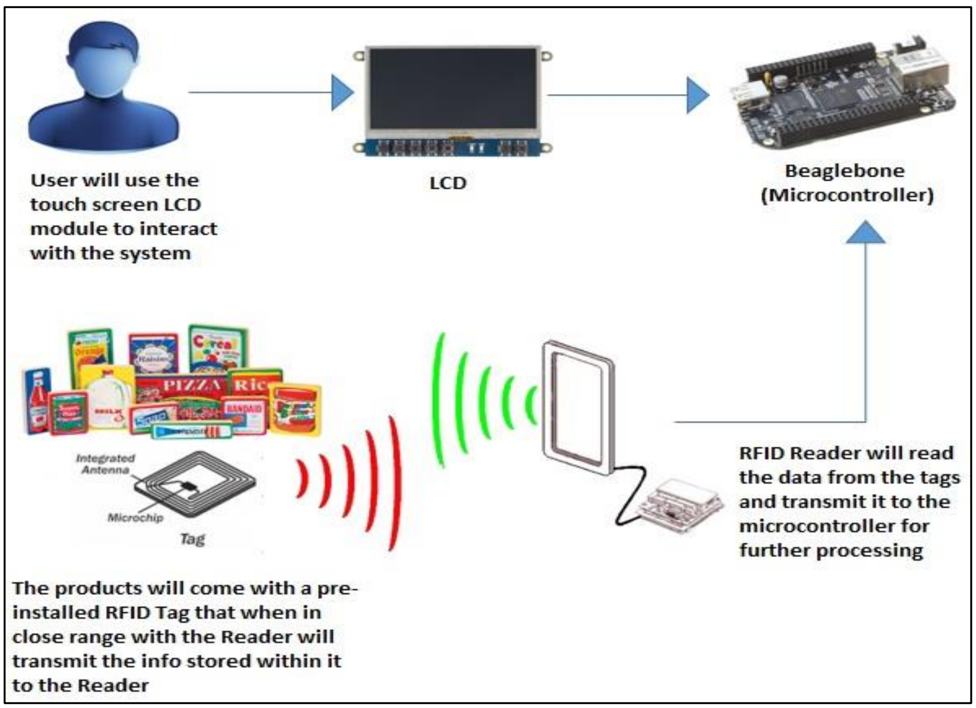

Figure 1 - High Level System Overview [3] [4] [5] [6]

3 Overall System Design

Figure 2 below is a 3-dimensional SolidWorks model of the overall Shop Smart system. It displays how the BeagleBone Black board, touch screen module and RFID reader will be connected together.

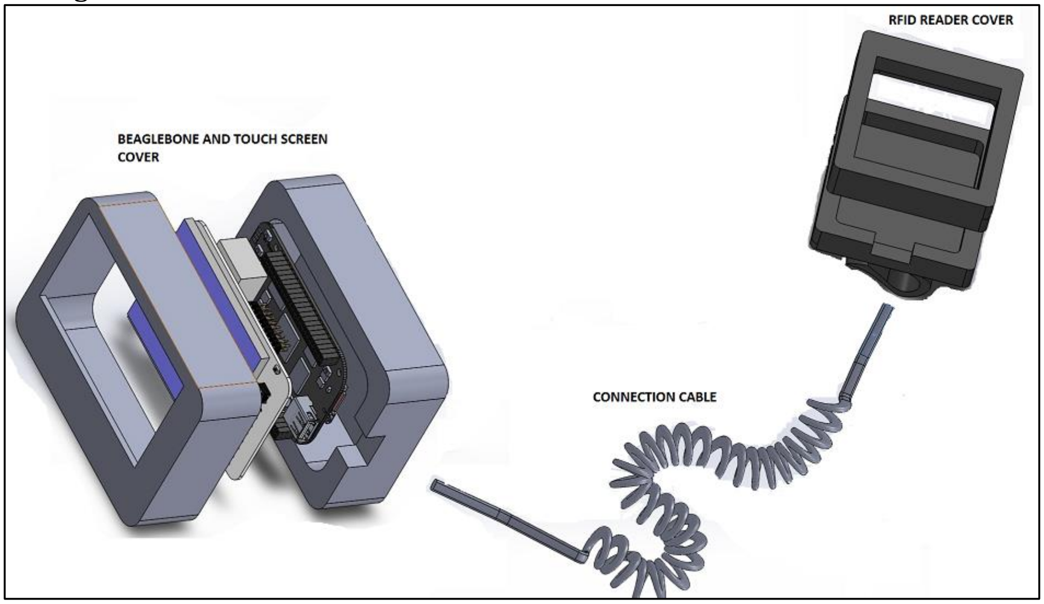

Figure 2 - SolidWorks Diagram of the BeagleBone Black Board Connection with the RFID Reader

3.1 Software Design

Shop Smart is an automatic checkout system on wheels that consists of a wide range of functionalities and features which are integrated using various hardware and software components. The software system design consists of two options. Option 1 is being able to use the touch screen GUI to begin adding and/or deleting items from the shopping cart list. The GUI is implemented using scripts written in python, as well as with the help of various software processes running at the back end.

Option 2 is for customers who prefer using their smartphones to create a shopping list as opposed to the GUI. They are able to create this shopping list on their phone with an android application developed using an SDK from Android Studio. Once the list is created, it can simply be imported onto the main GUI and the user can continue shopping throughout the store.

3.2 Hardware Design

The main hardware component of the Shop Smart system is the BeagleBone Black board. This board runs on an embedded Linux operating system and will be powered up using a DC power supply of 5V and 1A. Interestingly, the system can also be powered up using a USB client port connection. In addition to the BeagleBone Black board, our system will include the touch screen module seen in Figure 3 below.

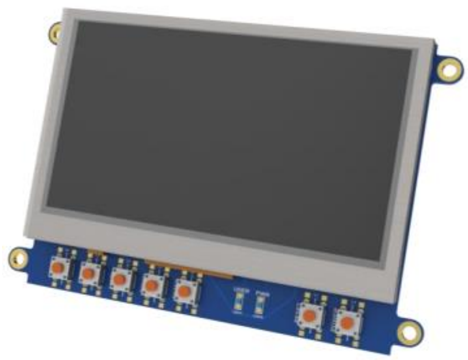

Figure 3 - Touchscreen Module [7]

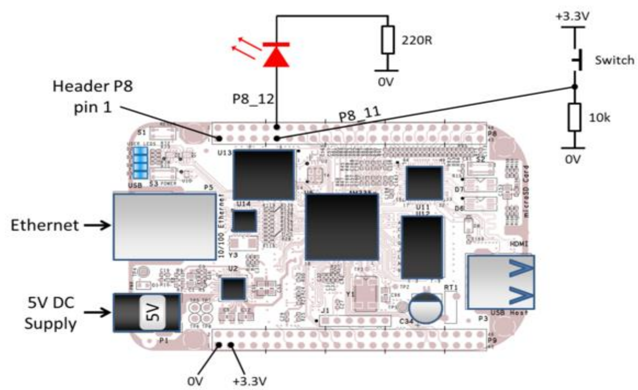

Figure 4 - BeagleBone Black High Level Schematic [8]

As seen in Figure 4 above, the BeagleBone Black board consists of a debug serial header, an Ethernet port, 2 LED lights, one of which turns on if the board is powered and the other will be custom configured by our team for other use, a USB connection hub and a DC power outlet.

