OTTER STALKER SYSTEM

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Abstract

The Otter Stalker System is designed to enhance the current technology of wildlife monitoring that is available to wildlife researchers. The Otter Stalker System is designed to have optimal monitoring coverage to enhance wildlife study experiences.

When the otters are present in the study site, the sensor networks will detect their presence and location. Then, the sensors' feedback will be send wirelessly to the main controller. The microcontroller will interpret the information received. Based on the sensors' output, the main controller will send appropriate trigger pulse to activate the video recording of corresponding camera. The recorded video will then be saved into a memory card.

Although our design was successful, there are improvements that could be made. The audio capability of the Otter Stalker System can be improved. This will enrich the wildlife study experience as acoustic can be a useful material to learn more about otters. Besides that, a battery power indicator will also be useful because this will ease the user of the system.

The final cost of the project is higher than expected. There are several ways to reduce the cost of production and they are discussed in the Cost section.

Contents

1. Introduction

This project is in collaboration with Illinois Natural History Survey, Institute of Natural Resource Sustainability, University of Illinois Urbana Champaign in the study of the river otters. The main motivation of this project is to enhance the current technology available to wildlife researchers. The current otter habitat-monitoring method employs trailing cameras with limited range of sensing mechanism and fixed camera view. In other words, they are only able to detect and record the wildlife behaviors in one direction. To address the limitations of current habitat monitoring system, the Otter Stalker System is designed to have optimal monitoring coverage to enhance wildlife study experiences.

1.1 Purpose

The goal of this project is to improve the sensitivity of detecting the presence of otters, which is limited by the conventional habitat-monitoring methods. This system enables habitat-monitoring in all directions without compromising the effectiveness of the wildlife data obtained. Besides, it also increases the monitoring coverage of the habitat and is able to operate autonomously for up to four days.

1.2 Project Functions

The Otter Stalker System integrates two cameras with one sensing network wirelessly. When the otters are present in the study site, the sensor networks will detect their presence and location. Then, the sensors' feedback will be send wirelessly to the main controller. The microcontroller will interpret the information received. Based on the sensors' output, the main controller will send appropriate trigger pulse to activate the video recording of corresponding camera. The recorded video will then be saved into a memory card.

Otter Stalker System is able to detect the presence of wildlife within an area of 3m x 3m. It is weatherproof and possesses the capability of taking color day video clips and infrared night video clips with audio recording. Besides, it is inconspicuous to the otters. The signal to noise ratio (SNR) from the transmitters to the receivers is larger than 20dB. Batteries that support this system have a lifetime of at least four days as the researchers will visit the site twice a week to collect data and change the batteries.

The Figure 7.1 (*all diagrams, figures, and tables appear in Chapter 7 and Appendix*) shows the block diagram of the Otter Stalker System. The Sensing Module will detect the presence and position of otters at the otter study site. The information from Sensing Module is encoded into Hamming code and is sent wirelessly to the Main Controller through the Wireless Communication Module. Then, the Main Controller will analyze and interpret the information. Based on the information, the Main Controller will generate appropriate trigger pulse to the Camera Module. The trigger pulse will activate the video recording of Camera Module. Once the recording is finished, the recorded video is saved into a memory card.

1.2 Subprojects

The system consists of six subprojects, with each performs a specific task. The subprojects are described as below:

1.2.1 Sensing Module

Sensing Module plays an important role in this system as it is used to detect the presences of the otters. It consists of four Panasonic NaPiOn Spot Type PIR sensors, with two of them have a horizontal detection angle of 22° and the other two have a horizontal detection angle of 38°. All of them have a sensing length of 5m. To ensure the full coverage of the 3m x 3m area, they are placed in a designed arrangement, as shown in Figure A.1 in the Appendix.

1.2.2 Wireless Communication

The function of the Wireless Communication module is to encode the data collected from the Sensing Module and to transmit the data to the Main Controller wirelessly for further analyzing. This module can be subdivided into two sections, which are the transmitter interface and the receiver interface. The transmitter interface consists of one LINX-TXM-418-LR transmitter, one 8-bit CIP-8E encoder, one Texas Instrument MSP430G2553 microcontroller, one whip antenna, resistors and capacitors. The receiver interface is made of two LINX RXM-418-LC receivers, two 8-bit CIP-8D decoders, two whip antennas and two 0.1μF capacitors, one for each camera.

1.2.3 Main Controller

The main controller plays an important role in the Otter Stalker System as it is the brain of the system. The main controller functions to control the activation of video recording of camera module based on information provided by sensing module. Based on the feedback from the sensors, it controls the field of view of the camera by deciding which camera to be woken up. The camera's video recording is activated by generating a trigger pulse using the main controller to the camera. Besides that, the main controller is also able to detect up to 2-bit error and correct 1-bit error as the information sent to the main controller from the decoder implements Hamming (7,4) Code.

1.2.4 Camera Module

The camera module functions to capture video when otters are present in the study site. The activation of the camera module will be controlled by main controller. The cameras will record a short-length video and store it in memory storage. Cameras are placed at specific locations as shown in the Figure A.1 to ensure the full coverage of the otter study site.

1.2.5 Power Supply

Power supply is important because it provides 3.3V voltage to all the components except the trail camera. Spy Point Pro X Plus Trail Camera originally comes with a 12V rechargeable lithium battery, thus no external power supply is needed.

1.2.6 Casing Design

The purpose of the cases is to protect the circuit from the otters and possible weather hazards.

2 Design Procedure

2.1 Sensing Module

Four sensors with smaller sensing range, instead of fewer sensors with larger sensing range (>60°), are used so that the exact position of the otter can be determined as the whole study site can be divided into four smaller areas. With this information, the Main Controller is able to decide which camera should be turned on. On the other hand, two sensors with sensing range of 38° are used at the left side and the up side of the area to make sure that the Sensing Module is actually covering the area outside of the 3m x 3m study site, as shown in the Figure A.1. The larger sensing area will be able to compensate the delay of sending the signal from sensors to cameras.

2.2 Wireless Communication Module

The Wireless Communication module is included in this system to minimize the wiring needed because the system will be operated at the outdoor and the Sensing module will be set far apart from the Camera Module. By connecting the components wirelessly, the system can also be protected from destroying by the otters. The LINX-TXM-418LR transmitter and LINX RXM-418-LR receivers are used as they are ideal for cost-effective wireless transfer of serial data in the favorable 260-470MHz band, which fulfill the requirement of the system. Besides, the transmitter and receiver are capable of sending and receiving the serial data at up to 10,000bps at a distance of up to 3,000 feet. The 8-bit CIP-8E encoder and the 8-bit CIP-8D decoders are chosen because they offer an easy to use and low-cost solution for simple remote control applications in a convenient industry standard 20-pin PDIP package. Moreover, the encoder is also power-efficient. It will enter low power sleep mode once powered-up until the transmit enable pin is pulled to ground. The Texas Instrument MSP430G2553 microcontroller is used to construct the Hamming code from the data received from the Sensing module. It is cost-effective and power-efficient. Furthermore, it consumes less area compared to standard logic gates, such as OR and AND gates in constructing the Hamming code.

2.3 Main Controller

The main controller used in this project is MSP430G2553 microcontroller from Texas Instrument. There are other good alternatives of microcontrollers such as PIC, and Arduino. However, the MSP430G2553 microcontroller is used for the following reasons:

a) It is able to accomplish the main controller functions
b) It is a low power consumption microcontroller
c) It is affordable and comes with a development kit tool that allows direct interface to a PC for easy programming, debugging, and evaluation.
d) It is easy to use as it can be programmed using C language.

The microcontroller is configured and programmed using Code Composer Studio. The hardware configuration and software program is written in C language. The Main Controller can be divided into two sub-algorithm which are Hamming Code Checking and Correction and Sensor Interpretation.

2.3.1 Hamming Code Checking And Correction Of The Main Controller

The Single Error Correction Double Error Detection (SECDED) of Hamming Code can be implemented by using the following equations [12]:

$$z = H \cdot r = \left[\begin{pmatrix} 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{pmatrix} \begin{pmatrix} p_1 \\ p_2 \\ a \\ p_3 \\ b \\ c \\ d \end{pmatrix} \right] mod\ 2 = \begin{pmatrix} z_0 \\ z_1 \\ z_2 \end{pmatrix} \qquad (2.1)$$

Where

H is a parity check matrix

z is a syndrome vector

The syndrome vector, z, indicates whether an error has occurred. The syndrome vector, z, determines the bit position which has error. If syndrome z is a null vector, then there is no error.

Bit Position	1	2	3	4	5	6	7
Transmitted Bit	P_1	P_2	a	P_3	b	c	d

Thus, the value of the specified bit position (determined by the syndrome vector, z,) is inverted to perform a one-bit error correction.

2.3.2 Sensor Interpretation Of The Main Controller

After error checking and correction, the encoded data can be decoded to obtain the sensors' output of a, b, c, and d. The sensors' output interpretation can be implemented using if-else statement in C language. Then, the corresponding trigger pulses are generated and sent to the corresponding camera.

There is a slight modification made to the main controller after the design review. For the camera module, the camera used needs a recovery time of 10 seconds after a recording session. This is clearly a drawback to the Otter Stalker System. There might be a 10 seconds period where otters' activity is not captured. Since two cameras are implemented, a 10 seconds difference time of activation trigger between both cameras is implemented if the otters are in the view of both cameras. Thus, the 10 seconds recovery time of the camera can be compensated. The sensors' output interpretation of the microcontroller is shown in Figure 7.2.

2.4 Camera Module

The camera module contains two Spy Point Pro-X Plus trail cameras. Few other alternatives for camera module are considered as shown in Figure 7.3.

Thus, the Spy Point Pro-X Plus trail camera is chosen for the following reasons:

a) Record a video with audio for duration of 90 seconds

b) Video recording activation can be controlled by the main controller
c) Weatherproof and chew-proof
d) It has night vision capability with bright IR LED illumination which is inconspicuous to otters

In order to have full coverage of the otter's study site, two trail cameras are implemented. Previously, a single rotating camera controlled by navigation module is suggested in proposal. However, the navigation module is omitted because the loud noise caused by this module might be conspicuous to the otters. However, the trail camera has a limitation of 10 seconds recovery period after each video recording session. This limitation can be compensated through the main controller.

An interface between the camera module and main controller is also needed. This is to ensure that the main controller can interact with the camera module. Since the camera is originally connected to a PIR sensor used to trigger the video recording, experiments have been carried out to look for a method to modify accordingly to this project, such that the video recording should be triggered by the Main Controller of this system. Two pins were found to be able to trigger the video recording function of the camera when they are shorted together. The voltage across these two pins is 3V. Thus, a digital N-type MOSFET (FDV301N) can be used as a switch to turn on the video recording function. The MOSFET will be the interface between the camera module and main controller.

The pin (White) with the higher voltage will be connected to the drain of the FET while the pin (Black) with the lower voltage will be connected to the source of the FET as a ground. The switch will be controlled by the output voltage of the microcontroller, which will be connected to the gate of the FET. The maximum threshold voltage of the FET is 1.06V. Theoretically, when $V_{GS} > V_{th}$, the FET is turned on and the current is allowed to flow between the drain and the source as inversion layer is created. On the other hand, when $V_{GS} < V_{th}$, the FET is turned off, then there is no conduction between drain and source. Therefore, when the output voltage is larger than 1.06V, the video recording will be triggered.

