OTTER RFID ANTENNA SYSTEM

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Contents

1.0 Introduction

1.1 Motivation

The Illinois Prairie Research Institute requires a robust RFID antenna system in order to track the movement of river otters into and out of a pond. River otters have only very recently been found in significant number in the state of Illinois, and researchers would like to monitor otter behavior to determine their impact on the ecosystem. Most commercial systems available that can read passive RFID tags from a great distance cost tens of thousands of dollars. The purpose of this project is to develop a viable system at only a fraction of the cost of a commercially available RFID antenna and receiver system.

1.2 Objectives

1.2.1 Goals

- To make an otter tracking RFID antenna system at a low cost
- To store data acquired and provide it to researchers for analysis
- To design an energy efficient system requiring minimal battery replacement

1.2.2 Functions

- To read the unique PIT (passive integrated transponder) tag IDs to identify otters
- To keep a log of otter movement into and out of the pond

1.2.3 Benefits

- Data acquired easily accessible by researchers
- Allows tracking of river otter terrestrial behavior in a certain area
- Cheaper RFID tracking and data collection system compared to commercially available systems

1.2.4 Features

- Solar panel to recharge batteries powering the system
- Two passive infrared (PIR) sensors to detect direction of movement and manage power consumption
- Easy access to acquired data via USB flash drive
- Energy efficient design that allows for continued use for at least a week

2.0 Design

2.1 Block Diagram

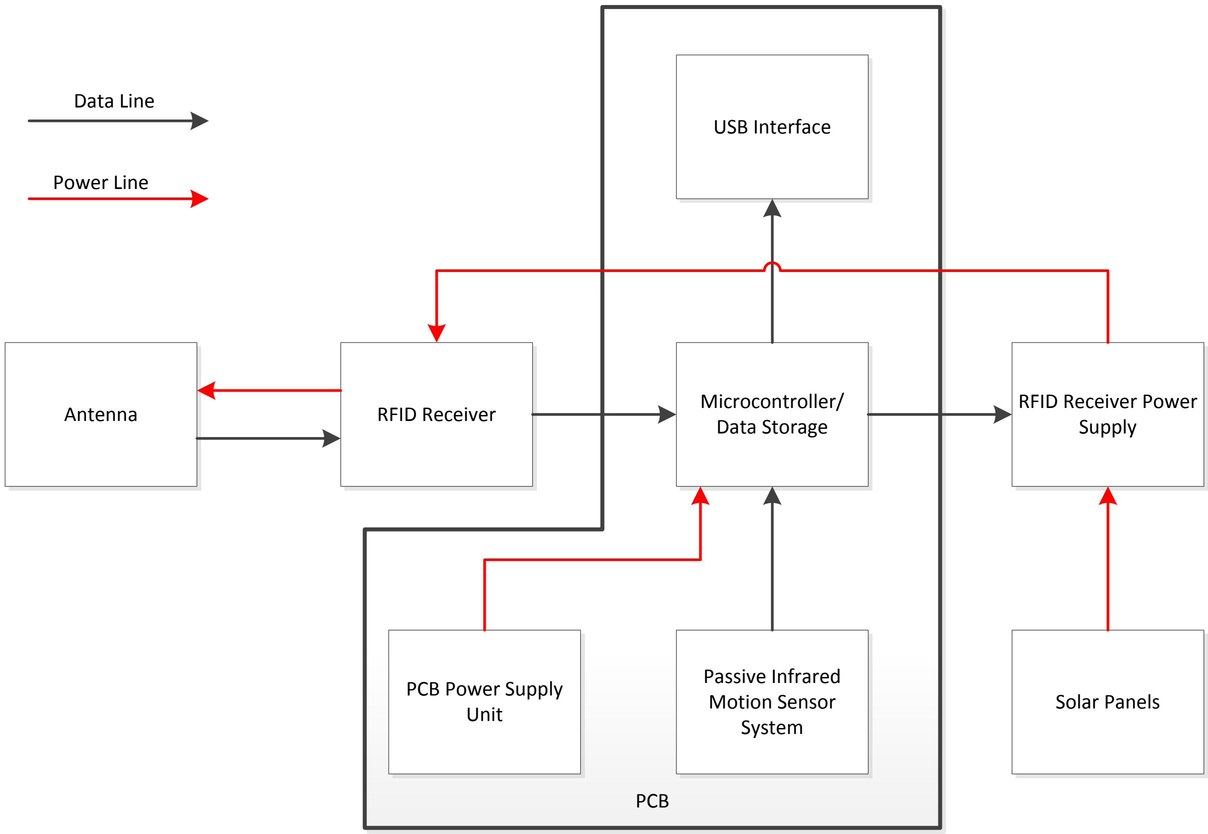

Figure 1: Overall Block Diagram

2.2 Block Descriptions

1. Antenna

The antenna (ANT-G01E-30) is a commercially available rectangular loop antenna which operates at 134.2 kHz. The antenna will be powered by the RFID receiver unit. The antenna will send a signal to the PIT tags (TRP-RR2B-30) which will be the source of power for the tags. Using the power transmitted by the antenna, the PIT tags in return will send the unique ID number back to the antenna. The antenna's inductance must match the induction requirement of the RFM module to ensure that the antenna is in resonance with the RFM module. The antenna then sends the data received to the RFID receiver unit.

2. RFID Receiver

The RFID receiver used in the design will be a commercially bought unit. Its function will be to receive the modulated signal that the antenna sends and to demodulate it. The receiver then sends the signals to the microcontroller/data storage unit for analysis and storage. The unit also supplies the necessary power to the antenna. The RFID receiver consists of the RFM and control module. A signal is sent by the

RFM module to the antenna to send out a wave. This wave is transmitted to the PIT tag and powers it. The minimum voltage that is required by the PIT tag to power on is 5V. The PIT tag sends its unique 22 ASCII character ID to the receiver when its required voltage is achieved [1]. The unique ID starts with the ASCII character for the letter 'L', followed by another letter to indicate whether the data recorded was a pass or fail. If the next letter is 'R', then the data is a valid ID, but if the next letter is 'I' then the data read is an invalid ID [1]. The next four characters determine the type of transponder read, and the last sixteen characters are the unique ID code of the transponder. The RFM module receives this data, demodulates it, and sends it to the control module. The control module then decodes this data and sends it to the MAX232N chip using the RS-232 interface [1].