3.3 Device Enclosure

According to [R29-C] of the Functional Specification document [1], the device needs to be securely placed in an enclosure that is strong enough to withhold the weight of the system, but is not too bulky. Due to its resilience and inertness, we chose to use polystyrene thermoplastic material for the casing. Please note that this casing, as illustrated in Figure 5 below, will be applied in the final production line and not in the prototype phase.

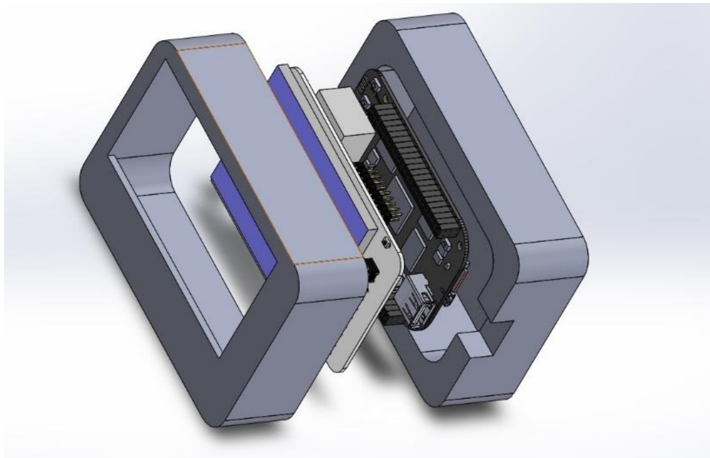

Figure 5 – SolidWorks example model of an enclosing case

4 Software Design

The software design is divided into two subsections: the python GUI application and the android application. The python GUI will be running on the embedded system for the user to interact with, whereas the smartphone application will be solely created with the intention of users using it to create a shopping list, and importing this list onto the GUI.

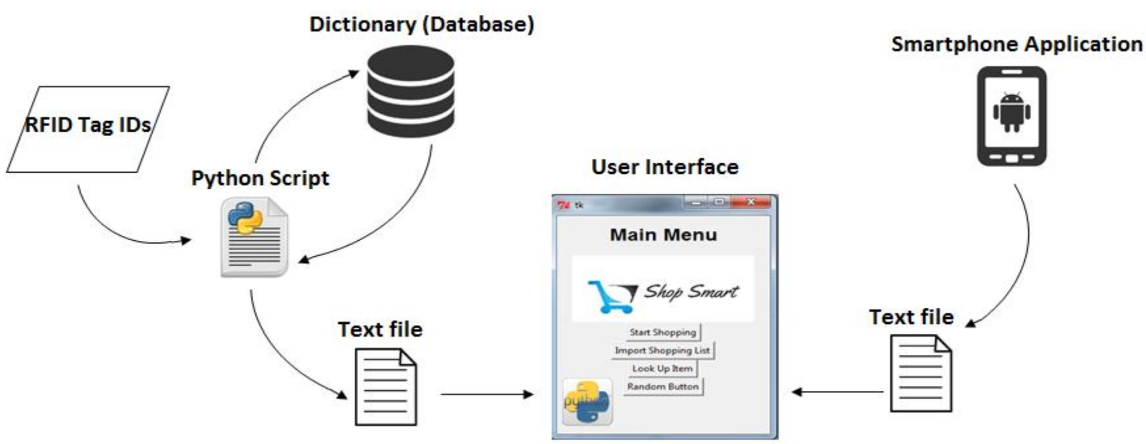

Figure 6 – Overall Software System Design [9] [10] [11] [12] [13]

Figure 6 above depicts the overall software system design. As soon as the first RFID tag is scanned by the RFID reader, a python script will read the tag ID and will match it with the IDs contained within a pre-defined python dictionary. This dictionary will contain the name, price and location associated with the IDs and will return this information back to the script. Once the script receives data from the dictionary it will write it within a text file (.txt), which will be read by the GUI application. The GUI will read the contents of the .txt file and display it within a list box. The items will keep stacking up on the list box as the user continues to add items in the shopping cart.

The smart phone application will help the user create a shopping list before entering the store. This application will prompt the user to select various items that are available in the store in order to add them onto their shopping list. Additionally, the user will be given the option to save and export this list onto the GUI. This shopping list will also be written into a text file and will be transferred to the embedded system with the help of a Wi-Fi module.

4.1 GUI Application

The GUI application is designed to be very simplistic, so that users of any age group will have no difficulties working with it. It has been developed with the help of a python platform that was chosen due to existing team expertise and familiarity with this programming language.

The GUI is employing by a number of classes in such a way that if one of the feature breaks down it will have no effect on the other features of the application. A separate class is created for each of the different operations and functions that are being used at various points within the shopping process. The application features will include “Start Shopping”, “Importing Shopping List”, “Look up an Item” and “Checkout”.

Figure 7 below displays an example of the GUI application screen. In this example the user has clicked on the “Look up Item” option from the home screen and has been consequently provided with a list of items to choose from. After selecting a specific item, the ‘Load’ button will display the item details including the price and the item’s location. These features are in accordance with the [R22-A] requirement of the functional specifications from reference [1]. Please note that these requirements have been slightly modified to incorporate a dictionary in place of a database.

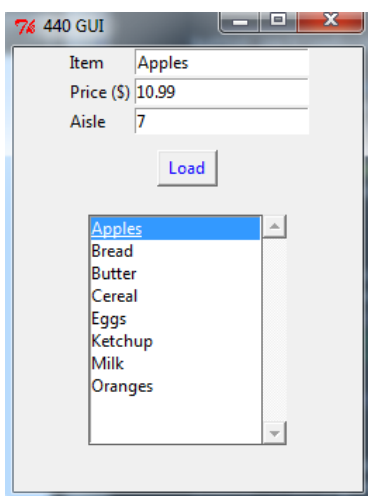

Figure 7 – Look up Item Menu screen

The item list is imported from a predefined python dictionary that includes all the information about each individual item. The data is called from the python dictionary as opposed to the program itself in order to keep the application script short. If any changes are to be made, it can be simply done within the dictionary without altering anything within the GUI's code, which can also be done during run time [14]. The GUI employs a dictionary and not a database which overrides [R23-B]'s database requirements from reference [1]. The reason for this change is because the application does not require complex or large data sets. Additionally, with the help of a dictionary multiple data types can be easily handled such as strings and lists, not just numbers [15].

4.2 Android Smartphone application

As stated in the overall design section and under [R26-A]'s software requirements of the functional specification [1], the smartphone application will allow users with android devices to make a shopping list before entering the store. The user will be able to select or unselect items from a list provided within the application. Once the list is saved, it will be exported to the GUI application with the help of the Wi-Fi module.