2.5 Power Supply

Power Supply Module is designed to provide power to the system on the otter field for at least four days. The operating voltage for each component is shown in Figure 7.4 Despite the performance of sensors, decoders and encoders are better when they are supplied with 5V voltage, regulated voltage 3.3V is provided to all units to reduce the power consumption of the system. Four Energizer Max Alkaline C Batteries, which have capacity approximately 8350mAh each, are connected in series to produce 6V voltage. Then, a 3.3V voltage regulator, LD1117V33, is used to regulate 6V to 3.3V. Since the transmitter and receiver used require power noise lesser than 20mV p-p for optimal performance, capacitors and resistors are added to reduce the noise voltage swing. There will be three sets of power units. Each set will provide power to the following modules respectively:

(a) Sensor Module and Transmitter Interface Unit
(b) Receiver Interface Unit, Main Controller Module and MOSFET switch of Camera 1
(c) Receiver Interface Unit, Main Controller Module and MOSFET switch of Camera 2

The Power Supply Module is made detachable from the rest of the components so that the substitution of different batteries size and types, depending on user's preference, can be easily done. For extended period system operation on the otter field, alkaline batteries can be chosen for its large power storage capacity. On the other hand, rechargeable NiMH can be cost effective in the expense of the frequent labor of changing the batteries.

2.6 Casing Design

Three cases are made to protect the circuit. The three cases are used to shield the components as shown below:

(a) Sensor Case: Four PIR sensors
(b) Transmitter Case: Transmitter Interface Unit
(c) Receiver Case: Receiver Interface Unit, Main Controller and MOSFET switch

The transmitter case and receiver case has rubber-laminated lid to effectively prevent water leakage into the cases. The trail camera is mounted on a height-adjustable stands. There are three possible stands available for us, which are monopod, tripod and microphone stand. Monopod is chosen since it is cheaper and doesn't require further physical modifications to be applied to the project. Unlike tripod, it can be easily buried into the ground and it stands stably.

3 Design Details

3.1 Sensing Module

The horizontal detection angle of the Panasonic NaPiOn Spot Type PIR sensor is 38° and the vertical detection angle is 22° as shown in Figure A.2. Thus, for sensor b and sensor c as shown in Figure A.1, two of the sensors are rotated 90° to change their horizontal detection angle to 22°. The output of the sensor is shown in Figure A.3 and Figure A.4. As stated in the data sheet, when the sensor detects, the minimum output voltage is V_{dd} -0.5V. Since V_{dd} = 3.3V, the minimum output voltage will be 2.8V. When the sensor does not detect, the output voltage is 0V. However, the typical output voltage obtained after performing several tests is 3.3V. The output voltage will be considered as binary logic, in which 1 = high voltage (3.3V) and 0 = low voltage (0V) when it is sent to the Wireless Communication module. The sensor with digital output is chosen over the sensor with analog output since the data from the sensors will be constructed into Hamming code, in which binary logic data will be required.

Since the sensors are separated from the camera, they will have to be mounted on some surfaces to be able to function. Besides, mounting them on the surfaces will make connecting the wires easier when putting all the four sensors in a small waterproof case. Thus, PCBs have been designed using Eagle for the sensors to mount on as shown in the Figure 7.5 and Figure 7.6. Since the sensor has a diameter of 11mm, the board will be made a bit larger than that, with its dimension is 15mm(width) x 15mm(length), to support the sensor. In order for the sensors to cover the study site completely without overlapping, the placement of the sensors has been designed as shown in Figure 7.7.

The angles shown in the Figure 7.7, which are 149.5° and 157°, are obtained by placing the PCBs of sensors side by side, with the sensing area of each sensor to be parallel with the sensing area of the sensor beside, in order to ensure that no overlapping occurs. Although there is a gap between each sensing area, it will not affect the sensing module since the gap is small (0.021m and 0.023m). Typically, the average body length of the otters is 0.978m to 1.129m, which is much larger than the gaps not covered by the sensors. Thus, as long as the otters appear in the study site, the detection of them is ensured.

According to the datasheet, the sensors have to be connected in parallel when multiple of the sensors are used. Figure 7.8 shows the schematic of the sensors. To simplify the wiring of the sensors, they are connected to a base PCB which has been designed as shown in Figure 7.9. VDD and GND are connected to the power supply while a, b, c, d are the outputs of sensors a, b, c, d respectively.

The data collected from the sensors will then be sent to the Wireless Communication Module for encoding and transmitting to the receivers attached to the Main Controller. The sensors are powered by four 1.5V batteries connected in series (total voltage provided is 6V), which is regulated to 3.3V by using a 3.3V voltage regulator.

3.2 Wireless Communication Module

Figure A.5 in the Appendix shows the schematic of the transmitter interface. The output of the Sensing module will be connected to the microcontroller for Hamming code implementation. By using Hamming code as a form of encoding the output of the Sensing module, 1-bit errors can be corrected and 2-bit errors can be detected. This will reduce the errors made during the data transmission significantly. Figure A.6 in the Appendix shows the programming of constructing the Hamming code. The encoder will then encode the Hamming code in a 8-bit data package as shown below:

D7	D6	D5	D4	D3	D2	D1	D0
0	d	c	b	P_3	a	P_2	P_1

where a, b, c, and d are either 0 (not detecting) or 1 (detecting) according to output voltage of sensor a, b, c, and d respectively and P_1, P_2, and P_3 are the parity bits where

$$P1 = a \text{ XOR } b \text{ XOR } d \quad (3.1)$$

$$P2 = a \text{ XOR } c \text{ XOR } d \quad (3.2)$$

$$P3 = b \text{ XOR } c \text{ XOR } d \quad (3.3)$$

The signals encoded will then be sent to the transmitter for data transmitting at frequency 418MHz to the receiver interface which is attached to the Main Controller.

Figure A.7 shows the schematic of the receiver interface. The receiver will receive the data package sent by the transmitter and send it to the decoder for decoding. The decoded signal will then be sent to the Main Controller for further analyzing.

Since the Wireless Communication module will be attached to the same monopod as the camera, it is preferred to be as small and light as it can. Thus, all the components of the Wireless Communication module, Main Controller, and the voltage regulators of the power supply will be mounted on the PCBs, instead of protoboard which has a larger and heavier. The PCBs are designed by using Eagle PCB Design Software. Figure 7.10 and Figure 7.11 show the PCB designs for transmitter interface and receiver interface respectively.

3.3 Main Controller

The schematic of the main controller module is shown in Figure A.8. The main controller receives encoded Hamming Code data as inputs from the encoder of Wireless Communication module originated from Sensing module. Then, the main controller will check, correct and decode the received data. From the data, the sensors' outputs are interpreted and the corresponding trigger pulses are generated to activate the correct camera for video recording.

The program codes written for the main controller implementation by using the main controller algorithm can be seen in the Figure A.9.

3.4 Camera Module

The schematic of the camera module is shown in Figure A.10. The N-MOSFET acts as a switch with the gate pin of NMOSFET connected to the microcontroller while both the shutter trigger pins are connected to drain and source of the NMOSFET respectively. Thus, when a trigger pulse is generated from the microcontroller to the gate of MOSFET, an inversion layer occurs which creates a channel connecting drain and source. Hence, both the shutter trigger pin will be shorted and the camera's video recording will be activated.

3.5 Power Supply

The diagram of Power Supply Module is shown in Figure A.11. A 10Ω resistor is added in series with the power supply to attenuate the power noise. It is followed by a 10μF tantalum capacitor from VCC to ground. Shunt tantalum capacitor can reduce the noise ripple considerably. A default value, 0.1uF, bypass capacitor is added after the voltage regulator for the same reason. Beside the concern of power noise, the power consumption of the whole system is also an important issue since the system will be unmanned and work independently for a certain period. The supply current drawn from each component is shown in Figure 7.12. The total unloaded supply current drawn by the Sensing Module and Transmitter Interface Unit, which have the worst power consumption among the three set power supplies, is approximately 31.05mA according to equation (3.4).

$$I_{cc,total} = 4\times I_{cc,sensor} + I_{cc,TX} + I_{cc,decoder} + I_{cc,MSP430} + I_{cc,regulator} \tag{3.4}$$

$$= (4\times 5.48 + 3.4 + 0.5 + 0.23 + 5)mA = 31.05\ mA$$

Each battery provides an average voltage of 0.8V. According to the constant current performance of Energizer C-cell batteries as shown in Figure A.12, the service hours of the batteries are approximately 210 hours. The system can last for at least 8.75 days.

3.6 Casing Design

A draft of case design is shown as Figure A.13. The final product is shown in Figure A.14. The Sensor Case is cylindrical with diameter of 7cm, and height of 4cm. The Sensor Case is permanently attached on top of the Transmitter Case. Four holes are punched at the side of the Sensor Case to allow the front tips of PIR sensors to be exposed outside the cases. Then, the holes are sealed using the waterproof silicone glue.

The dimension of the Transmitter Case is 16cm x 9cm x 6.5cm. It is mounted on a metal plate which is attached to the body of monopod. The clamp can be adjusted for different heights.

The dimension of the Receiver Case is 16cm x 7cm x 6.5cm. It is mounted on a metal plate which is attached to the top of monopod. Four holes are made on the metal plate. Two of the holes allow wire connection between the camera and the MOSFET switch. The wire goes beneath the metal plate to prevent it from any possible damage. The third hole is used to mount the camera on the monopod and the last hole is placed near to the microphone position so that the performance of the microphone is not compromised. The camera is placed behind the Receiver Case on the metal plate. Two Receiver Cases are made for two respective trail cameras.

4 Verifications

4.1 Sensing Module

Since the system will be operating outdoor to cover a 3m x 3m study site, the Sensing module must be able to output high when motion is detected in the study site and output low when no motion is detected in order for the whole system to work as desired. Two tests have been carried out to investigate the functionality of the Sensing module, which are False Alarm Test and Miss Test. The purpose of False Alarm Test is to ensure that the Sensing module will output low when no animal and human are inside the study site. The weather, such as strong wind, and the motions of trees and bushes should not have significant effects on the performance of the Sensing module. Therefore, the desired probability of the Sensing module outputting high for this test is less than 10%. On the other hand, the objective of carrying out the Miss Test is to verify that the Sensing module will output high when animals or humans are inside the study site. It should not miss detecting any motion made by animals and humans. Thus, the desired probability of the Sensing module outputting low for this test is less than 10%.

Both of the tests were carried out by using Labview Test Program. It is a user-interfaced testing program used to provide quantitative analysis of the system performance for field-testing where lab equipment is not available. User can input threshold voltage, sampling time and time duration to model multiple possible situations. The program returns the probability of miss and false alarm numerically and recent input voltage graphically. The results of both of the tests are shown in Figure 7.13. The results obtained meet the requirements, which are less than 10%.

The tolerance of the Sensing module was verified by conducting the False Alarm Test and Miss Test with the sensor array is deviated from the original position 5° each time. The two tests will be repeated until the probability is above 30%. From the test results, the maximum allowed angle deviation obtained is 20° - 25°.