3. Microcontroller/Data Storage

The microcontroller/data storage unit is responsible for power management, data storage and downloads to a USB flash drive. When there is no sensor detection, the microcontroller will operate in low power idle mode. The microcontroller (PIC24FJ32GB002) receives digital signals as inputs from two passive infrared (PIR) motion sensors. When motion has been detected, the PIR sensors will signal the microcontroller, which will switch the power MOSFET that controls the RFID receiver power supply; the receiver unit will then be powered for 30 seconds. The microcontroller/data storage unit will then receive information from the RFID receiver once an otter's PIT tag has been read. The unit will store the identification information, the time, and the movement direction on the microcontroller's built-in 8kB of SRAM.

$$Bits\ for\ PIT\ tag\ ID = 22\ ASCII\ chars\ \times 8\ bits = 176\ bits \qquad \text{(Eq. 1)}$$

$$Bits\ for\ time = 40\ bits\ [2] \qquad \text{(Eq. 2)}$$

$$Bits\ for\ direction = 1\ bit \qquad \text{(Eq. 3)}$$

$$Total\ bits = 176 + 40 + 1 = 217\ bits \qquad \text{(Eq. 4)}$$

$$Total\ bytes = \frac{217}{8} \approx 28\ bytes \qquad \text{(Eq. 5)}$$

$$Total\ bytes\ stored\ per\ week = 28\ bytes\ \times 10\ detections = 280\ bytes[3] \qquad \text{(Eq. 6)}$$

The built-in memory is sufficient for the amount of data collected per week. The movement direction will be determined based on which PIR sensor is activated, and the time will be recorded from the microcontroller's built-in real time clock. The direction of movement will be recorded as a single bit, with '0' referring to sensor 1 and '1' referring to sensor 2.

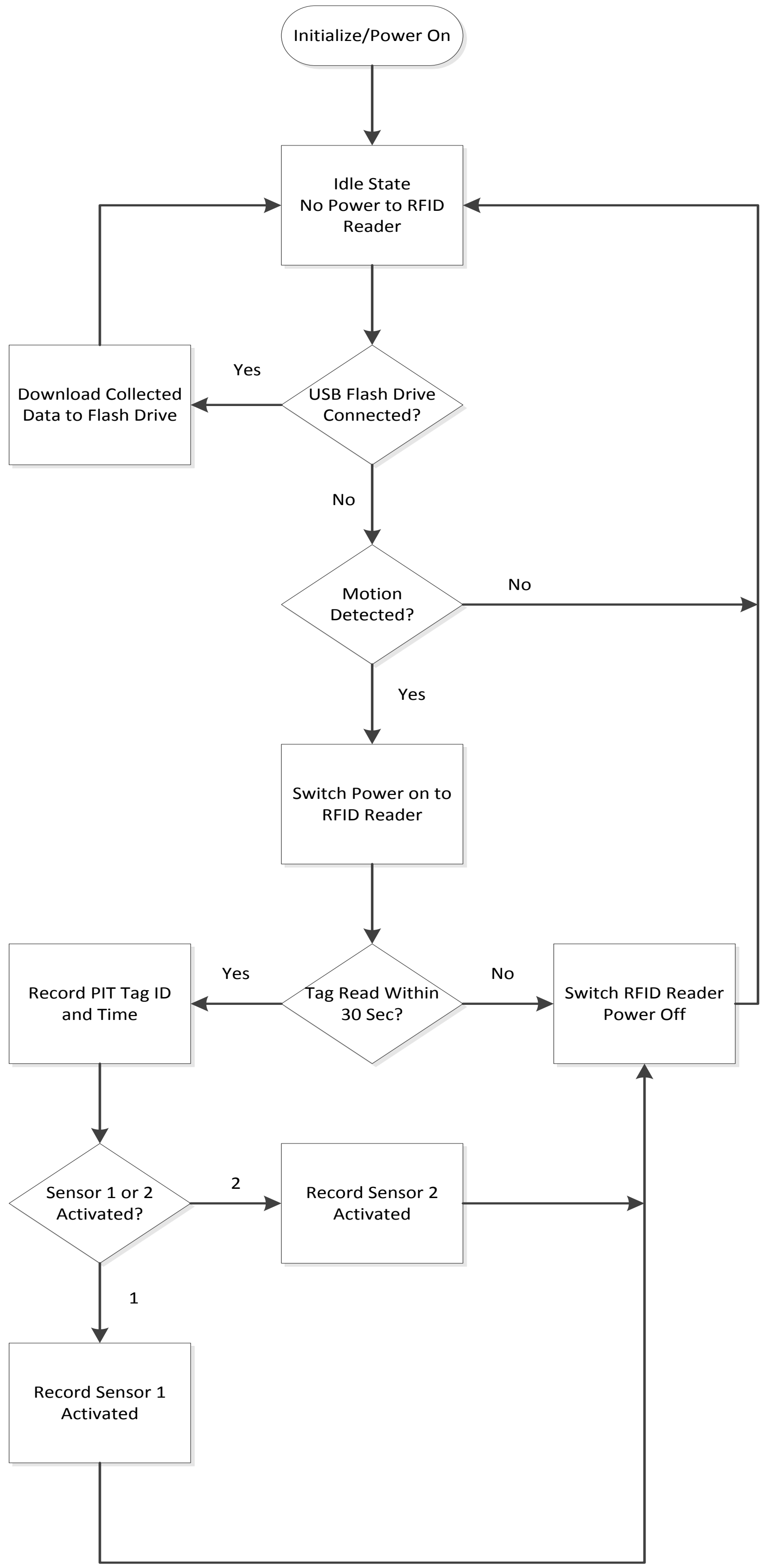

Figure 2: Flow Chart of PIC Microcontroller Functions

4. Passive Infrared Motion Sensor

The system will incorporate two passive infrared (PIR) motion sensors, which will each provide a high digital signal [4] to the microcontroller when motion has been detected. The two PIR sensors will also provide researchers information about the direction of movement of the otters depending on which sensor detects motion; one motion sensor will be directed towards the land, while the other motion sensor will be directed towards the pond.