Figure 8 - Main Screen

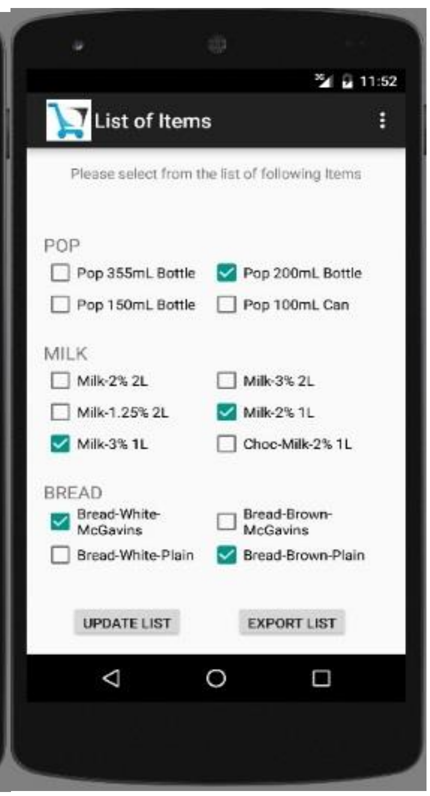

Figure 9 – Page displaying list of items

Figures 8 and 9 display the Shop Smart android application. The items listed on the smartphone application can be chosen with the help of a user interactive page containing a list of items. All items inside the shop can be pre-stored on the mobile application and sorted into different categories. Once the user selects all of the items they intend to buy, an array list gets generated in the background. In situations where a shopper changes his/her mind about a particular item, they can simply unselect the item from the page and press the

'Update Cart' button. This will refresh the array list of items sought to be purchased. Thereafter, the user can press the 'Export Items' button which will generate a text file (.txt) containing the list of selected items. This text file will then be exported onto the GUI of the Shop Smart system. Please note that the requirements of [R27-B] from reference [1] were modified from the user tapping their smartphone to using a Wi-Fi module to transfer the shopping list. This modification arose as we are now using a Wi-Fi module to send the list as opposed to using NFC technology as originally documented.

After the shopping list is successfully imported to the touchscreen device, the user will be shown two separate lists. These two lists are seen in Figure 10 below, and are created on the GUI with the help of two separate text files. As the user continues to place items into the shopping cart, one of the lists will be updated and a python script that is running in the background will compare and update the data every 500 milliseconds between these two text files. If two entries are found to be similar, that item will be automatically removed from the shopping list. This way the user can continually keep track of the items still pending to be added into the cart.

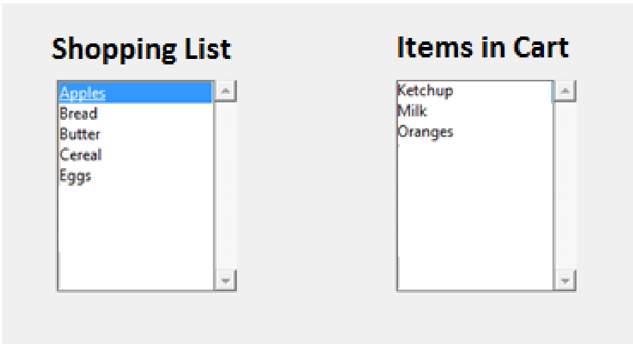

Figure 10 – Screenshot of 'Import List' Menu Item

5 Hardware Specifications

The Shop Smart solution consists of the following hardware components:

- An RFID Reader and an ID-12LA module
- Various RFID tags
- The BeagleBone Black board
- An LCD cape
- Communication components between the BeagleBone Black board and the LCD cape
- A Wi-Fi module

5.1 Communication between RFID Reader and ID-12LA Module

As seen in Figure 11 below, we chose to use is the SparkFun RFID USB Reader due to its simplicity and ease of operation. It consists of a USB to serial base that can be attached to the BeagleBone Black board using a miniUSB cable.

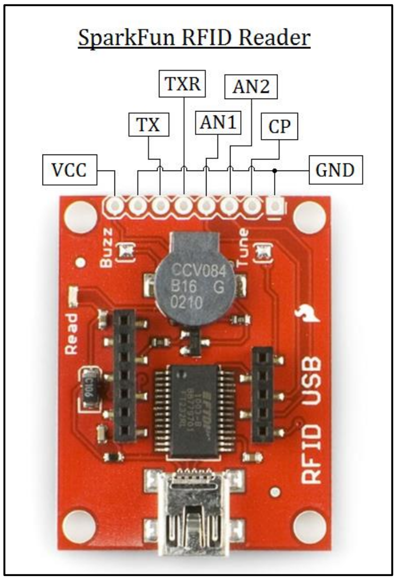

Figure 11 - SparkFun RFID Reader Layout with Labeled Ports [16]

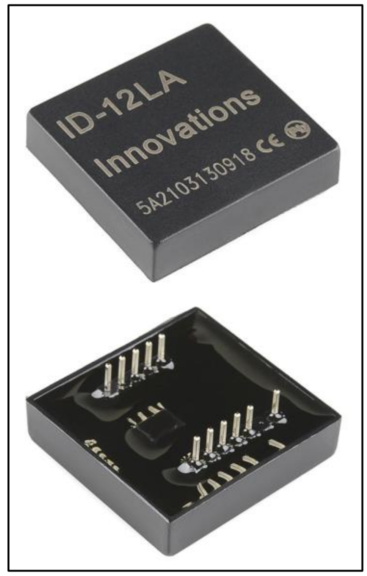

Figure 12 - ID-12LA RFID Reader [16]

Combining the RFID USB Reader with the ID-12LA, 125kHz reader shown in Figure 12 above, we were able to create a workable RFID Reader which can now be used to scan items that are placed in or removed from the shopping cart.
Table 1 displays the ID-12LA pin assignment corresponding to Figure 13.

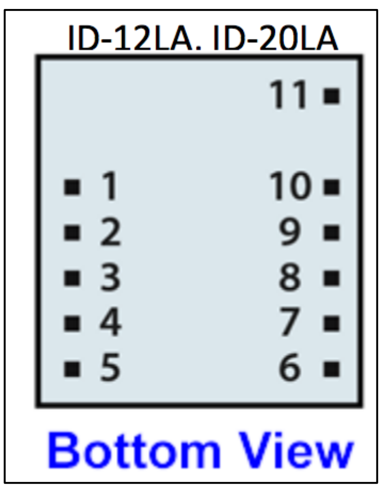

Figure 13 - ID-12LA Pin Overview

Table 1 - ID-12LA Pin Assignments

PIN	
1	GND
2	RES (Reset Bar)
3	NC
4	NC
5	CP
6	Tag in range
7	Format Selector
8	D1 (Data Pin 1)
9	D0 (Data Pin 0)
10	Read (LED/Beaper)
11	+2.8 thru ++5.0V

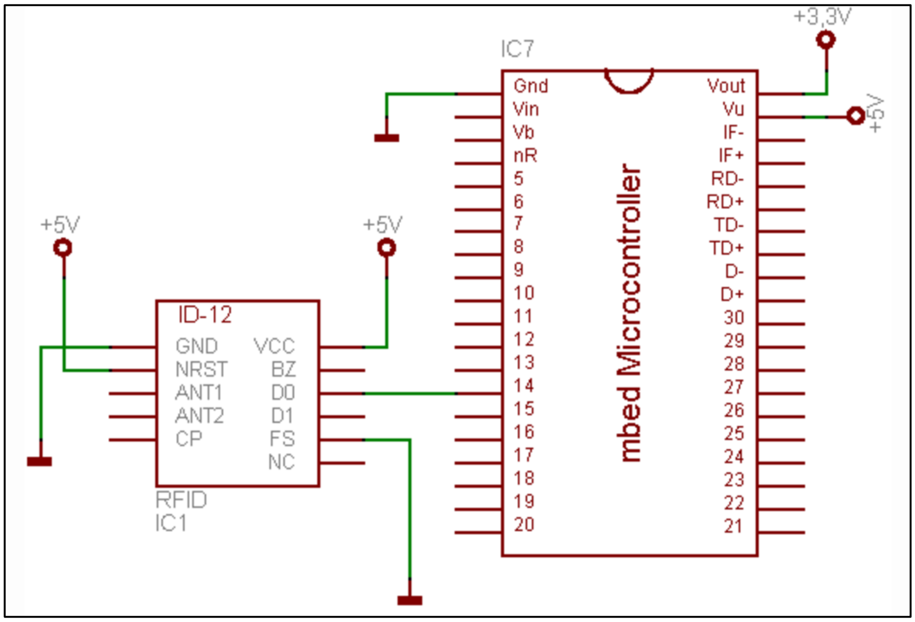

Figure 14 - Communication between ID-12LA module and RFID reader microcontroller [17]