4.2 Wireless Communication Module

The output of the Sensing module must be sent correctly to the Main Controller by the Wireless Communication module. Therefore, a random 8-bit signal was fed into the encoder and the exact 8-bit signal was obtained at the output of the decoder with the transmitter and receiver interfaces were placed 5m away from each other.

To estimate the performance of the receiver, the signal to noise ratio (SNR) is calculated. The sensitivity formula is given as:

$$S_i = k\times(T_A + T_{Rx})\times BW_{3dB}\times\frac{S_o}{N_o} \tag{4.1}$$

Rearranging it, the signal to noise ratio formula is:

$$\frac{S_o}{N_o} = \frac{S_i}{k\times(T_A+T_{Rx})\times BW_{3dB}} \tag{4.2}$$

Where S_i is the sensitivity of the antenna

k is the Boltzmann constant

T_A is the temperature of the antenna

T_{Rx} is the temperature of the receiver

BW_{3dB} is the bandwidth of the signal

Assuming the receiver use single pole RC filter,

$$nBW = \frac{\pi}{2} BW_{3dB} \tag{4.3}$$

According to the datasheet, the noise bandwidth, nBW is 280kHz[10]. Thus, the $BW_{3dB} = 178.3kHz$. The sensitivity of the receiver for 10^{-5} BER is typically -95dBm. Assuming the temperature of the antenna and receiver is at room temperature ($T_A = T_{Rx} =$ 293K), the signal to noise ratio is

$$\frac{S_o}{N_o} = 219.248 \approx 23.4\ dB \tag{4.4}$$

In order to achieve a good performance, the measured SNR must be around the similar value. The SNR of the receiver was measured by using oscilloscope and the result is shown in Figure 7.14. The data obtained was then analyzed by using MATLAB as shown in Figure 7.15.

$$SNR = 20\log\left[\frac{mean\ high\ voltage - mean\ low\ voltage}{2 \times mean\ std\ deviation}\right] \tag{4.5}$$

$$= 20\log\left[\frac{1.3226 - 1.0695}{0.0206}\right]$$

$$= 21.7dB$$

The result from measurement, SNR = 21.7dB is only slightly lower than the theoretical value and therefore is considered as a good result.

The tolerance of the Wireless Communication module was verified by testing the maximum distance between transmitter and receiver in which valid data is received. From the test results, the maximum operating distance obtained is 17.3m which is much better than the requirement.

4.3 Main Controller

Hamming Code Checking and Correction Test using the correct input data results is shown in Figure 7.16. From the results, it can be observed that the output data is the same as the input data. This is because the input data into the microcontroller are without errors. Thus, the Hamming Code Checking and Correction of the Main Controller did not need to perform any correction on the input data. This is the expected result. Thus, the microcontroller is functioning correctly.

Hamming Code Checking and Correction Test using input data with one bit error results are shown in Figure 7.17. From the results, it can be observed that the Hamming Code Checking and Correction of the Main Controller perform a correction on the one-bit error input data. Thus, the output data is the same as the intended data. Thus, the microcontroller is functioning correctly and is performing its Hamming Code Checking and Correction on one-bit error data.

Sensor Interpretations Test results are shown in Figure 7.18. From the results, the LED corresponds to the generated pulse of the main controller (LED lights up if trigger pulse is high and LED does not light up if trigger pulse is low). The results obtained above are consistent with the intended results shown in Figure 7.2. Thus, the Main Controller is interpreting the sensors' output correctly and is generating correct trigger pulse to the intended cameras of Camera Module.

4.4 Camera Module

By following the testing procedures, it can be concluded that the camera module is activated when a trigger pulse is sent by main controller. Photos are taken and saved inside the memory card. The camera is not activated when it is in the 10 seconds recovery period despite a trigger pulse is sent. This is expected due to limitation of the camera.

4.5 Power Supply

The power supply unit is able to provide constant voltage 3.3V with voltage swing 10mV p-p as shown in Figure 7.19. The power noise is much lower than the maximum required value, 20mV p-p.

By switching on the system for four days continuously, the batteries voltage drops from initial value, 5.92V to 5.66V. The system is still able to operate correctly after the four-days-power consumption test.

4.6 Casing Design

The cases are splashed with water stream. The inside of the cases are examined. The case design passes the waterproof test successfully. Then the cases are stabbed with scissors to make sure that the case design can withstand any physical attack. It passes this test successfully too.

5 Cost

5.1 Parts

The cost of parts for this system is shown in Figure C.1. Since the system consists of two trail cameras, the cost is fairly high, which is \$803.33. However, it is assumed that the cost will be reduced by at least 20%, which is approximately \$642.66 for the whole system, if the system is produced in larger quantity in the future. Besides, an alternative camera with cheaper cost can be used to further reduce the total cost of the system.

5.2 Labor

Referring to Figure C.2, the labor cost is estimated by using the following formula.

$$\text{Total} = \text{Hourly Rate} \times 2.5 \times \text{Total Hours Invested} \tag{5.1}$$

By using a rate of \$30.00 and estimated time length of 240 hours each, the total is

$$\text{Total} = \$30.00 \times 2.5 \times 240 \times 3$$

$$= \$54{,}000.00$$

6 Conclusion

6.1 Accomplishments

All the module tests conducted yield satisfactory results and the system works perfectly as desired. The Otter Stalker System can detect motions in an area of 3m x 3m and trigger the trail camera to start the video recording. The 10s trigger delay between two camera, which is a feature desired by Illinois Natural History research group, can be implemented successfully. This feature ensures that either of cameras will record a video when otter is detected inside the field. We are able to achieve our goal to increase the quantity of video data taken if the otter is present in the field. Besides, the camera and sensors height is adjustable, thus it makes the system applicable in various geometrical landscape or circumstances.

6.2 Uncertainties

Although the power supply module can last for at least 8 days, the average service hours of the power supply module is not known. The standard power supply tolerance test is not conducted due to time constraint. By powering the system continuously for a certain period, the number of days for the system to fail due to depleted batteries will be counted. As this test can only be conducted after all modules are assembled, thus far, we are able to carry out this test for 5 days and the system is still working fine. We estimate the system can last for two weeks, but further testing is required to support our estimation.

The average lifespan of this system is not known exactly. This requires some long-term tests to obtain the necessary information. Although the system passes the waterproof and "chewproof" tests, the system might be vulnerable to other hazards such as big animals, bird nesting and others which can compromise the system efficiency. Feedback should be collected from the user to improve the system.

6.3 Future Works

This project can be further developed to make it user-friendlier. A power level indicator can be added to notify the user when the power level is low. Transceiver with internal antenna can be used to eliminate the need of external antenna and reduce the size of the case in the expense of wireless transmission ranges and efficiency. By reducing the size of the case, it can be more aesthetically presentable. Cases with camouflaged colors can be custom-made to replace the current one. Besides, the microphone feature of the camera can be further modified to improve the quality of video data obtained. This can be done by substituting the internal microphone with a directional microphone with a better performance. Furthermore, a stand, which allows the camera to tilt at desired angle, can be custom-made to replace the current monopod. This allows the camera to record at desired angle.

6.4 Ethical Issues

In the process of designing the Otter Stalker System, ethical guidelines based on the IEEE Code of Ethics had always been referred and practiced.

The main objective of this project is to enhance the current technology available to the river otter researchers in habitat-monitoring. In the accordance with code 5, which states that "*to improve the understanding of technology; its appropriate application, and potential consequences*", researches had been carried out on the current available technology, otters' habitats and active hours in order to fulfill the requirements of this project.

Since Wireless Communication module is an essential part of this project, related Federal Communication Commission(FCC) regulations are complied. In the accordance with code 1, which states that "*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*", the legal considerations section in the data sheets of the products used in this project has been consulted. Since the transmitter and receivers used in this project operates at 418MHz, Part 15, Section 231 of the FCC regulations, which regulate 260-470MHz band, had been adhered.

7 Figures and Tables

Figure 7.1: Block Diagram of the Otter Stalker System

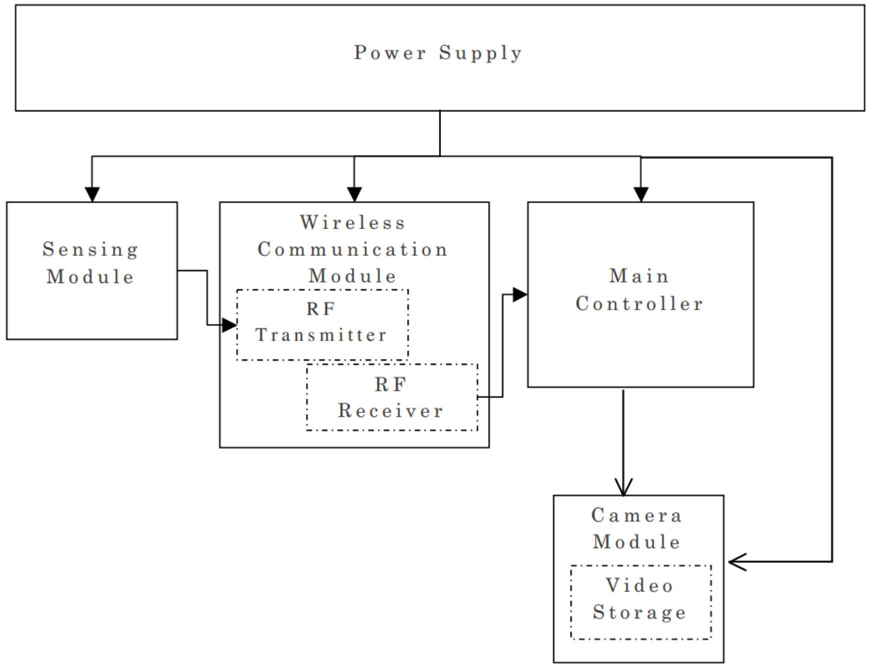


Figure 7.2: Sensors' Output Interpretation and Action Performed

Sensor Condition				Action Performed
a	b	c	d	
1	0	0	0	Only trigger pulse for Camera 1 is generated
0	0	0	1	Only trigger pulse for Camera 2 is generated
X	1	X	X	Trigger pulse for Camera 1 is generated. After 10 seconds, trigger pulse for Camera 2 is generated.
X	X	1	X	Trigger pulse for Camera 1 is generated. After 10 seconds, trigger pulse for Camera 2 is generated.