5. USB Interface

The USB interface will allow researchers physical access to download the saved data to a flash drive. The USB host capabilities will be programmed into the microcontroller. The USB interface will provide the 5V necessary on the Vbus line to power the USB flash drive. The USB interface provides the physical connections to the USB flash drive.

6. RFID Receiver Power Supply Unit

This unit is the main power source for the antenna and RFID receiver using a 12V car battery. When motion is detected, the microcontroller signals the power supply unit to power the RFID receiver unit. To extend the battery life, a solar panel will be connected to the unit to recharge the battery. By calculating the power usage for the unit, the required battery rating can be determined. It is estimated that there will be approximately ten otter movement detections per week [3]. There will also be movements by other animals which can activate the PIR sensors, so the number of detections per day is estimated to be as high as 30. For each detection, the system will draw power for 30 seconds which means the system could be operating for as long as 1.75 hours every week. The max current draw for the RFM/CTL units is 300mA, and the max current draw for the MAX232N chip is 10mA, so the total current draw is 310mA [5], [6], [7], [8], [9].

$$RFID\ Receiver\ Unit\ Current\ Draw\ [Ah] = Max\ Current\ [mA] \times Max\ Hours\ [h] \quad \text{(Eq. 7)}$$

$$RFID\ Receiver\ Unit\ Current\ Draw\ [Ah] = 310mA \times 1.75hours \approx 0.543Ah \quad \text{(Eq. 8)}$$

Since a 12V battery with a 75Ah rating is being used, the RFID receiver system will be able to run for more than a week, so researchers will not have to increase their visits to the site to replace the battery.

7. Solar Panel

The solar panel will be connected to the 12V car battery to charge and extend the battery life. It will be connected to the 12V car battery via battery clamps. The solar charger has an integrated battery overcharge protection system to prevent overcharging, and it also has a blocking diode that will protect the battery from being discharged through the panel's circuitry when there is no sunlight. In central Illinois, the average hours of sunlight per day is 4.2 hours [10]. The design uses a 5W solar panel which charges at a current of 0.3A [11].

$$Solar\ Charger\ Rating\ [Ah] = 0.3A \times 4.2h = 1.26Ah/day = 8.82Ah/week \quad \text{(Eq. 9)}$$

Based on the calculations, the solar charger will charge the battery enough to power the RFID receiver unit for more than a week.

8. PCB Power Supply Unit

This unit powers the microcontroller/data storage unit. Two 9V batteries will be used for convenient replacement after complete discharge. The microcontroller unit will have its voltage regulated to 3.3V and the max current draw is 500mA [2]. The 9V supply will also be regulated to 2.5V for the microcontroller, as well as 5V to support USB host capabilities. The microcontroller will operate in idle mode when there is no detection. The bulk of the power consumption occurs when the sensors detect movement, which is estimated to be about 30 times per day; the microcontroller will be active for 30 seconds per activation.

$$Microcontroller\ Power\ (Idle)[W] = 4.5\mu A \times 3.3V = 14.86\mu W\ [2] \quad \text{(Eq. 10)}$$

$$Motion\ Sensors\ Power\ (Idle)[W] = 130\mu A \times 5V = 650\mu W\ [4] \quad \text{(Eq. 11)}$$

$$9V\ Battery\ Rating\ (Idle) = \frac{(14.86 + 650)\mu W \times (168 - 1.75)h}{9V} \approx 0.0123Ah \quad \text{(Eq. 12)}$$

$$Microcontroller\ Power\ (Active)\ [W] = 500mA \times 3.3V = 1.65W \quad \text{(Eq. 13)}$$

$$Motion\ Sensors\ Power\ (Active)[W] = 23mA \times 5V = 0.115W\ [4] \quad \text{(Eq. 14)}$$

$$9V\ Battery\ Rating\ (Active) = \frac{(1.65 + 0.115)W \times 1.75h}{9V} \approx 0.34Ah \quad \text{(Eq. 15)}$$

$$Total\ 9V\ Weekly\ Battery\ Usage\ [Ah] \approx 0.36Ah \quad \text{(Eq. 16)}$$

Each 9V battery has rating of 0.5Ah, so the batteries will last for at least a week based on the weekly power consumption calculated [12].