The SparkFun RFID reader was selected for its reliable microcontroller, flexibility between pins and its compatibility with multiple modules. Each module has a specific frequency range and, for future operations, if the Shop Smart system requires operating on a higher frequency it can be done by simply replacing the ID-12LA module. We have ensured that this ID-12LA module is firmly connected to the reader board, fulfilling the [R35-B] requirements as mentioned in the functional specification document [1].

The ID-12LA RFID reader provides a serial communication, which streams the data by one single bit at a time and therefore is simple and capable of providing seamless data flow. Additionally, its interfaces can easily operate on as little as one wire. Moreover, the ID-12LA module operates at a 9600 baud rate and uses ASCII characters for the data operation via pin number 9, as seen in Figure 13. These properties are used to communicate to the ID-12LA module from a PC.

Pin number 8 is used to connect to a computer with an R232 input. A screenshot of this operation is shown in Figure 15 below. Also, please note that pin number 6 is activated when an RFID tag is in the range of the reader, which is +12cm for ID-12LA [18].

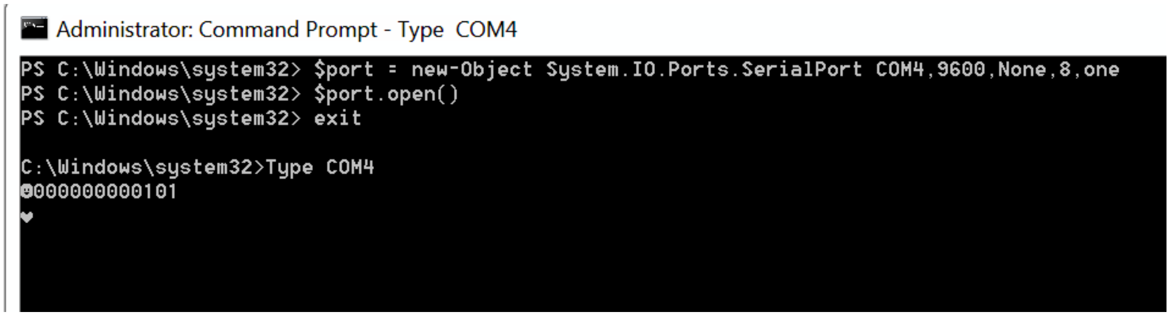

Figure 15 - Screenshot of Data operation between a computer and ID-12LA

For the power supply, a maximum voltage of +5V can be applied to pin number 2. Further details on the power operation are discussed in section 5.3 below.

5.2 RFID Tags

We chose to purchase the L-Link 125kHz passive RFID tags shown in Figure 16 below mainly for their relative inexpensiveness, large quantity (100 pieces in a pack) and durability due to the ABS housing material.

Figure 16 - L-Link 125kHz RFID Tags [19]

Additionally, the fact that these tags have an operating and storing temperature of roughly -20°C to 80°C make them ideal to attach to different items that one may find in a store, such as food packaging that needs to be placed in a freezer. Furthermore, our RFID reader is fully compatible with tags that operate at 125 kHz, thereby satisfying [R18-B] of electricals requirements of reference [1]. Table 2 below contains further details on these RFID tags.

Table 2 - RFID Tags Specifications

Type	Frequency	Properties
Passive Tags	125kHz	Operating Temperature: -20 to -70 Storage Temperature: -20 to +80 Data Retention(year): >10

5.3 Power Supply

The BeagleBone Black board comes with a built-in power management IC (PMIC) based on the TI TPS6217C specifications. The IC also has the capability of built-in battery charging. Even though the USB has a power requirement of 5V, the BeagleBone Black board can still run on a lower power, which is why we will be using a 3.7V lithium cell battery to power the entire board.

Table 3 below displays the compatibility, reading range and power requirements needed for the ID-12LA RFID reader to function properly. It is important to note that ideally the power supply will be a linear type of 3.3V, however that batteries may also be used without a regulator and with a suitable arrangement of a 3V lithium cell or three 1.5V cells [18]. Also, switching power supplies can be used, but care must be taken to ensure that the switching frequency is not close to a multiple of 125kHz, as it can severely interfere with the RFID reader and cause the range the be significantly reduced.

Table 3 - Compatibility, Reading Range and Power Requirement of the ID-12LA RFID Reader [18]

Parameter	ID-2LA, ID-12LA, ID-20LA
Frequency	125 kHz nominal
Card Format	EM 4001 or compatible
Read Range ID3	Up to 30 using suitable antenna using ID-Innovations clamshell card @5v
Read Range ID13	Up to 12cm using ISO card, up to 18cm using ID-Innovations clamshell card @5v
Read Range ID23	Up to 18cm using ISO card, up to 25cm using ID-Innovations clamshell card @5v
Encoding	Manchester 64-bit, modulus 64
Power Requirement	+2.8 VDC thru +5 VDC @ 35mA ID-12LA, 45mA ID-20LA
RF I/O Output Current	+/- 200mA PKPK

5.4 BeagleBone Black Board

As shown in Figure 17 below, we are using the BeagleBone Black board, Revision C which is the latest version, as our main hardware component for the Shop Smart system. The reason why we have chosen BeagleBone Black Rev C is because this latest edition has an AM3358BZCZ100 processor which is relatively faster than all of its predecessors. Also, it is compatible with the touchscreen module that is being used to display the list of items. This compatibility ensures that meet the requirements of [R52-B] from reference [1].

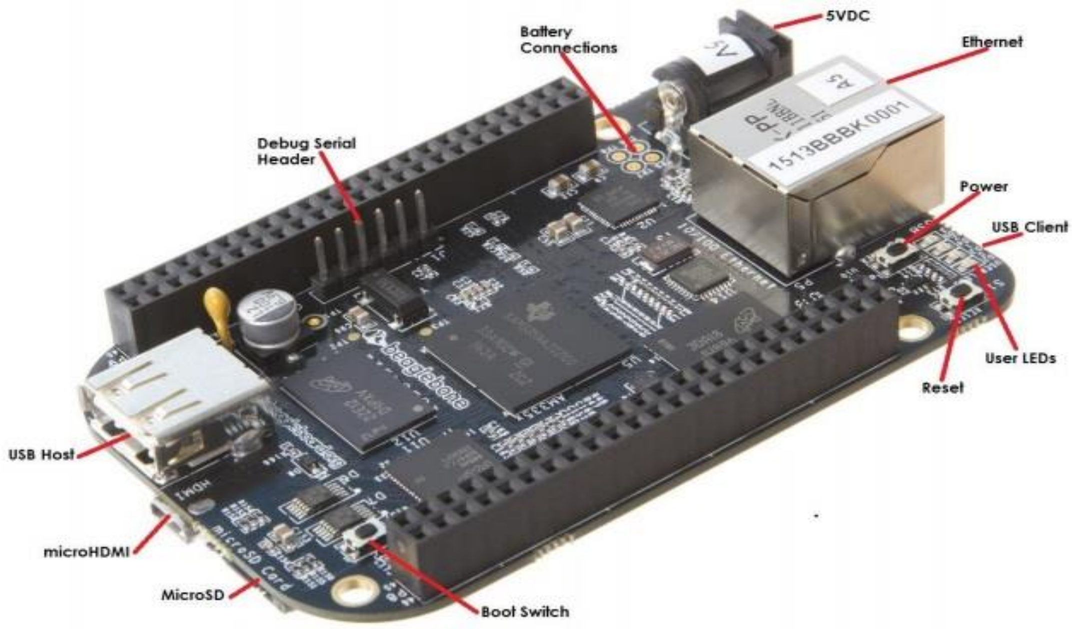

Figure 17 - BeagleBone Black Rev C [20]