Figure 7.3: Alternatives for Camera Module and its disadvantages

Video Recording Device	Disadvantage
Outdoor CCTV Camera	Need a expensive portable DVR to store the video since the study site is remote
Wireless IP Camera	The place is remote and thus hard to find internet connection
Car Back-up Assist Camera	Need a expensive portable DVR to store the video since the study site is remote
Car Camera	Not weatherproof

Figure 7.4: Operating Voltage for each Component [2][3][7][8][9][10]		
Component	Min (VDC)	Max (VDC)
PIR Sensor	3.0	6.0
Transmitter	2.7	3.6
Receiver	2.1	3.6
Encoder/Decoder	3.0	5.5
Microcontroller	1.8	3.6

Figure 7.5: PCB design for sensor with sensing range of 38°

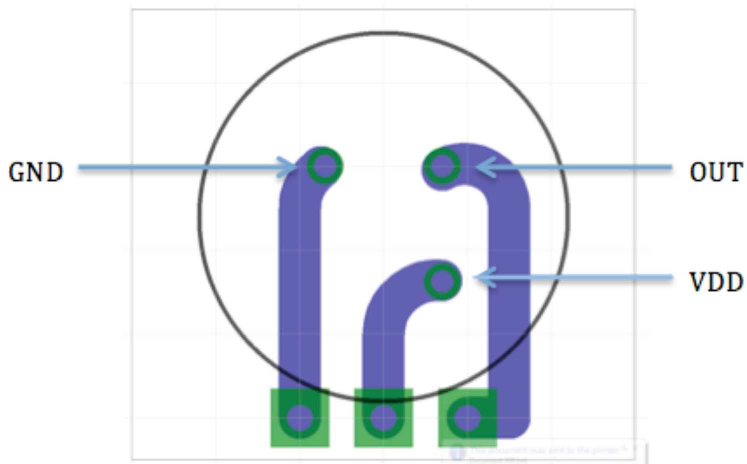


Figure 7.6: PCB design for sensor with sensing range of 22°

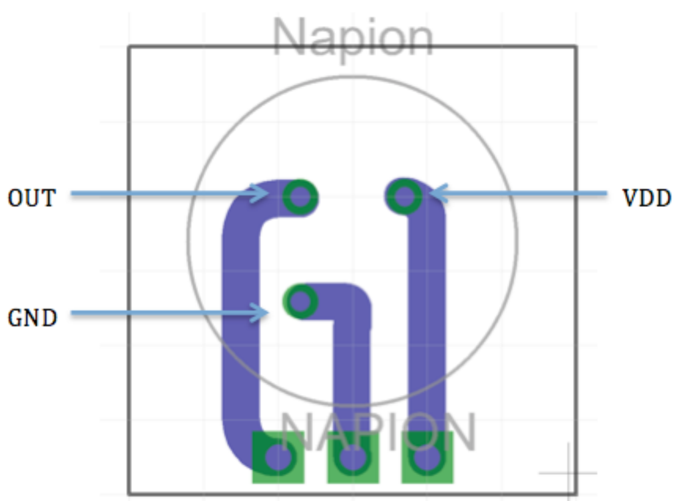


Figure 7.7: Arrangement of the sensors

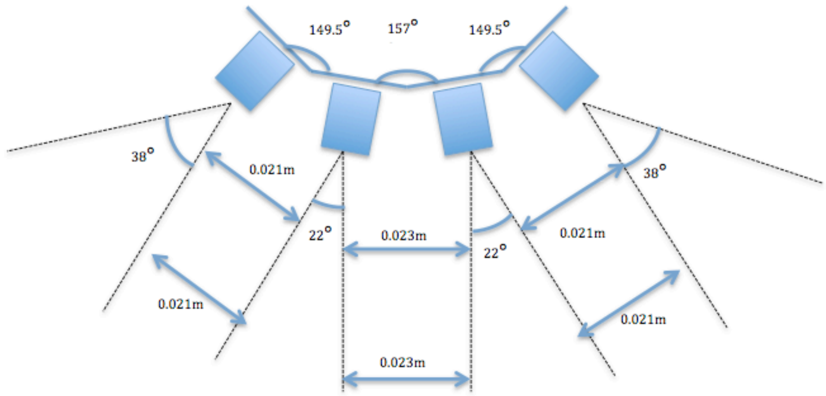


Figure 7.8: Schematic of sensors

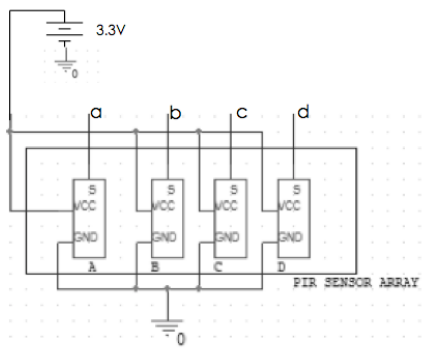


Figure 7.9 : Design of base PCB

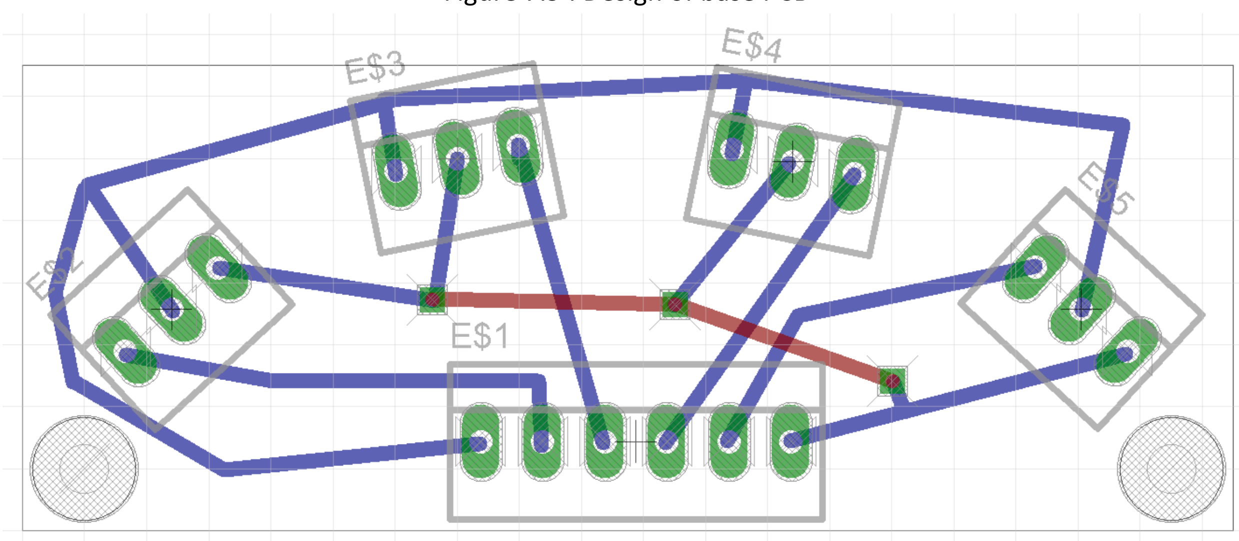


Figure 7.10: PCB of transmitter interface

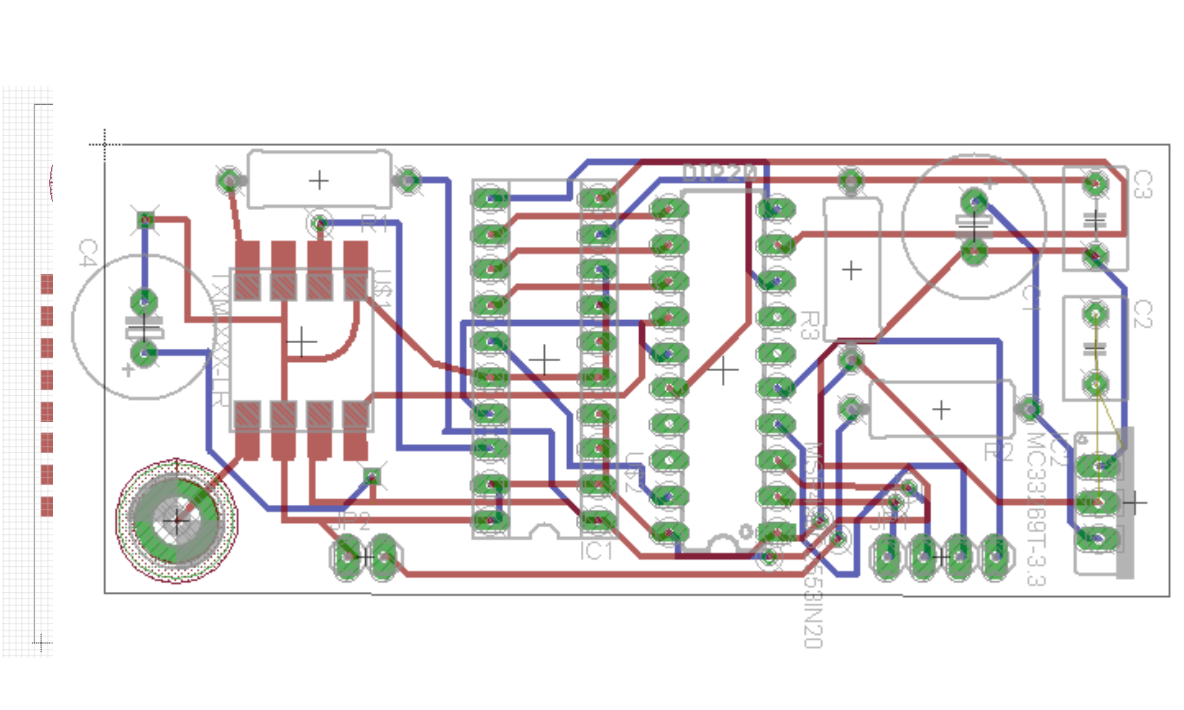


Figure 7.12: The Unloaded Supply Current for Each Component	
Components	**Supply Current (mA)**
PIR sensor	5.48
Transmitter	3.40
Receiver	5.20
Microcontroller (Active Mode)	0.23
Decoder/Encoder	0.50
3.3V Voltage Regulator	5.00

Figure 7.13: Results of False Alarm Test and Miss Test for indoor and outdoor

<table>
<tr><th></th><th>False Alarm Test</th><th>Miss Test</th></tr>
<tr><td>Indoor</td><td rowspan="4">0.55%</td><td rowspan="4">2.17%</td></tr>
<tr><td>Temp: 20°C</td></tr>
<tr><td>Wind: -</td></tr>
<tr><td>Humidity: 44%</td></tr>
<tr><td>Outdoor</td><td rowspan="4">0.00%</td><td rowspan="4">7.84%</td></tr>
<tr><td>Temp: 17°C</td></tr>
<tr><td>Wind: SSW 19kph</td></tr>
<tr><td>Humidity: 53%</td></tr>
</table>

Figure 7.14: The Analog Output from the Receiver

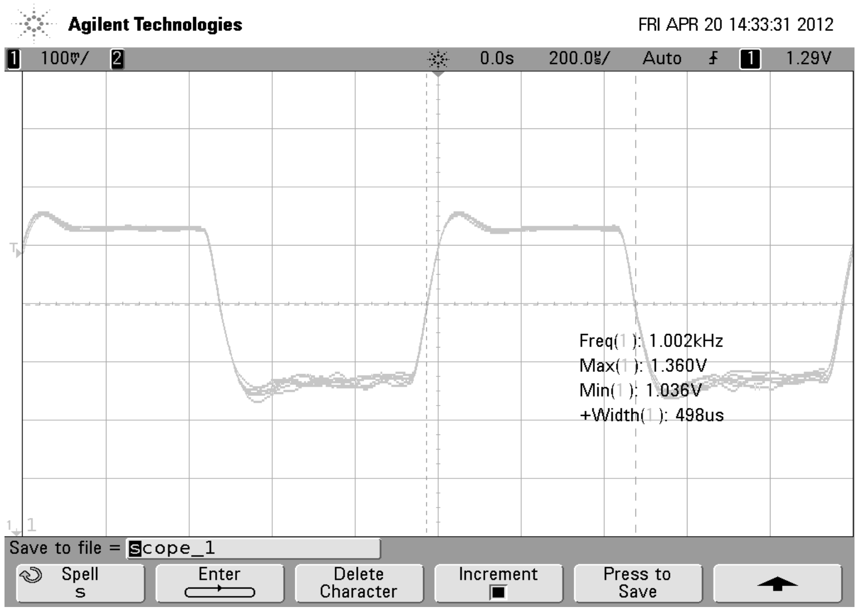


Figure 7.15: Matlab SNR Calculation Results

Workspace

Name	Value
SNR	24.6096
SNRdb	27.8221
data	<1000x2 double>
high_mean1	1.3230
high_mean2	1.3221
high_std_dev1	0.0114
high_std_dev2	0.0083
low_mean1	1.0662
low_mean2	1.0727
low_std_dev1	0.0143
low_std_dev2	0.0071
meanhi	1.3226
meanlo	1.0695
meanstd	0.0103