2.3 Detailed Schematics

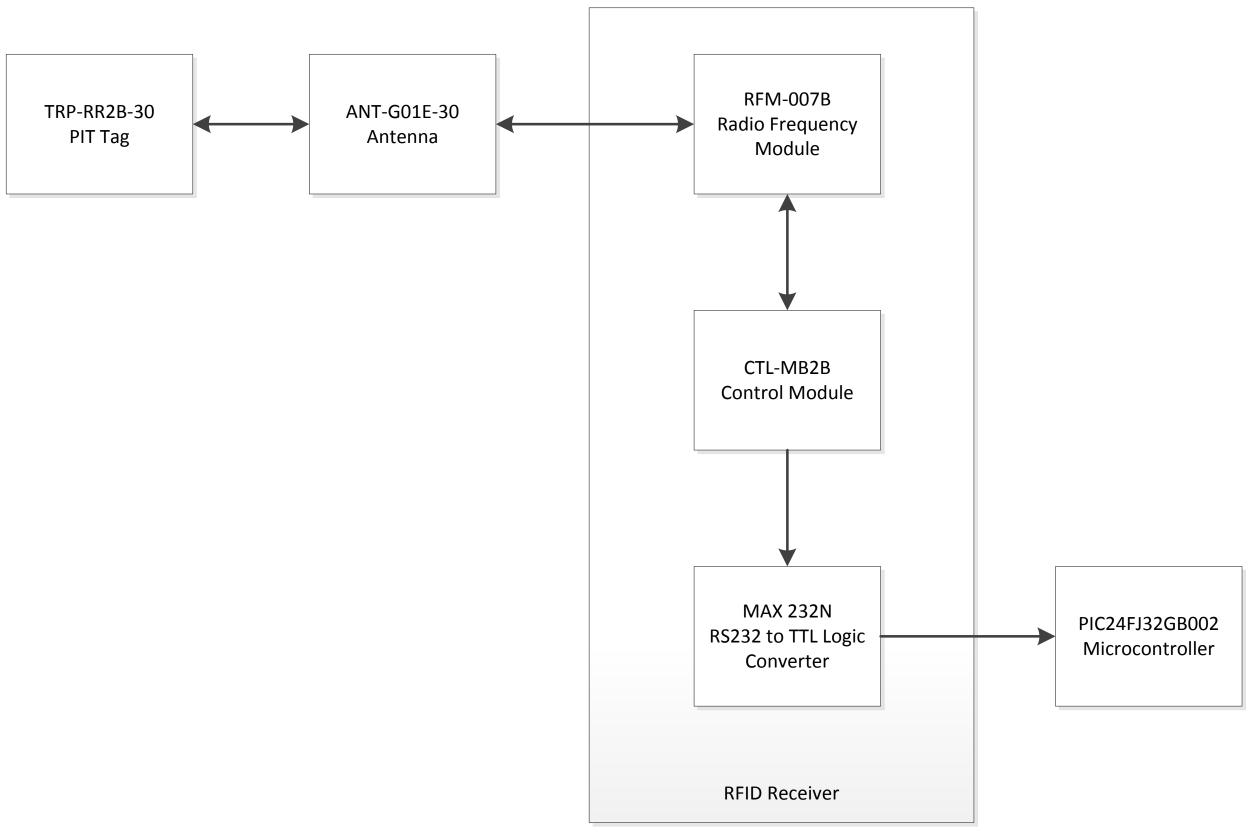

Figure 3: RFID Receiver System Data Flow

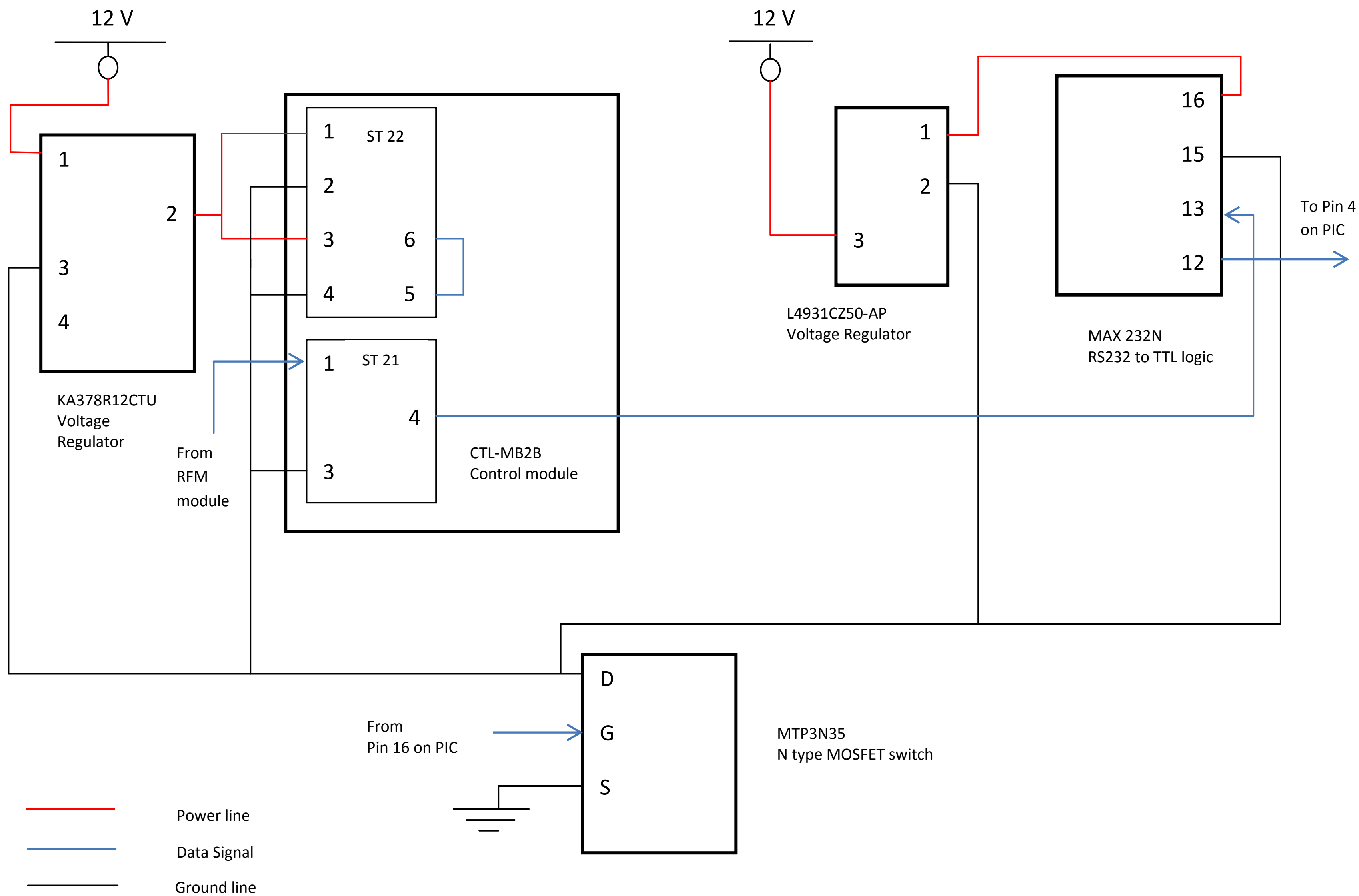

Figure 4: Pin Assignments and Connections for RFID Receiver and Power Supply

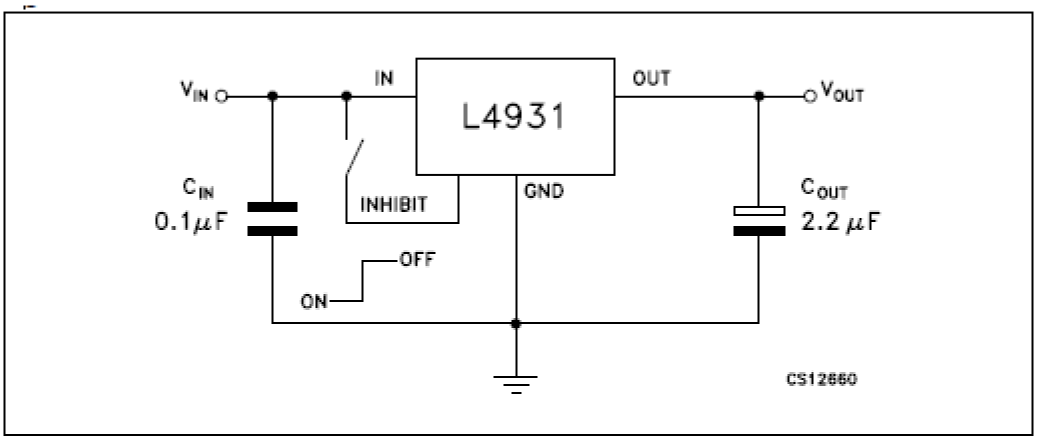