As depicted in Figure 17, this board also has a boot switch. If this switch is pressed down while the power is being reapplied, it will attempt to boot from the USB port client. The power for this board is sourced as required by TPS65217C PMIC standards to individual sections of the board.

There are three memory devices onboard the BeagleBone Black – an SDRAM Memory of 512 MB DDR3L, which operates at 800 MHz, a single 4KB EEPROM memory that contains the basic board information, and lastly, an embedded 4GB eMMC which is enabled at the MMC1 port of the processor by default.

The USB host port provides a current of up to 500mA and acts as power HUB. This component of the BeagleBone board will be extremely important for our project as it is where we will be connecting our RFID reader and Wi-Fi module.

Table 4 below provides a high level description of the BeagleBone Black specifications used for developing our Shop Smart system.

Table 4 - BeagleBone Black Specifications

Processor	Sitara AM3358BZCZ100 1GHz, 2000 MIPS
SDRAM Memory	512MB DDR3L 800MH
PCB	3.4” x 2.1” 6 layers
Indicators	1-Power, 2-Ethernet, 4-User Controllable LEDs
HS USB 2.0 Client Port	Access to USB0, Client mode via miniUSB
HS USB 2.0 Host Port	Access to USB1
Serial Port	UART0 access via 6 pin 3.3V TTL Header
Ethernet	10/100, RJ45
User Input	Reset Button Boot Button Power Button
Weight	5.5 oz (39.68 grams)

5.4.1 Battery Connections

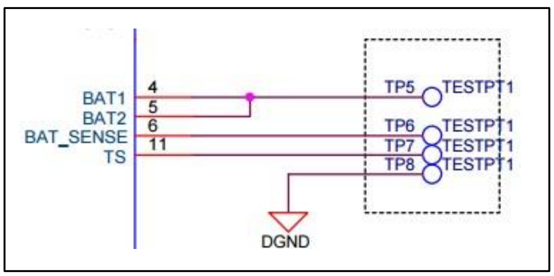

Figure 18 - Battery Schematic [20]

Currently, the system is being powered by the USB connection. For the battery operation we will need to connect pins 4, 5, 6 and 11 of the BeagleBone Black board, seen in Figure 18 above, with test pins TP5 through TP8.

5.4.2 USB Host

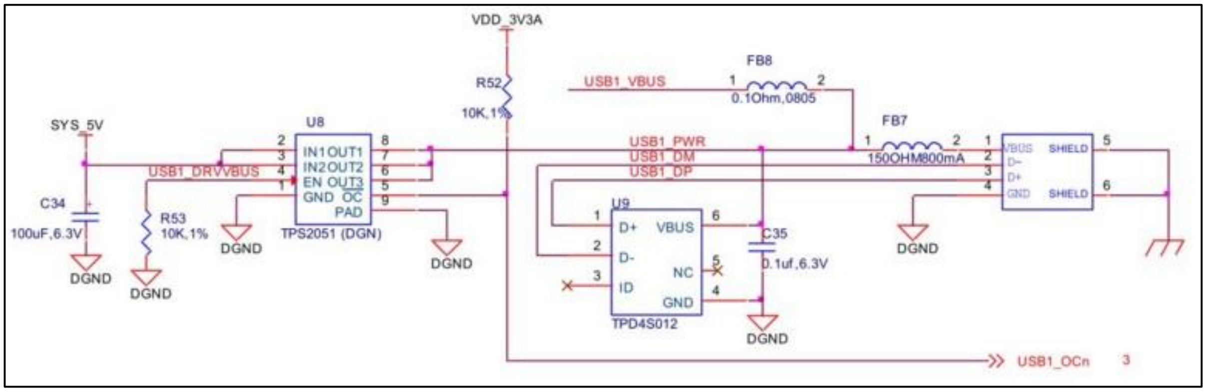

Figure 19 - USB Host Schematic [21]

Figure 19 above is a schematic of the USB host component on the BeagleBone Black board. The USB host is being used as a connection between the RFID reader and board itself. Please note that the Wi-Fi module will also make use of USB port.

5.4.3 USB Client

The schematic seen in Figure 20 below is for the USB client on the BeagleBone Black board. Currently, the system is being powered with the help of the USB client which provides a 5V DC supply to the LCD cape that is installed. This 5V DC power is provided on the SYS_5V pin which comes from TPS65217C power rail of the expansion header used by the Cape.

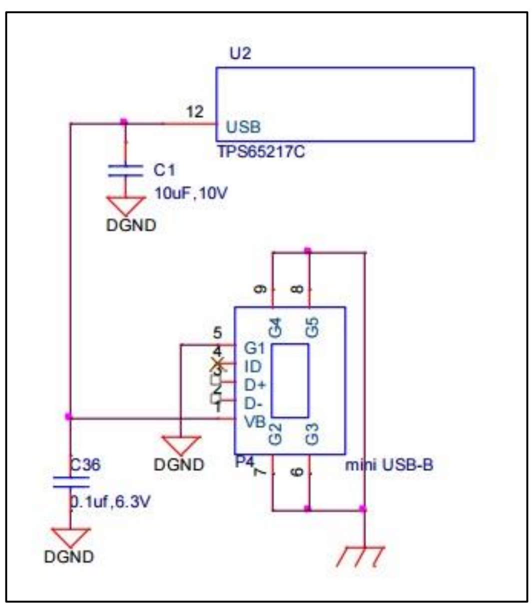

Figure 20 - USB Client Schematic [21]

5.5 LCD Cape

The 4DCAPE-43T touchscreen module is a 4.3" TFT LCD 480x272 resolution display that is designed to be compatible with only the BeagleBone Black board. The 120.4 x 80.0 x 24.8mm module, seen in Figure 21 below, comes with four mounting holes on the cape to fit easily and firmly inside an enclosure.