Figure 7.16: Result for Hamming Code Checking and Correction Test Using the Correct Input Data

Input Data							Results (Output Data)							Status
0	*0*	0	*0*	0	0	0	0	0	0	0	0	0	0	Correct
1	*1*	1	*1*	1	1	1	1	1	1	1	1	1	1	Correct
1	*1*	1	*0*	0	0	0	1	1	1	0	0	0	0	Correct
1	*0*	1	*1*	0	1	0	1	0	1	1	0	1	0	Correct
0	*0*	1	*0*	1	1	0	0	0	1	0	1	1	0	Correct
0	*0*	1	*1*	0	0	1	0	0	1	1	0	0	1	Correct
1	*0*	0	*0*	0	1	1	1	0	0	0	0	1	1	Correct
0	*1*	1	*0*	0	1	1	0	1	1	0	0	1	1	Correct

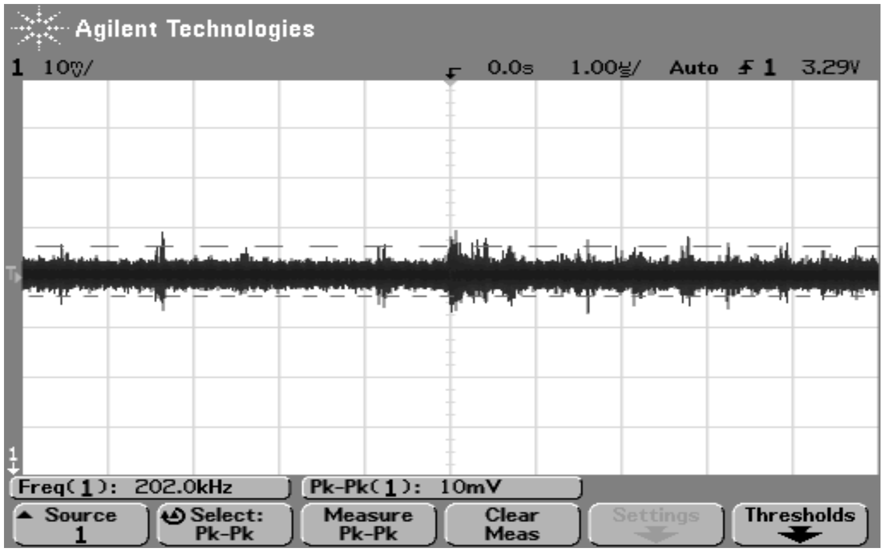
Figure 7.17: Result for Hamming Code Checking and Correction Test with One Bit Error

Intended Data							One-bit Error Input Data							Result (Output Data)							Status
0	*0*	0	*0*	0	0	0	*1*	0	0	0	0	0	0	0	0	0	0	0	0	0	Correct
1	*1*	1	*1*	1	1	1	1	*0*	1	1	1	1	1	1	1	1	1	1	1	1	Correct
1	*1*	1	*0*	0	0	0	1	1	*0*	0	0	0	0	1	1	1	0	0	0	0	Correct
1	*0*	1	*1*	0	1	0	1	0	1	*0*	0	1	0	1	0	1	1	0	1	0	Correct
0	*0*	1	*0*	1	1	0	0	0	1	0	*0*	1	0	0	0	1	0	1	1	0	Correct
0	*0*	1	*1*	0	0	1	0	0	1	1	0	*1*	1	0	0	1	1	0	0	1	Correct
1	*0*	0	*0*	0	1	1	1	0	0	0	0	1	*0*	1	0	0	0	0	1	1	Correct
0	*1*	1	*0*	0	1	1	0	1	1	*1*	0	1	1	0	1	1	0	0	1	1	Correct

Figure 7.18: Sensor Interpretations Test Result

Sensors' Output	LED Status
Only Sensor "a" is high	The red LED (P1.0) blink for a while and the green LED(P1.6) did not blink
Only Sensor "d" is high	The red LED (P1.0) did not blinks and the green LED(P1.6) blink for a while
Either Sensor "b" or "c" is high	The red LED (P1.0) blink for a while. After 10 seconds, the green LED (P1.6) blink for a while.

Figure 7.19: Noise Voltage Swing of Power Supply Module



8 References

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Appendix A: Diagrams and Figures

Figure A.1: Placement of sensors and cameras

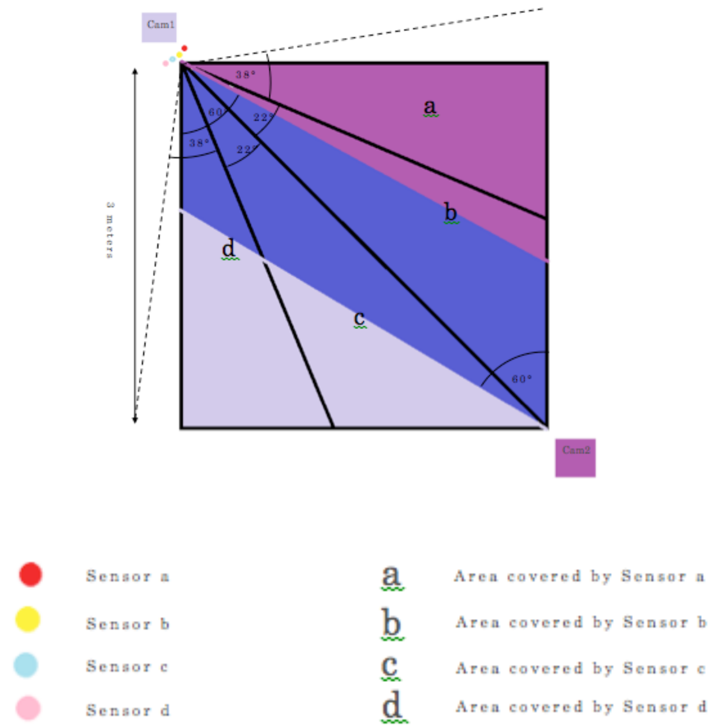

Figure A.2: Top view (horizontal) and side view (vertical) of the detection angle

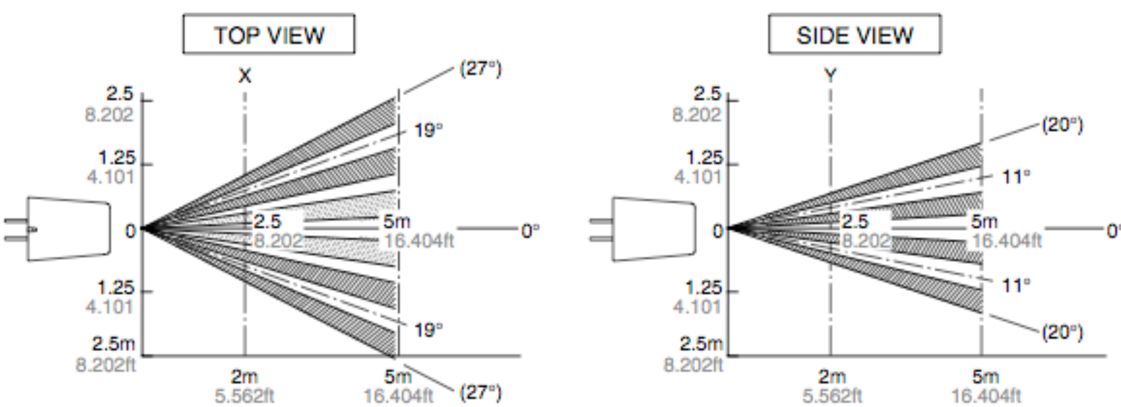

Figure A.3: Digital output of the sensor (Graph)

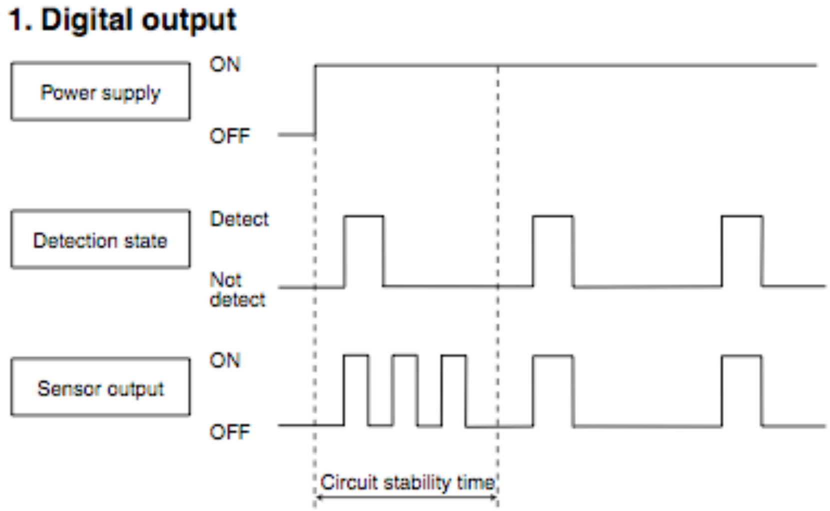

Figure A.4: Digital output of sensor (Table)

1) Digital output

Items		Symbol	Electrical characteristics *( ) is low current consumption type	Measured conditions *( ) is low current consumption type
Rated operating voltage	Minimum	Vdd	3.0 V DC (2.2 V DC)	
	Maximum		6.0 V DC (3.0 V DC)	
Rated consumption current (Standby) Note)	Typical	Iw	170 µA (46 µA)	Ambient temperature = 25°C 77°F Operating voltage = 5V (3V) Iout = 0
	Maximum		300 µA (60 µA)	
Output current (when detecting)	Maximum	Iout	100 µA	Ambient temperature = 25°C 77°F Operating voltage = 5V (3V) Vout ≧ Vdd−0.5
Output voltage (when detecting)	Minimum	Vout	Vdd −0.5	Ambient temperature = 25°C 77°F Operating voltage = 5V (3V) Open when not detecting
Circuit stability time	Typical	Twu	7 s	Ambient temperature = 25°C 77°F Operating voltage = 5V (3V)
	Maximum		30 s	

Note: The current which is consumed during detection consists of the standby consumed current plus the output current.