Figure 5: Schematic of L4931C250-AP Voltage Regulator [13]

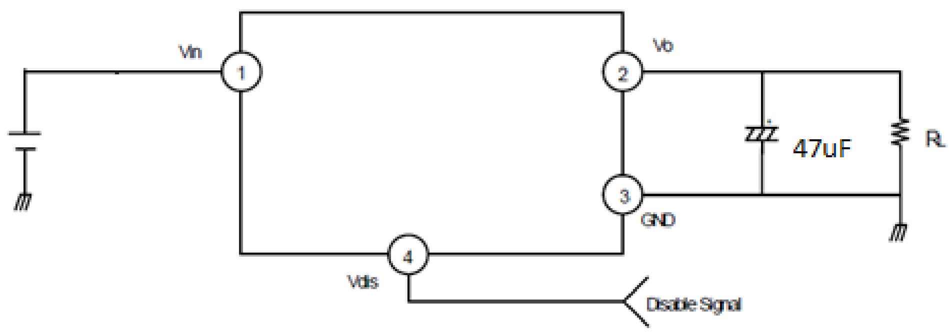

Figure 6: Schematics of KA378R12CTU Voltage Regulator [14]

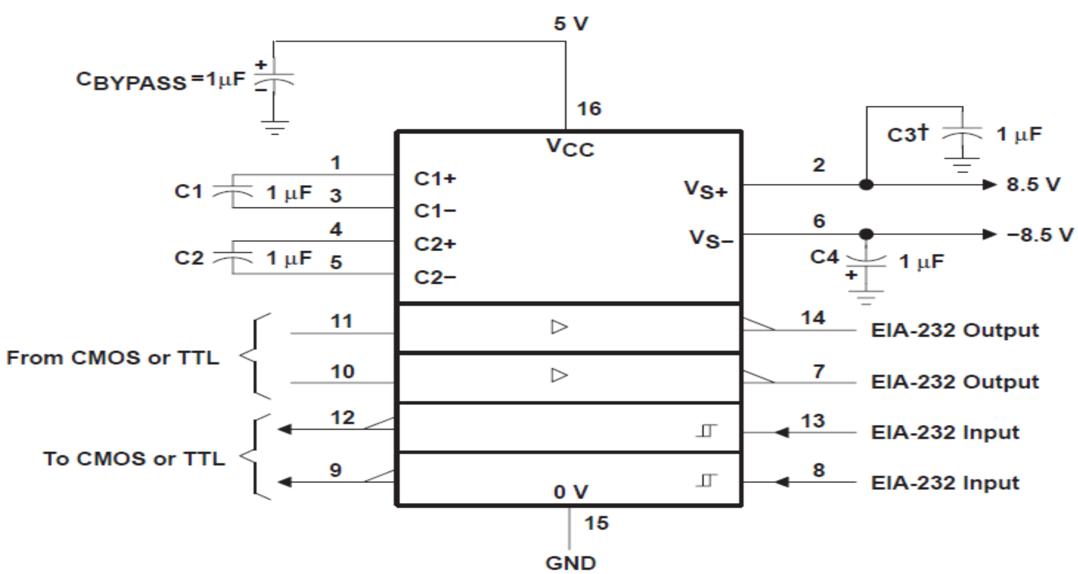

Figure: 7 Schematic of MAX232N [8]