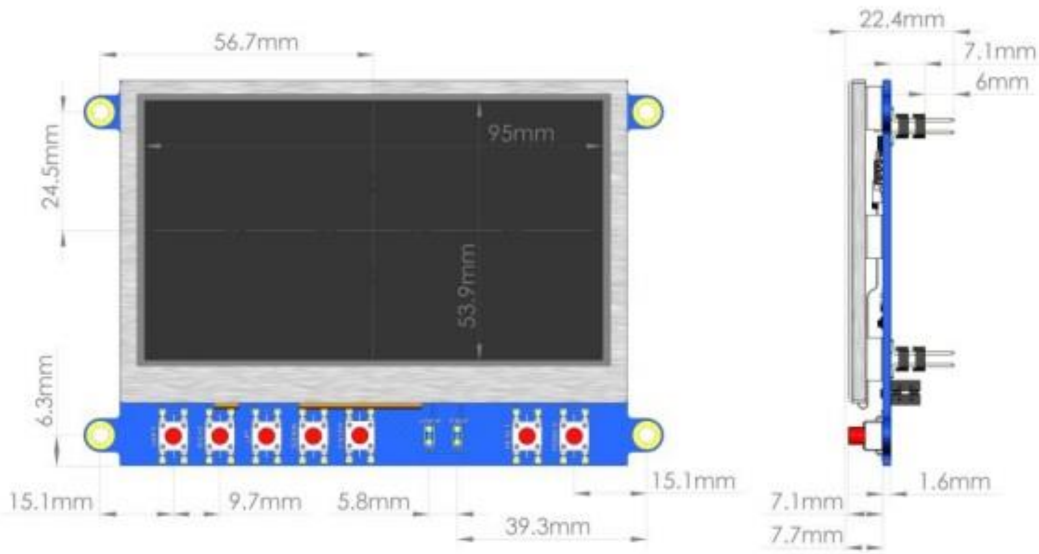

Figure 21 - LCD Dimensions [7]

Table 5 below outlines the module specifications of the LCD cape

Table 5 – LCD Cape Specifications

Module Specifications
4.3" TFT LCD Display, 480x272 Resolution
7 push buttons, including LEFT, RIGHT, UP, DOWN, ENTER, RESET and POWER
2 LED Lights for Power and User Inputs
Module dimensions: 120.4 x 80.0 x 24.8mm
4x 3.5mm Mounting holes
Powered directly from BeagleBone Black

Besides the power button and system reset button, there are 5 other push buttons that can be used to navigate the touchscreen. These buttons are titled "Left", "Right", "Up", "Down", and "Enter", and are used to select items on the screen. The reason why we have chosen the 4DCAPE-43T version is because it has resistive touch capabilities, which are in line with the [R8-B]'s requirements of our functional specification document [1]. As a result, the functional requirements under [R56-A] will be abandoned, which means the push buttons won't be used to scroll the list that will be displayed on the GUI.

5.6 Communication between BeagleBone Black and LCD Cape

BeagleBone black possesses a number of connectivity options such as Ethernet, HDMI and audio capabilities. Our Shop Smart system will use the battery connections, USB host connector, USB client connector and expansion header. These functionalities will be used to assist the LCD cape with its communication with the AM3358BZCZ100 microprocessor. Figure 22 shows the schematic and pin assignments that are employed by the LCD on the expansion header. I2C2_SDA, GPIO0, GPIO1, GPIO2 and GPIO3 are used for data communication via different protocols to provide video signals from the BeagleBone Black board to the LCD display.

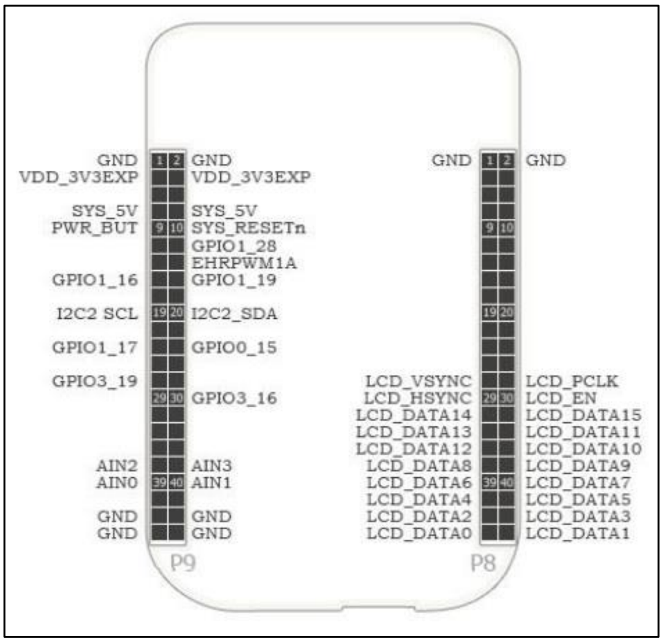

Figure 22- Pin Assignments for LCD Cape on expansion header [7]

5.7 Wi-Fi Module

In order to connect an android smartphone with the BeagleBone board, to transfer the shopping lists and to enable on-cart purchasing, we decided to buy a USB Wi-Fi module. We chose to purchase the Tenda W311MI Mini Wireless USB Adapter seen in Figure 23 below, due to its small size (21mm by 15mm by 7.7mm), simplistic USB 2.0 connection, compatibility with Linux and it's considerably low cost of roughly $20.

Figure 23 - Tenda W311MI Wi-Fi Module [22]

Since it uses the IEEE 802.11b/g/n and USB 2.0 standards, it has a theoretical maximum wireless speed of 150Mbps. This was not a major concern for our system considering an upgrade to USB 3.0 would have meant a higher cost. Additional specification can be found in Figure 24 below.

Specification

Hardware Features	
Standards	IEEE 802.11b/g/n
Interface	USB 2.0
Antenna	2dBi fixed antenna* 1 (internal PCB) Frequency: 2.4GHz
Button	None
Dimensions (L*W*H)	21mm×15mm×7.7mm
LED	1* Link/Act
Wireless Features	
Wireless Speed	Up to 150Mbps over 11n
Frequency	2.4 GHz
Channel	1~13
Transmit Power	18dBm (Max)
Operating Mode	Infrastructure Ad-Hoc
Software Features	
Security	64-/128-bit WEP WPA-PSK, WPA2-PSK, WPA-PSK/WPA2-PSK WPS
Compatible OS	Windows 2000, Windows 2003, Windows XP 32-/64-bit, Windows 7 32-/64-bit, Linux 2.2X/2.4X/2.6X, MAC OS
Others	Connect PSP, WII and NDS to Internet and Xlink Kai

Figure 24 - Tenda W311MI Mini Wireless USB Adapter Specifications [23]

For a Wi-Fi connection to work properly there are three main components that must be taken into account: the wireless transceiver module, the wireless driver and the electromagnetic spectrum.

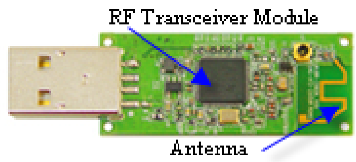

Figure 25 - USB Adapter Wi-Fi PCB [24]

The wireless transceiver, seen in Figure 25 above, is composed of an integrated circuit (IC) placed on a PCB. This wireless module contains an RF transmitter, receiver and antenna. Depending on the wireless standards, the transceiver can transmit on the 2.4GHz or 5GHz frequency bands using 20 MHz or 40 MHz wide channels [25]. These signals are generated with the use of a modulator component of the transceiver, which modulates the binary data stream into 2.4GHz or 5GHz frequencies, which are then sent out of the IC to a connected antenna.

The Wi-Fi driver is the software portion which enables a user to change the mode of operation of the transceiver module with the use of a GUI. A large variety of hardware features can be controlled using the device settings or manager applet that is provided.