Figure A.5: Schematic of Transmitter Interface

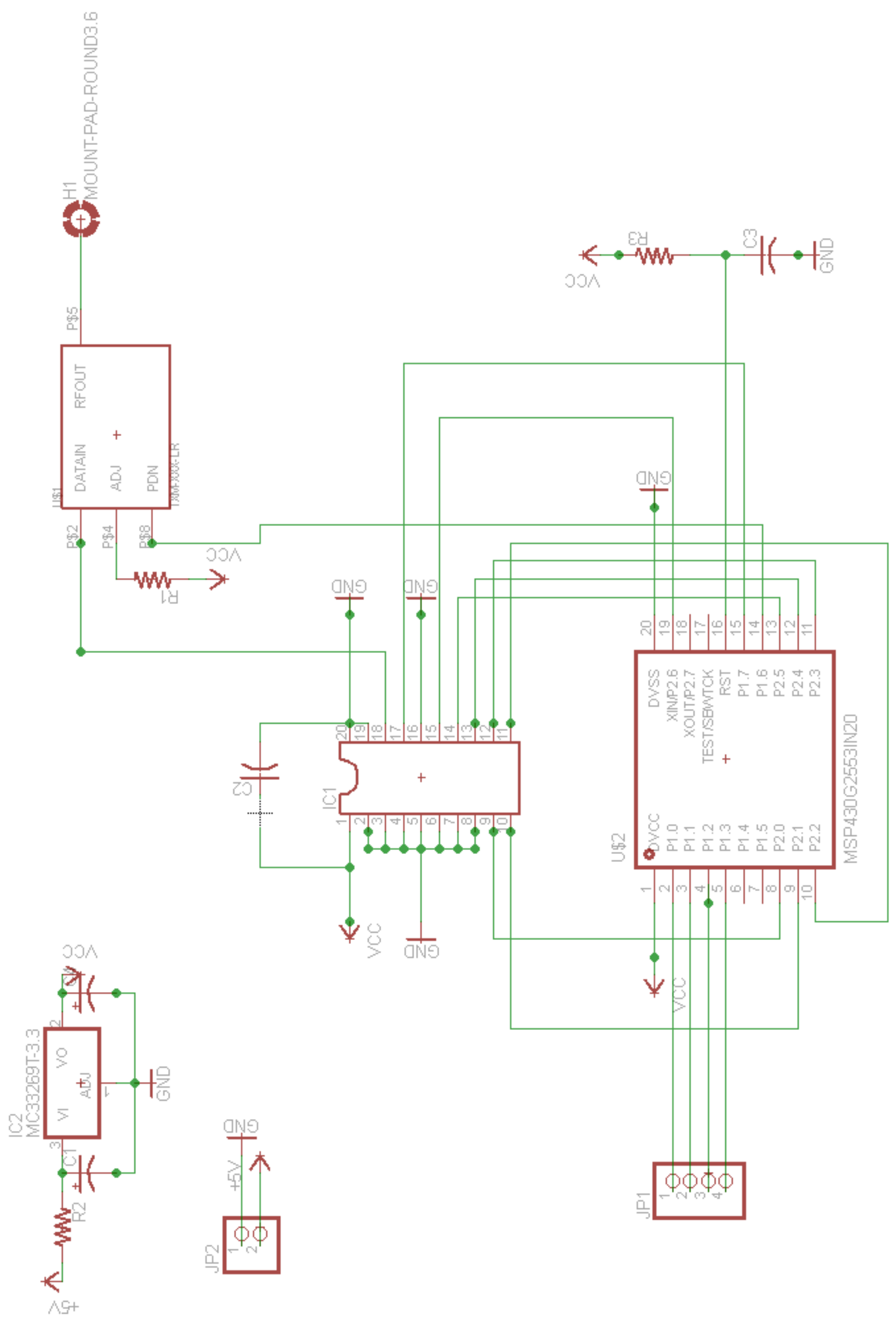

Figure A.6: Programming of constructing the Hamming code

```
/*
 * ======== Standard MSP430 includes ========
 */
#include <msp430.h>

/*
 * ======== Grace related includes ========
 * Below are what's included in CSL.h
 * Refer the following files for microcontroller hardware configuration:
 * Microcontroller System Registers Configuration (System_init.c)
 * Basic Clock System Configuration (BCSplus_init.c)
 * WatchDog Timer+ Configuration (WDTplus_init.c)
 * General Purpose Input/Output (GPIO) Configuration [Port 1 and Port 2] (GPIO_init.c)
 */
#include <ti/mcu/msp430/csl/CSL.h>
#include<stdlib.h>
/*
 *  ======== main ========
 */
short unsigned int a,b,c,d;
short unsigned int TE, TE_bar;
short unsigned output;

unsigned int edata[7]; //Array integer used to store corrected Hamming Code (7,4)

int main(void)
{
    CSL_init();                     // Activate Grace-generated configuration
                                    // Microcontroller hardware configuration
                                    // Refer csl.h library for more information

while(1)
{

            //Assign input value to integer sensor a,b,c,d
            a = P1IN & 0x01;
            b = P1IN & 0x02;
            c = P1IN & 0x04;
            d = P1IN & 0x08;


            //Create Hamming Code
            if (a > 0) {edata[2] = 1;} else if (a == 0) {edata[2] = 0;}
            if (b > 0) {edata[4] = 1;} else if (b == 0) {edata[4] = 0;}
            if (c > 0) {edata[5] = 1;} else if (c == 0) {edata[5] = 0;}
            if (d > 0) {edata[6] = 1;} else if (d == 0) {edata[6] = 0;}
            edata[0] = edata[2] ^ edata[4] ^ edata[6];
            edata[1] = edata[2] ^ edata[5] ^ edata[6];
            edata[3] = edata[4] ^ edata[5] ^ edata[6];


            //Create Transmit Enable Signal
            TE = edata[2] || edata[4] || edata[5] || edata[6];
            TE_bar = !(TE);

            output = 0x00;
            //Output Generated Hamming Code and Transmit Enable Signal
            if (edata[0] == 1) {output = output | 0x01;}
            if (edata[1] == 1) {output = output | 0x02;}
            if (edata[2] == 1) {output = output | 0x04;}
            if (edata[3] == 1) {output = output | 0x08;}
            if (edata[4] == 1) {output = output | 0x10;}
            if (edata[5] == 1) {output = output | 0x20;}
            if (edata[6] == 1) {output = output | 0x40;}

            P2OUT = output;
            if (TE == 1){
                P1OUT = 0x40;
            }
            else {
                P1OUT = 0x80;
            }
}
}
```

Figure A.7: Schematic of Receiver Interface

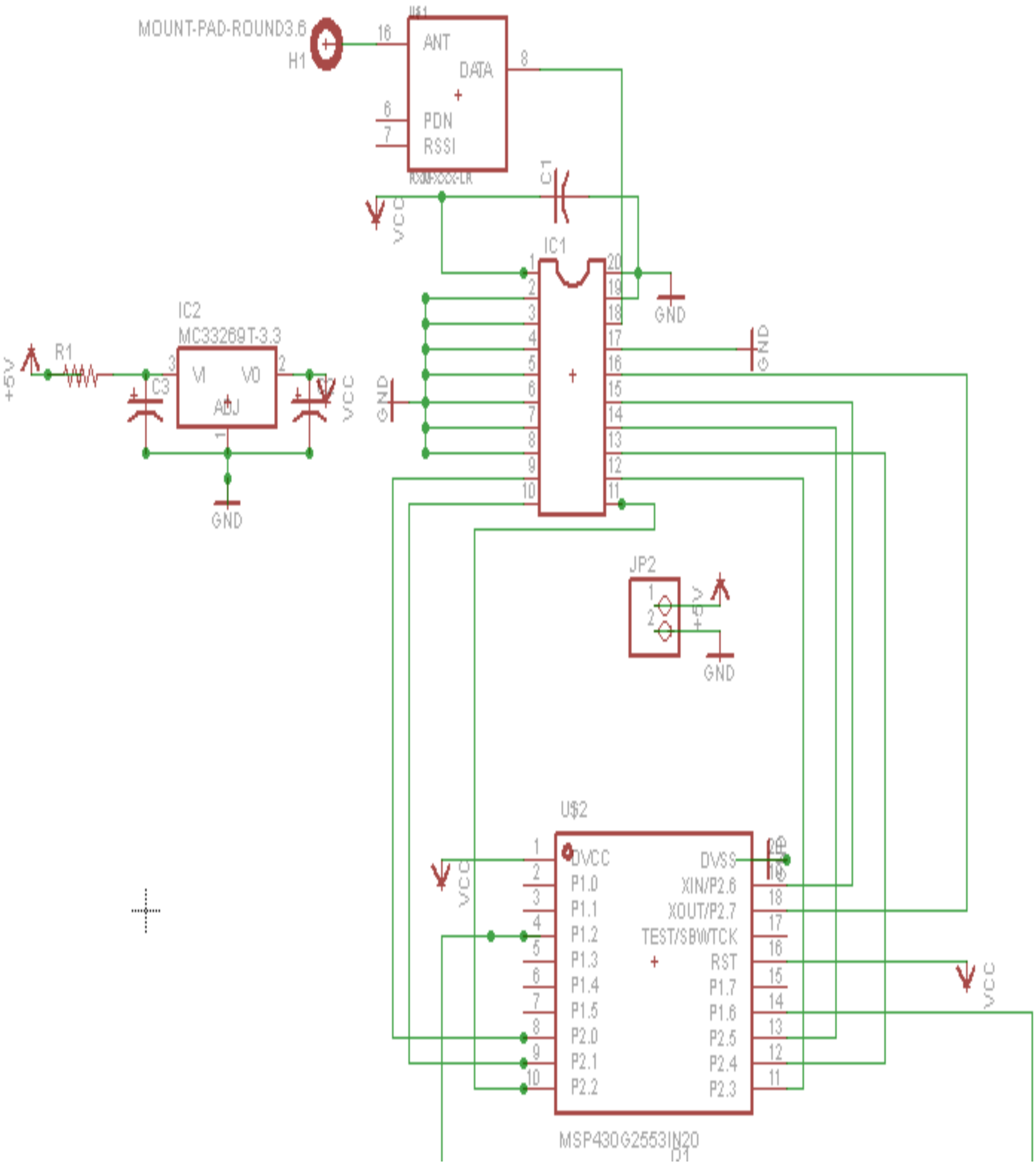

Figure A.8: Schematic of the Main Controller [2]