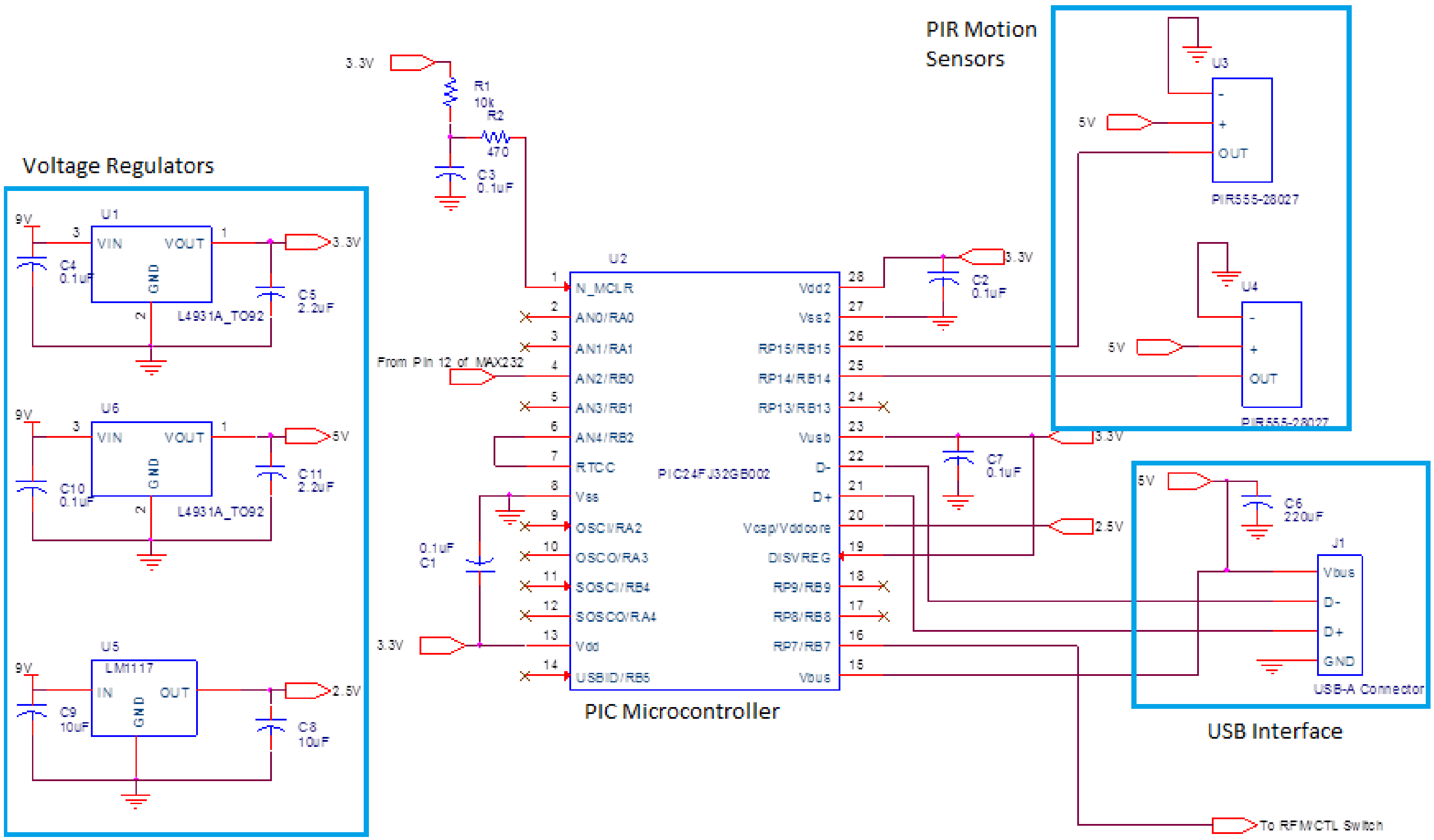

Figure 8: PCB Schematic

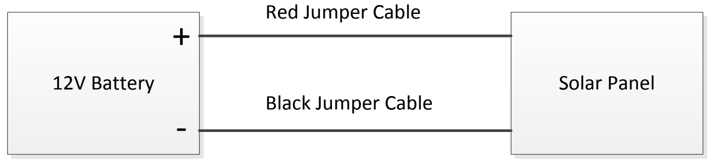

Figure 9: Battery-Solar Panel Connections

3.0 Requirements and Verification

Requirements	Verifications
Antenna 1. The antenna must match its inductance to the induction requirement of the RFM module. The antenna inductance must be between 26 to 27.9 µH. 2. The antenna must be able to read the transponder's unique ID from a distance of 6".	**Antenna** 1. The antenna will be connected to the vector signal analyzer to check if its inductance is between 26 and 27.9 µH. 2. The PIT tag will be moved across the antenna at a distance of 6" and the output (pin 4) of the control module will be probed by an oscilloscope to verify that the PIT tag has been read.
RFID Receiver 1. The control module should decode the PIT tag ID number. 2. The receiver must output an ASCII 'L' and 'R' as the first and second characters from a successful read of the PIT tag.	**RFID Receiver** 1. The output (pin 4) of the control module would be analyzed using an oscilloscope to see what the ASCII code is. 2. The ASCII codes of 'L' and 'R' will be verified via an oscilloscope at the RS-232 output of the control module. The ASCII code for 'L' is 01001100 and the ASCII code for 'R' is 01010010.

3. The output to the microcontroller must be converted to TTL voltage levels between -7V and 7V.	3. The output of the MAX232N chip will be probed by a multimeter to verify the voltage levels are between -7V and 7V.
Microcontroller/Data Storage 1. The microcontroller must operate in low power idle mode when there is no motion, drawing no more than 1mA. 2. The microcontroller must operate in normal mode when there is motion detected. 3. The microcontroller must signal the 12 V power supply to provide power to the RFID receiver when motion has been detected. a. PIR sensor 1 must signal the microcontroller that motion has been detected. b. PIR sensor 2 must signal the microcontroller that motion has been detected. c. The microcontroller must send a high signal to the MOSFET once the microcontroller receives a high signal from either PIR sensor. d. The output signal from the microcontroller to the MOSFET must be between 2V and 4.5V. e. The power supply must be switched on for 30 seconds.	**Microcontroller/Data Storage** 1. Probe the Vdd pins on the microcontroller with an ammeter to verify current is less than 1mA when in idle mode. 2. Probe the Vdd pins on the microcontroller with an ammeter to verify current is between 1 to 15 mA. 3. Probe pin 16 from the microcontroller to the MOSFET switch with the oscilloscope to verify that a high signal is sent when movement is detected. a. Activate sensor 1 and verify the sensor output signal is high on the oscilloscope. b. Activate sensor 2 and verify the sensor output signal is high on the oscilloscope. c. Probe pin 16 on the microcontroller with the oscilloscope to verify that a high signal has been sent. d. The gate-source voltage on the MOSFET will be probed with the oscilloscope to verify the high signal is between 2V and 4.5V. e. Verify that the waveform for the gate-source voltage on the MOSFET is high for 30 seconds.