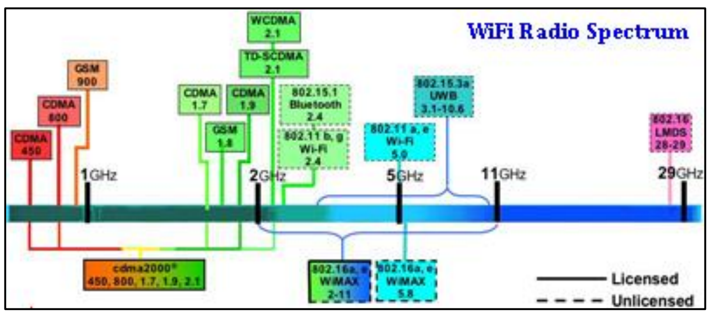

Figure 26 - Wi-Fi Radio Spectrum [24]

The radio frequency spectrum, seen in Figure 26 above, is regulated by the IEEE 802.11 standards and has a direct impact on the network performance based on the device's frequency band. The 2.4GHz frequency band has a large wavelength, which enables the signal to pass more easily through dense and solid objects, however causes the data transfer rate to be slow due to the large sine wave. Comparatively, the 5GHz frequency band has a relatively short wavelength, causing more data to be transmitted at a faster rate. However, the 5GHz frequency range can reduce the network performance by having difficulty sending data across solid objects, and needing quite a few more packet resends for the data to be properly received.

6 Test Plan

In order to make sure the final prototype meets the expectations and goals set by our team, a test plan has been devised. This test plan, depicted in Figure 27, section 6.3, clearly outlines various stages of the testing process. The prototype can be broken into several components such as the RFID Reader, the RFID tags, the BeagleBone Black board, the battery, the Wi-Fi module and the smartphone application. These components can be tested individually as well as part of complete system as a whole.

6.1 Phase I Testing

Phase I testing relates to the RFID reader, the RFID tags and the BeagleBone Black board:

Physical Inspection: During the stage of Physical Inspection, the RFID reader and tags were checked for any compatibility issues. This was done by confirming that the tags could indeed be scanned by the reader. Additionally, we analyzed the minimum range of the reader could scan a tag. Moreover, the dimensions of the RFID reader and the BeagleBone Black board were also examined during this stage.

Electrical Testing: Electrical testing was done on the BeagleBone Black board to confirm that its performance and functionality were up to our requirement standards. The ports were analyzed for their computability with the rest of the components.

Compatibility Testing: Once both of the initial stages of physical and electrical testing were passed, several compatibility testing techniques were executed to validate the operation of the BeagleBone Black board with the RFID reader. This preliminary stage of testing played a pivotal role in reducing the likelihood of major issues during the later development phase of the prototype.

Once the embedded system was ready, a graphical user interface was and a series of software tests were done:

Software Testing: To verify the performance of the GUI and to confirm that it meets the design specifications, different types of functional testing techniques were initiated, some of which are still ongoing.

- **UI Testing:** During the implementation of the GUI, the process of unit testing checked if the code written contained any logical errors. This unit testing measure also allowed us to continually ensure that a unit of code does what is intended to do, even as associated units change [27].
- **Regression Testing:** Whenever a new software update is introduced, tests are performed to ensure that new bugs are not introduced in the current system. This is done by closely monitoring the outputs of the code.
- **White Box Testing:** After GUI implementation, detailed analysis of the code was done. Tags were scanned on the reader and the item's associated name and price was displayed on the GUI. To ensure that item's details are from the matching tag ID, it was compared to the database file which contains a list of complete items

6.2 Phase II Testing

Testing of the smartphone app and Wi-Fi module:

Electrical Testing: Similar to the Phase I's electrical testing, Wi-Fi module will be tested for its performance and proper functionality. Tests will be performed on the BeagleBone to make sure that this Wi-Fi module can be detected successfully.

Compatibility Testing: Compatibility tests will be run between Wi-Fi module, smartphone app and the BeagleBone by analyzing the configuration setting of each system standalone and how it can be optimized for the best and efficient performance. This computability is necessary for the swift communication between BeagleBone and smartphone's app through the Wi-Fi module.

Software Testing: To test the proper working of the app, similar software testing like Phase I will be followed.

- **UI Testing:** According to [R20-A] of the functional specification [1], GUI shall be user friendly. In order to meet this requirement, appearance of the text and their font size on an android device will be tested. User should also be able to scan through a list of items easily and select items of interest which he/she plans to buy in a store.
- **White Box Testing:** Once the UI is working according to the expectations, in depth tests will be performed on the actual functionality of the app. The list made by the user on their smartphone should be transferrable to GUI through a Wi-Fi module.

6.3 Phase III Testing

Testing of the battery and the final Kit:

Electrical Testing: This testing will include the debugging of battery's circuitry by checking for shorts, low/high voltage issues or any other electrical wiring problems. Electrical testing will play a vital role in determining if the assembly was correctly fabricated and will prevent the BeagleBone from getting short-circuited.

Integration Testing: Once all the above tests are cleared, every single component will be put together and will be thoroughly tested as a whole system for errors or issues. This will again be done by observing the functionality of different components and by identifying any unexpected behavior.