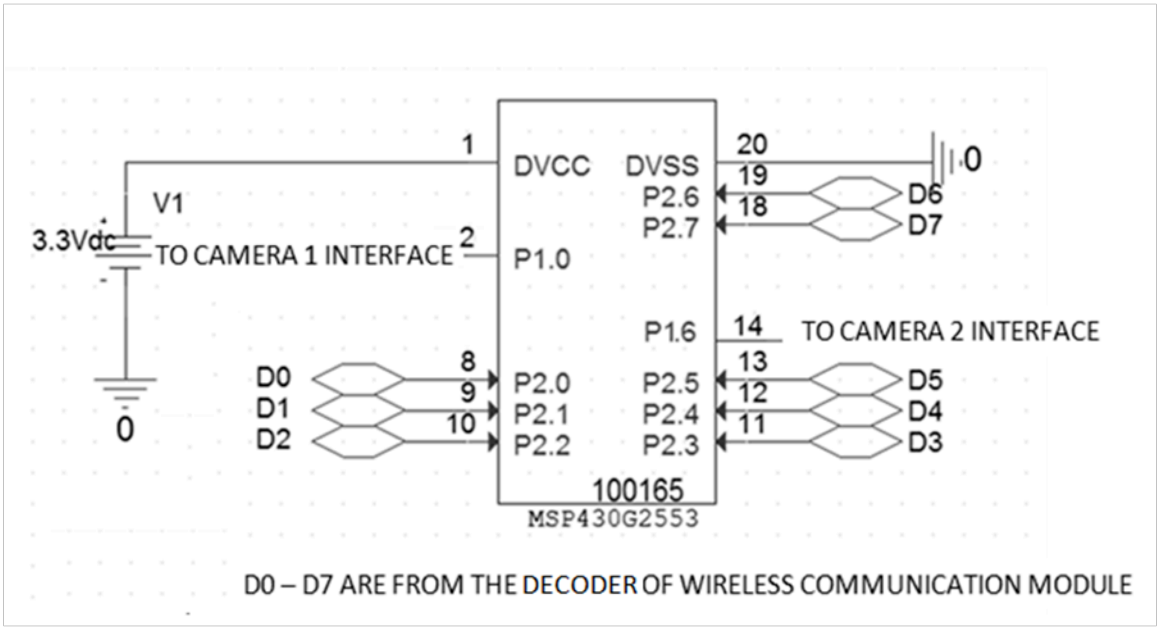

Figure A.9: Main Controller Code Script

```
#include <msp430.h>
/*
 * ======== Grace related includes ========
 * Below are what's included in CSL.h:
 * Refer the following files for microcontroller hardware configuration:
 * Microcontroller System Registers Configuration (System_init.c)
 * Basic Clock System Configuration (BCSplus_init.c)
 * WatchDog Timer+ Configuration (WDTplus_init.c)
 * General Purpose Input/Output (GPIO) Configuration [Port 1 and Port 2] (GPIO_init.c)
 */
#include <ti/mcu/msp430/csl/CSL.h>
#include<stdlib.h>
//  ======== main ========

//flag counter controlled by Port 2 interrupt to enable input data interpretation if input is detected
short int PIR_SIG; //Help to control microcontroller power operating mode

//integers used as "for" loop counter
unsigned int i;
unsigned int j;
unsigned int k;

unsigned int data[7];  //Array integer used to store the Hamming Code (7,4) input
unsigned int edata[7]; //Array integer used to store corrected Hamming Code (7,4)
unsigned int syndrome[3]; //Syndrome matrix (Indicate whether an error has occured)
int hmatrix[3][7] = {
                    1,0,1,0,1,0,1,
                    0,1,1,0,0,1,1,
                    0,0,0,1,1,1,1
                    };             //Parity-Check matrix
//Code generator matrix (Not used as we are receiving Hamming Code as input)
char gmatrix[7][5]={"1101","1011","1000","0111","0100","0010","0001"};

int main(void)
{
    CSL_init();                     // Activate Grace-generated configuration
                                    // Microcontroller hardware configuration
                                    // Refer csl.h library for more information

while(1)
{
        if (PIR_SIG == 1) //If inputs are detected (input interrupt), data intepretation begins
        {
            P2IE &= 0x80;   //Temporary disable interrupt
            PIR_SIG = 0;    //Reset flag counter

            //Assign input value to array integer "data"
            data[0]= P2IN & 0x01;
            data[1]= P2IN & 0x02;
            data[2]= P2IN & 0x04;
            data[3]= P2IN & 0x08;
            data[4]= P2IN & 0x10;
            data[5]= P2IN & 0x20;
            data[6]= P2IN & 0x40;

            //Turn obtained input bits value into binary value (1 or 0)
            for(i=0;i<7;i++)
            {
                if (data[i] > 0)
                {
                    edata[i] = 1;
                }
                else  if (data[i] == 0)
                {
                    edata[i] = 0;
                }
            }
```

Figure 9: Main Controller Code Script (Continued)

```
            //Generating syndrome matrix to check if there is error
            for(i=0;i<3;i++)
            {
                for(j=0;j<7;j++)
                {
                syndrome[i]+=(edata[j]*hmatrix[i][j]);
                syndrome[i]=syndrome[i]%2;
                }
            }

            //Checking through syndrome matrix for bit position that has error
            //Integer j represents the bit position that has error
            //j = 7 if there is no error
            //Single Error Correction Double Error Detection system (SECDED)
            for(j=0;j<7;j++)
            if((syndrome[0]==hmatrix[0][j]) && (syndrome[1]==hmatrix[1][j]) && (syndrome[2]==hmatrix[2][j]))
            break;

            if(j==7) //If data input is error free, do nothing
                ;
            else //else invert the bit value that has error
            edata[j]=!edata[j];

// reset syndrome matrix to avoid error
            syndrome[0] = 0;
            syndrome[1] = 0;
            syndrome[2] = 0;

//Sensors intepretation
//   sensor a = edata[2];
//   sensor b = edata[4];
//   sensor c = edata[5];
//   sensor d = edata[6];

            if (edata[4] || edata[5]) //if sensor b or c high
            {
                P1OUT = 0x01;
                _delay_cycles(100000);  //Output P1.0 is high for 0.1s (Camera 1)
                P1OUT = 0x00;
                _delay_cycles(10000000); //delay 10 second
                P1OUT = 0x40;
                _delay_cycles(100000);  //Output P1.6 is high for 0.1s (Camera 2)
                P1OUT = 0x00;
            }
            else if(edata[2] && ~edata[4] && ~edata[5] && ~edata[6]) //if only sensor a high
            {
                P1OUT = 0x01;
                _delay_cycles(200000); //Output P1.0 is high for 0.2s (Camera 1)
                P1OUT = 0x00;
            }
            else if ((edata[6] && ~edata[2] && ~edata[4] && ~edata[5])) //if only sensor d high
            {
                P1OUT = 0x40;
                _delay_cycles(200000); //Output P1.0 is high for 0.2s (Camera 1)
                P1OUT = 0x00;
            }

            P2IE|= 0x7F; //Enable back interrupt
        }

    _BIS_SR(LPM3_bits + GIE); //Enter Low Power Mode 3(LPM3)

}

}

//Function used for Port2 Interrupt Configuration
//Turn microcontroller power operating mode into Active Mode upon interrupt
void InterruptPIR (void)
{
  PIR_SIG = 1; //Set flag counter to enable input interpretation
  P2IFG = 0x00;
}
```