f. The RFM/CTL unit must be powered on.	f. The LEDs on the control module will be checked to verify the RFM/CTL unit is powered on. Blinking or constantly lit up LEDs indicate the system is getting power.
4. The microcontroller must implement USB host functionality.	4. The LED on the flash drive will be used as an indicator to see if the flash drive is being powered by the microcontroller.
a. The USB host must detect and recognize mass storage class devices.	a. Test code will be written to check the status of the attached USB device. An LED will be attached to the pin 2 of the PIC, which will light up when the device has been detected and recognized.
b. The microcontroller USB data lines must output correct data from the SRAM to the flash drive.	b. Arbitrary data will be written to the SRAM. The data from the SRAM will be read and written to a connected flash drive. The D+ (pin21) and D- (pin 22) lines of the microcontroller will be probed with an oscilloscope to verify the data read is the same as the data written.
c. The microcontroller must signal when the data transfer is complete.	c. Code will be written that will send a signal to pin 3 on the microcontroller. An LED will be connected to pin 3 to indicate the status of the data transfer. A lit LED indicates that the data is being transferred, while an unlit LED indicates that the data transfer is complete.
d. The microcontroller must also detect when a flash drive has been detached.	d. Test code will be written to verify when a USB device has been detached. An LED will be connected to pin 5 on the

5. The microcontroller must properly process and store otter ID information when the PIT tag is read.	microcontroller and will light up when the device has been detached. 5. The data will be downloaded to a flash drive and analyzed to verify that data has been stored properly.
Passive Infrared Motion Sensor 1. The PIR sensor must detect otter movement at a minimum range of 3 m. 2. The V+ pin should draw no more than 150µA current.	**Passive Infrared Motion Sensor** 1. Probe the output of the PIR sensor with the oscilloscope to verify that a high signal is generated when there is motion at a 3 m distance from the sensor. 2. Probe the V+ pin with a multimeter to verify that the current is less than 130µA.
USB Interface 1. The USB interface must have a voltage of 5V +/- 10% on its Vbus pin.	**USB Interface** 1. Probe the Vbus pin with a multimeter to verify that the voltage is between 4.5V and 5.5V.
RFID Receiver Power Supply Unit 1. The battery should not be discharged when motion has not been detected. 2. The RFID Receiver power supply should provide a regulated 12V +/-5% for the RFM/CTL units. 3. The RFID Receiver power supply should provide a regulated 5V +/-10% to the MAX232N chip.	**RFID Receiver Power Supply Unit** 1. The 12V power supply will be probed by an ammeter to verify that no current is drawn when no movement is detected. 2. Probe the output (pin 2) of the voltage regulator (KA378R12CTU) with an oscilloscope to verify that the voltage is between 11.4V and 12.6V. 3. Probe the output (pin 1) of the voltage regulator (L4931CZ50-AP) with an oscilloscope to verify that the voltage is between 4.5V and 5.5V.

Solar Panel 1. The solar charger must recharge the 12 V battery when sunlight is present. 2. The solar charger should not charge the 12V battery when it is at full capacity. 3. The solar charger must not discharge the battery when there is not sunlight.	**Solar Panel** 1. The output will be probed using an ammeter to verify current generation when the panel is exposed to sunlight 2. An LED and 500Ω resistor will be placed in series between the battery and solar panel, with the anode oriented to the solar panel and the cathode to the battery. The solar panel will be exposed to sunlight. The LED must not light up when the battery is fully charged. 3. An LED and 500Ω resistor will be placed in series between the battery and solar panel, with the anode oriented to the battery and the cathode to the solar panel. The LED must not light up when the battery is not being discharged.
PCB Power Supply Unit 1. The PCB power supply unit should supply a voltage of 3.3V +/- 10% for the Vdd pins on the microcontroller. 2. The PCB power supply unit should supply a voltage of 2.5V +/- 10% to the Vcap/Vddcore pin on the microcontroller. 3. The PCB power supply unit should supply a voltage of 5V +/- 10% to the PIR motion sensors and Vbus for the USB interface.	**PCB Power Supply Unit** 1. Probe the output (pin 1) of the voltage regulator with an oscilloscope to verify that the voltage is between 2.97V and 3.63V. 2. Probe the output of the voltage regulator with an oscilloscope to verify that the voltage is between 2.25V and 2.75V. 3. Probe the output (pin 1) of the voltage regulator with an oscilloscope to verify that the voltage is between 4.5V and 5.5V.

3.1 Tolerance Analysis

The microcontroller/data storage unit is the most critical part of the design. Specifically, the signal that the microcontroller sends to the MOSFET switch for 12V power supply is vital for power management and the longevity of the system without requiring replacement batteries. First, the microcontroller must be tested with the code developed for signaling the power supply when motion is detected. Each sensor input will be toggled on the microcontroller, and the output signal that should be sent will be probed using an oscilloscope. The high output signal that is sent must be clear and any oscillations that can be interpreted as a false-positive must be avoided. The high signal voltage must fall between 2V and 4.5V, and any oscillations must not cause the signal to go outside this range [15].

4.0 Ethical Considerations

The primary ethical consideration is that the project does not harm the river otters or other animals. The enclosure must properly isolate the electrical components from the external environment, so that animals are not harmed. Furthermore, the enclosure for the system must be environmentally friendly and not introduce harmful elements to the ecosystem. With the use of batteries, acid leakage is a potential concern, and so batteries must be isolated from the environment within a container. Another ethical consideration is properly crediting every source consulted as well as not falsifying the data gathered from testing.