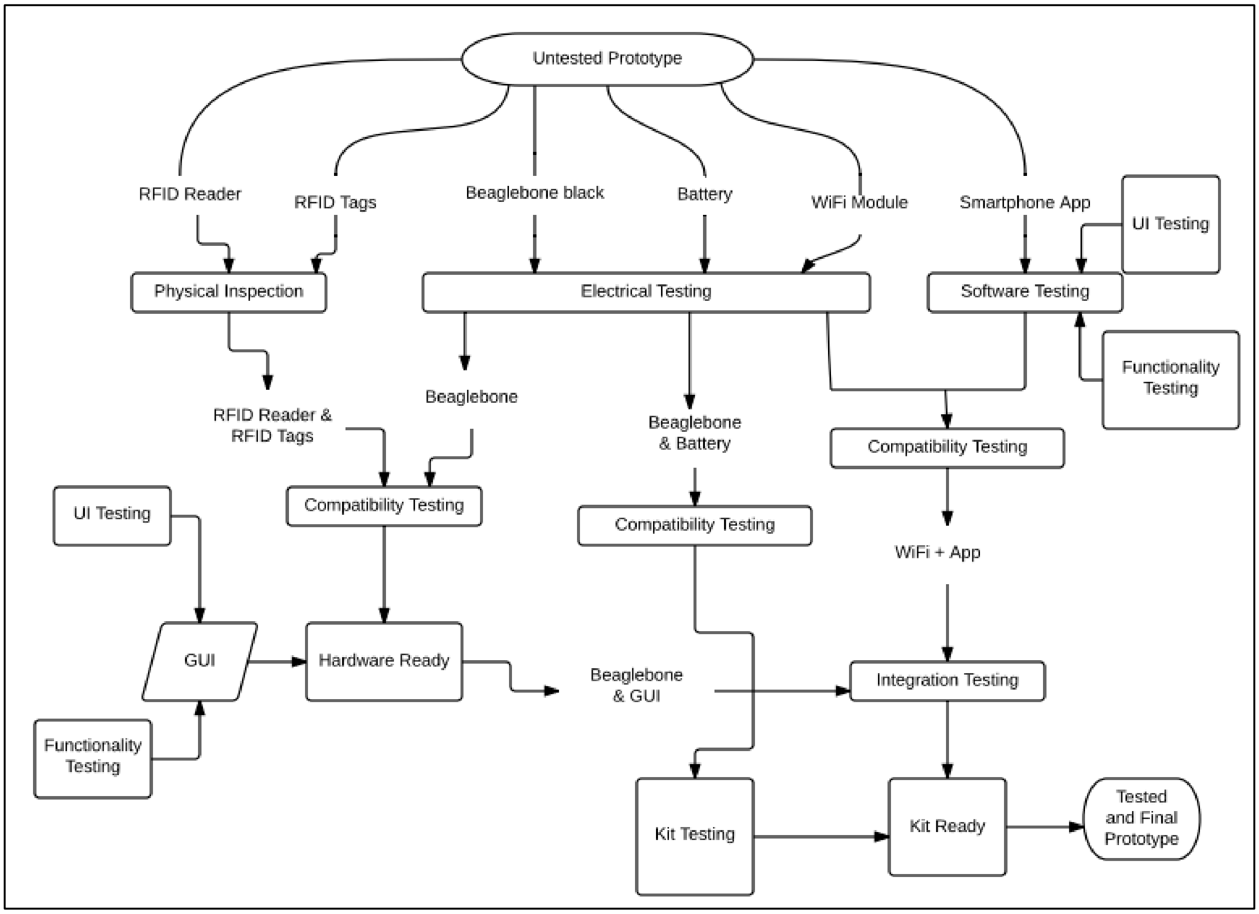

Figure 27 - Test Plan for Shop Smart

7 Sustainability

The aim for the device is to have zero waste as to comply with the cradle-to-cradle design principle. Using the principles of economy, ecology and equity [28] shown in Figure 27 below, we can discuss the cradle-to-cradle design of the Shop Smart device. The perfect cradle-to-cradle design will take all three aspects into account including Economy, Ecology and Equity.

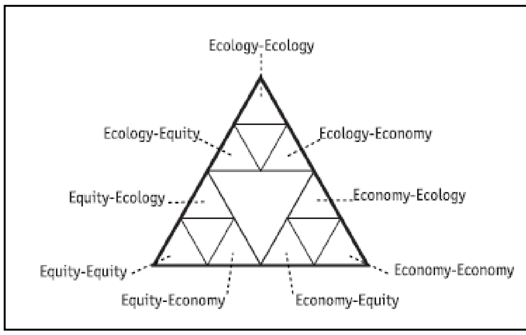

Figure 28 - Triangle for Cradle-to-Cradle Design [28]

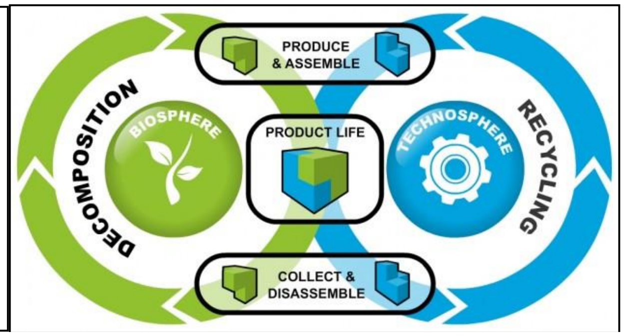

Figure 29 - Cradle to Cradle Life Cycle [29]

Economically, the cradle-to-cradle design aims to make and sell a product at a profit, while contributing to the wider economic health of the community and providing fair benefits and wage practices [28]. Shop Smart aims to create a product that will not only be profitable, but will help people use their time efficiently.
Measures will be required to certify eco-friendliness of the manufacturing plant and that it will not cause pollution or waste which can be potentially harmful to the surrounding community. Also taking steps to ensure that all components are processed accordingly in order to be reused or recycled. This method takes into account the cradle-to-cradle life cycle that is show in Figure 28.

Table 6 - Component Materials

Component	Material
Shopping Cart	Alloy, Nylon
BeagleBone Board	PCB, Silicone
RFID Reader	Alloy, Metal, PCB, Silicone
RFID Tags	IC, Metal, Plastic
Casing for Embedded system and RFID Reader	Polystyrene Thermoplastic
Battery	Lithium Ion

Table 6 above displays the materials that will be used during the various phases of the design along with the materials that will be used which include polymers and metals. These materials can be broken down into smaller parts that can easily be recycled. Although the IC and PCB components may be tricky to decompose, there are already companies that have created a treatments [30] in order to stay within the cradle-to-cradle design frame. As stated in the RFID Journal, “Eventually, RFID tags could even help ensure that manufacturers comply with regulatory mandates for disposal of toxic substances" [31] by keeping track of various products during all stages of their life-cycle, and particularly during their disposal.

8 Safety

The device will be securely placed onto the shopping cart to rule out any abuse to the electronic components enclosed within. The components will be individually tested/replaced before it is integrated with the rest of the system in order to avoid damages. Furthermore, measures will be taken into account to ensure that individual components are in compliance with the safety guidelines as specified on their safety manuals.

The system makes use of a portable battery that is capable of supplying up to 5VDC 1A. It can be harmful if the user comes in direct contact with the circuitry as there is chance of an electric shock. In order to cope up with the problem, the entire system is enclosed within a Thermoplastic material based casing. The casing will be applied in a way that there will be no direct contact between the electrical components and the user.

9 Conclusion

This document provides the design solutions to the functional specifications and requirements and addresses all the technical aspects of the solution provided by Shop Smart.

In the system overview section and specifications section the document provides a brief description of how all the components are put together to establish a complete product. Within the system, software and hardware requirements sections further explains how each feature and component is designed to work according to the electrical, physical, functional and performance requirements.

The test plan will include the steps to ensure the integrity of the device and will keep track of whether the requirements were met or there needs to be improvement. Overall the document lays out explained goals for the development of the product to its best potential.

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Appendix

RFID Reader and Tags				
Testing Type	**Test Case**	**Expectation**	**Results**	**Comments**
Physical Inspection	Condition of RFID Tags	Tags can be read successfully		
	Range of RFID Reader	Tags can be read within the range of 20cm		

BeagleBone-Black, Battery, Wi-Fi module				
Testing Type	**Test Case**	**Expectation**	**Results**	**Comments**
Electrical Testing	Power	Power is being supplied to all the individual components installed on the board		
	Connectivity with LCD cape	Male pins of the LCD Cape are inserted into their respective female pins of the Expansion Header (BeagleBone)		
	Battery	Provides sufficient power to all the components on BeagleBone		
	Insulation	Electric circuitry is enclosed within an insulating material (Production Phase).		
Compatibility Testing	LCD Cape, Wi-Fi Module and RFID Reader	Can be detected on the BeagleBone		

GUI Application

Testing Type	Test Case	Expectation	Results	Comments
Software Testing	UI Testing	UI is responsive to user inputs		
	Regression Testing	New software for the GUI application does not introduce new bugs		
	White-Box Testing	All the features in GUI behave according to the expectations		

Smartphone Application

Testing Type	Test Case	Expectation	Results	Comments
Software Testing	UI Testing	UI is responsive to user inputs		
	Regression Testing	New software for the GUI application does not introduce new bugs		
	White-Box Testing	All the features in the app behave according to the expectations		

Overall System Testing				
Testing Type	**Test Case**	**Expectation**	**Results**	**Comments**
Kit Testing	Integration Testing	GUI is running successfully on the embedded system		
		Shopping list can be successfully imported to the GUI		