Figure A.10: Schematic of the Camera Module

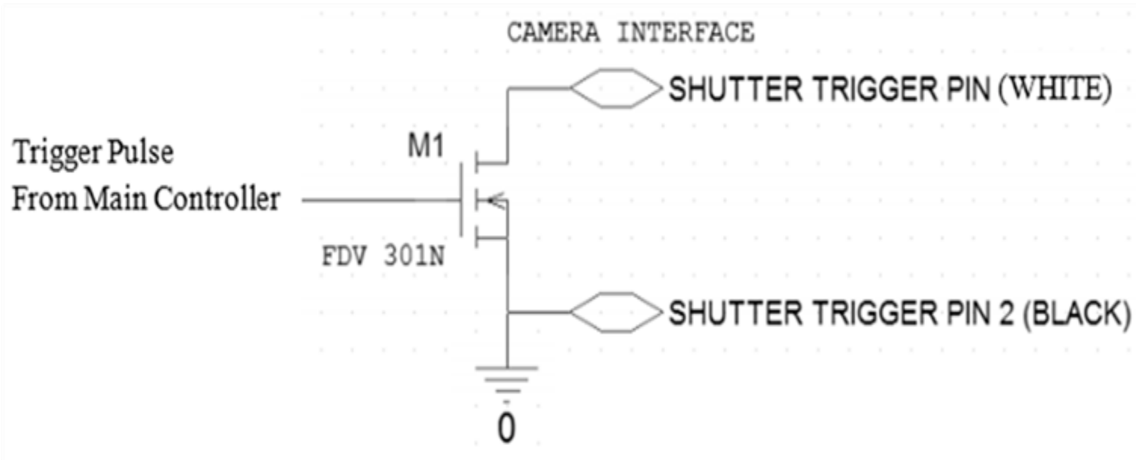

Figure A.11: Schematic of the Power Supply Module

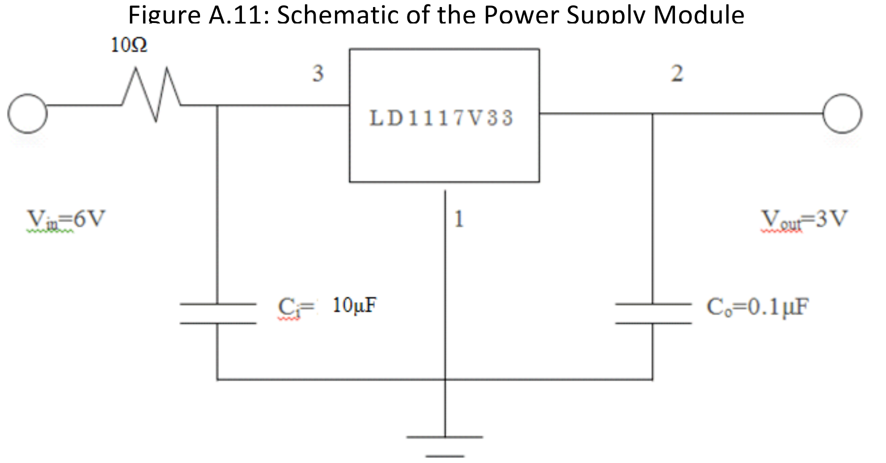

Figure A.12: Constant Current Performance of Energizer C-cell Batteries

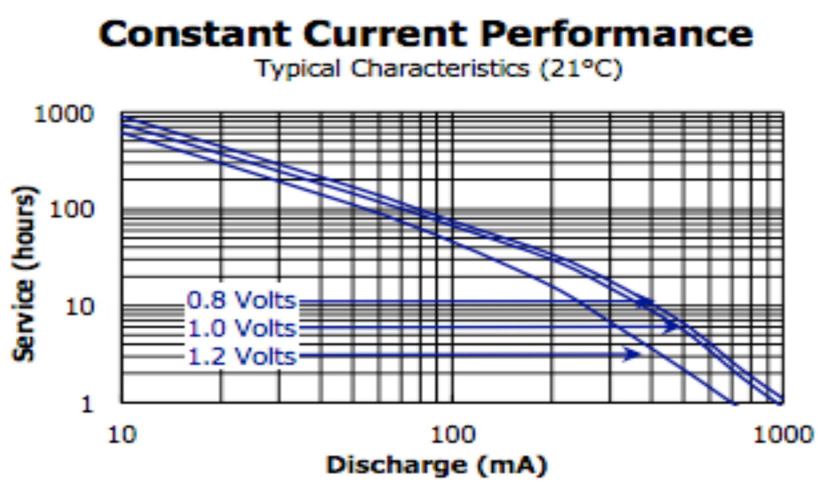

Figure A.13: Initial Case Design Draft

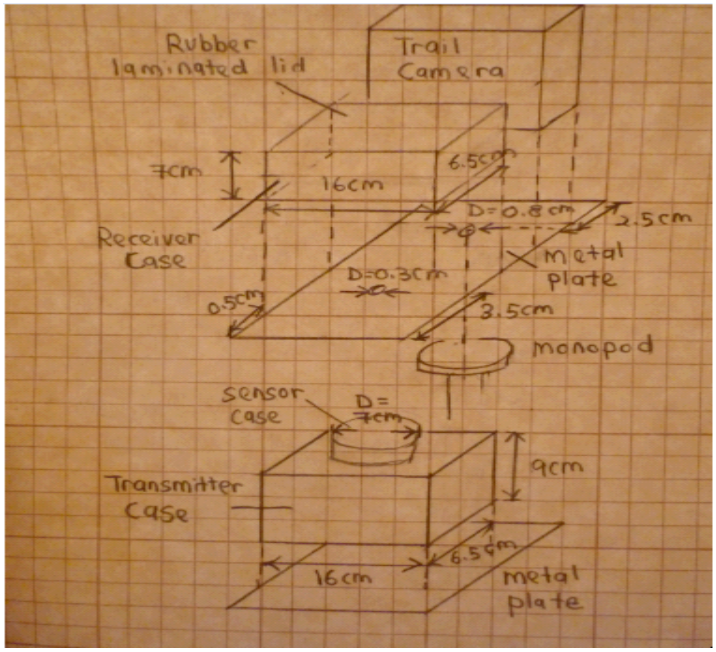

Figure A.14: The final product of the case

Appendix B: Requirement and Verification

Figure B.1: Requirement and Verification Checklist

Requirement	Verification	Verification Status
1. *Sensing Module* The PIR sensor output high when motion is detected within 3m x 3m outdoor area. The conditional probability of false alarm and miss of the sensors array should be within 10% a. Within an 3m x 3m indoor area with lesser interferences, the conditional probability of false alarm and miss of the sensors array should be within 15% b. The sensor is able to detect motion 4.5m away c. The output voltage vs distance from the PIR sensors should be constant with tolerance +/-0.5V The detection angle of the sensors is 22 degree with 10% tolerance.	A 3m x 3m test site is set up at Bardeen Quad. PIR sensors are placed according to Figure 1. NI MyDAQ is used to acquire digital output data from the sensors. *-Preliminary Function Test* Before going to the field test, a basic test is conducted to make sure that the sensor is working as expected. PIR sensor output is connected to oscilloscope with trigger voltage at about 4.5V. Hand is waved across the sensor and the oscilloscope waveform is observed. The waveform should indicate the sensor output 4.5V and above *-False Alarm Test* For 15 minutes, no motion or person will be inside the test site. The sensors' output must always be low. Within these 15 minutes, the output of the sensors will be sampled every 5 seconds. The false alarm probability is calculated and must be less than 10%. *-Miss Test* For another 5 minutes, a person will be moving randomly inside the test site. Within these 5 minutes, the output of the sensors will be sampled every 0.5 seconds. The miss probability is calculated and must be less than 10%. *If the tests above fail, the following steps will be performed.* a. Within an area of 3m x 3m in a dark room, the *False Alarm Test* and *Miss Test* are repeated. b. A person will be crossing perpendicularly through the sensor detection beam 4.5m away. The oscilloscope waveform should	Yes

Figure B.1: Requirement and Verification Checklist (Continued)

	indicate the sensor output 4.5V c. A person will be cutting through the sensor detection beam and zig-zagging away from the sensor. The zig-zag pattern is to make sure that the PIR sensors detect temperature differences within the angle of detection. The sensors output will be observed with oscilloscope. Since it is a digital PIR sensor, the output voltage should be constant. Placing a PIR sensor at fixed location, a line is drawn across the sensor 7cm away. The sensor output is connected to LED with 50Ohm in between. Hand is slowly moved along the line from the side (right and left). When LED is lighted up, the hand location is marked on the line. The length between both marks (right and left) should be more than 2.7cm.	
2. *Wireless Communication Module* A bits sequence can be transferred from transmitter to receiver. a. The SNR (Signal to Noise Ratio) is more than 20 dB b. The total response time of this module should be lesser than 5ms.	Precaution: While dealing with this module, ESD (Electrostatic Discharge) wrist strap must be worn all the time to avoid possible malfunction of transmitter and receiver. A random eight bits are fed into the encoder at the transmitter end. The decoder from the receiver end should output the same eight bits. The decoder outputs can be determined by eight LEDs. The transmitter and receiver should be placed 5m away. *If the tests above fail, the following steps will be performed.* a. The SNR of the receiver is measured with Vector Signal Analyzer. b. A 20% duty cycle pulse is generated by function generator and is inputted into the encoder. The encoder pin, which is fed with the signal pulse, is connected to oscilloscope channel 1. Then, the output from the decoder will be connected to the oscilloscope	Yes

Figure B.1: Requirement and Verification Checklist (Continued)

	channel 2. The time difference of both input and output signal is observed. The test is repeated with 80% duty cycle.	
3. *Main Controller* The microcontroller will output the results as stated from the truth table above by taking in 8 bits sequence inputs. It can correct one bit error. a. The microcontroller is able to detect two bit error. b. The microcontroller is able to correct one bit error. c. The VOH of the microcontroller should be 3.3V The response time of this module should be lesser than 5ms.	The main controller GPIO pins will be fed in with eight bits sequences according to the truth table, Table 1. The output should be as stated as the truth table. The outputs can be tested with LEDs. *Single Error Correction (SEC) Test* One bit of the sequences is made intentionally wrong. The output of the microcontroller should be as stated as the truth table. *If the tests above fail, the following steps will be performed.* a. The microcontroller will be fed with two different four bits sequence with distance 2. One of the GPIO pin is assigned for debugging use. When error is detected, the LED lights up. Five sample tests should be performed. b. The microcontroller will be fed with two different four bits sequence with distance 1. One bit of the sequences is made intentionally wrong. The output of the microcontroller is compared with its' input. They should be the same. c. The output of the microcontroller is connected to a multimeter. The inputs of the microcontroller is fed with bits "1111" and the voltage of the output is measured. Input bits "1111" will always activate the camera. d. A 20% duty cycle pulse is generated by function generator and is inputed	Yes

Figure B.1: Requirement and Verification Checklist (Continued)

	into the microcontroller. The input pin, which is fed with the signal pulse, is connected to oscilloscope channel 1. Then, the output from the microcontroller will be connected to the oscilloscope channel 2. The time difference of both input and output signal is observed. The test is repeat with 80% duty cycle.	
4. *Camera Module* Camera takes photos when 3.3V is supplied. a. The voltage FET switch has a linear I-V curve if gate voltage is within threshold voltage and 3.3V. b. When 3.3V is supplied to the FET switch, the signal input voltage of the camera should be zero.	The camera is set to *Photo* mode instead of *Video* mode. This is because the screen will flash when the photo is taken and it will be easier to be recognized. Since the delay between two photos taken is 10s, two consecutive tests should be conducted between 10s or more. 3.3V is supplied to the FET gate voltage, the camera screen should flash. *If the tests above fail, the following steps will be performed.* a. The gate voltage of the FET is connected to the batteries. The DC input voltage is regulated so that the gate voltage applied ranges from 0 to 3.5 with 0.5V spacing. The current will be measured with multimeter. If the current is too small to be measurable, a large resistor is placed in the circuit and the voltage difference between drain and source of the FET is measured. b. The gate voltage is applied with 3.3V using batteries with voltage regulator. The drain voltage is measured with multimeter.	Yes
5. *Power Supply* The power supply should be able to provide clean 5V and 3.3V. a. The power supply noise should be within 20mV pk-	The power supply tests should be done with batteries. The output of the power supply will be observed with an oscilloscope. *If the tests above fail, the following steps will be performed.*	Yes

Figure B.1: Requirement and Verification Checklist (Continued)

pk. 6VDC is provided to the voltage regulators. The output of the voltage regulator must be 3.3V and 5V respectively with tolerance 5%.	a. A DC power supply is connected directly to the oscilloscope. The peak to peak voltage is measure. b. The output of the voltage regulators is measured with multimeter. The desired output voltage should be obtained.	
6. *Case* The case should cover all external module and protect the circuit from any possible hazards. a. The case must be weatherproof b. The case must be “chew-proof”	All the important components are kept inside the case. With a sealed case, all the components cannot be taken out. a. The empty case will be sprayed with water from all directions. The inside of the case is examined and there should not have any trace of waterdrops. b. The case should be able to withstand a scissor stab. This test should be conducted carefully with no one standing around the experimenter.	Yes

Figure B.2: Tolerance Analysis Checklist

Module	Tolerance Tests	Results
Sensing Module	The *False Alarm Test* and *Miss Test* are conducted. The sensor array is deviated from the original position 5 degree each time. Two tests above are conducted repeatedly until the probability of miss and false alarm is above 30%. The maximum allowed angle deviation is recorded.	The maximum allowed angle deviation is 20° - 25°
Wireless Communication Module	A range test will be conducted. To emulate the habitat environment, it will be conducted at the Bardeen Quad. The receiver is moved away, with bushes and trees in between, and the maximum range in which valid data is not received is recorded.	The maximum range is 17.3m.

Appendix C: Cost

Figure C.1: Cost of Parts

PART	MANUFACTURER	COST	QUANTITY	TOTAL
SpyPoint Pro X Plus Trail Camera	SpyPoint	$289.00	2	$578.00
PIR Sensor (Panasonic NaPiOn Spot type)	Panasonic	$15.44	4	$61.76
Linx Transmitter (TXM-418-LR)	Linx	$6.42	1	$6.42
Linx Receiver (RXM-418-LR)	Linx	$7.77	2	$15.54
Antenna (ANT-418-PW-RA-ND)	Linx	$3.99	3	$11.97
Encoder (CIP-8E)	Reynolds	$4.30	1	$4.30
Decoder (CIP-8D)	Reynolds	$4.30	2	$8.60
3.3 Voltage Regulator (LD1117V33)	STMicroelectronics	$0.68	3	$2.04
Digital FET (FDV301N)	Fairchild Semiconductor	$0.20	2	$0.40
Microcontroller (MSP430G2553)	Texas Instrument	$4.30	3	$12.90
C-Cell batteries	Energizer	$2.50	12	$30.00
0.1uF Capacitor	-	$0.10	6	$0.60
0.33uF Capacitor	-	$0.10	6	$0.60
10uF Capacitor	-	$0.10	2	$0.20
PVC casing	-	$10.00	3	$30.00
Monopod	Dynex	$20.00	2	$40.00
			TOTAL	$803.33

Figure C.2: Cost of Labor

NAME	RATE/HR	HOURS	TOTAL (=RATE*HOURS*2.5)
Yon Chiet	$30.00	240	$18000.00
Yong Siang	$30.00	240	$18000.00
Hui Lin	$30.00	240	$18000.00
		TOTAL	$54000.00

Figure C.3: Total cost

SECTION	TOTAL
Labor	$54000.00
Parts	$760.57
GRAND TOTAL	**$54760.57**

Appendix D: Photos of the System

Figure D.1: Camera 1, Sensing Module, Transmitter interface and Receiver interface 1

Figure D.2: Camera 2 and Receiver interface 2