5.0 Cost and Schedule

5.1 Cost

5.1.1 Labor

Name	Hourly Rate	Total Hours Worked	Total = Hourly rate x 2.5 x Total Hours Worked
Jinwoo Bae	$35.00	200	$17500.00
Charles Huang	$35.00	200	$17500.00
Sumsaamuddin Mohammed	$35.00	200	$17500.00
Total			$52500.00

5.1.2 Parts

Part	Part Number	Unit Cost	Qty.	Total	Status
PIC Microcontroller	PIC24FJ32GB002	$4.00	1	$4.00	Will order through Digikey
PIR Motion Detector	555-28027	$11.00	2	$22.00	Will order through Digikey
Voltage Regulator (3.3V)	L4931CZ33-AP	$1.00	1	$1.00	Will order through Digikey
Voltage Regulator (2.5V)	LM1117T-2.5	$1.50	1	$1.50	Will order through Digikey
Voltage Regulator (12V)	KA378R12CTU	$0.57	1	$0.57	Part acquired
Voltage Regulator (5V)	L4931CZ50-AP	$0.75	2	$1.25	Will order through Digikey
0.1µF Capacitor		$0.25	7	$1.75	Part Shop
2.2µF Capacitor		$0.20	3	$0.60	Part Shop
220µF Capacitor		$0.50	1	$0.50	Part Shop
10µF Capacitor		$0.15	2	$0.30	Part Shop
47µF Capacitor		$0.35	1	$0.35	Part Shop
1µF Capacitor		$.10	3	$0.30	Part Shop
10kΩ Resistor		$0.04	1	$0.04	Part Shop
470Ω Resistor		$0.04	1	$0.04	Part Shop
PCB		$30.00	1	$30.00	Will order from Parts Shop
USB Type A Connector	292303-1	$1.50	1	$1.50	Will order through Digikey
Solar panel package		$70.00	1	$70.00	Order from Sundance solar
12 V Battery		$100.00	1	$100.00	Part acquired
Antenna	ANT-GO1E-30	$240.00	1	$240.00	Part acquired
Transponder	TRP-RR2B-30	$5.46	4	$21.84	Part acquired
Frequency module	RFM-007B	$350.00	1	$350.00	Part acquired
Control Module	CTL-MB2B	$320.00	1	$320.00	Part acquired
RS232 to TTL	MAX 232N	$0.62	1	$0.62	Part Shop
9 V Battery		$15.00	1	$15.00	Will order through Amazon
Casing		$30.00	1	$30.00	Machine Shop
Flash Drive		$10.00	1	$10.00	Part acquired
MOSFET	MTP3N35	$0.20	1	$0.20	Part Shop
LED		$0.25	3	$0.75	Part Shop

Perfboard		$4.00	1	$4.00	Will order through Digikey
Total				$1228.11	

5.1.3 Grand Total

Labor	$52500.00
Parts	$1228.79
Grand Total	$53728.79

5.2 Schedule

Week	Task	Responsibility
9/16	Research solar panels and rechargeable batteries	Jinwoo
	Finalize project proposal	Charles
	Research RFID antenna and receiver unit	Sumsaamuddin
9/23	Research and design solar panel and power supply units	Jinwoo
	Research and design microcontroller/data storage unit Complete PCB circuit schematic	Charles
	Research how to program code for microcontroller Sign up for design review	Sumsaamuddin
9/30	Finalize power supply and solar panel design schematic	Jinwoo
	PCB physical layout for microcontroller and USB interface units	Charles
	Program code for microcontroller to implement PIR sensor functionality	Sumsaamuddin
10/7	Order voltage regulators, MOSFET Build the RFID Receiver power supply unit	Jinwoo
	Put in order for PCB and parts for PCB Begin programming code to switch on RFID receiver power supply unit	Charles
	Begin programming code for microcontroller for data acquisition	Sumsaamuddin
10/14	Order solar panel Test RFID receiver power supply unit with antenna and RFID receiver units	Jinwoo
	Begin programming code to implement USB host functionality in microcontroller	Charles
	Program code for microcontroller for data acquisition	Sumsaamuddin
10/21	Research and design physical enclosure for microcontroller/PSU/solar panel Verify that antenna and receiver unit are reading PIT tags	Jinwoo
	Populate the PCB with components	Charles
	Program code for microcontroller for data acquisition	Sumsaamuddin
10/28	Mock-Up Demo Preparation Order physical enclosure for microcontroller/PSU/solar panels	Jinwoo
	Program microcontroller with code developed Assemble entire system and begin testing overall functionality	Charles
	Test PIR sensors with the microcontroller	Sumsaamuddin

11/4	Mock-Up Demo Preparation Work with machine shop on physical enclosure for microcontroller/PSU/solar panels	Jinwoo
	Schematic capture and layout of second revision PCB Mock-Up Presentation Preparation	Charles
	Mock-Up Demo Signup Mock-Up Presentation Signup Work with machine shop on physical enclosure for antenna	Sumsaamuddin
11/11	Begin assembly of physical enclosure	Jinwoo
	Order second revision PCB	Charles
	Order / work with machine shop on antenna enclosure	Sumsaamuddin
11/18	Thanksgiving Break	All
11/25	Assembly of physical enclosure for microcontroller/PSU/solar panels	Jinwoo
	Begin final paper Populate second revision PCB with components	Charles
	Sign up for demo and presentation Assembly of physical enclosure for antenna	Sumsaamuddin
12/2	Prepare presentation	Jinwoo
	Final paper	Charles
	Prepare and assemble final demo unit	Sumsaamuddin
12/9	Presentation preparation	Jinwoo
	Final paper	Charles
	Place any finishing touches on completed design in preparation for field deployment	Sumsaamuddin

6.0 Citations

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