Behavioral Otter Tracking

Design Review

Abstract

When studying wildlife, it is difficult for biologists to track when and where an animal leaves or enters a specific area. This system will identify individual otter movement across a predetermined boundary, while recording time and ambient temperature. It will include passive RFID tags on the otter, an antenna-receiver, a microcontroller and a temperature sensor, all powered by changeable batteries. It will then store the data for later reading by the user. This project will cost much less commercial RFID systems and be tailored to user needs.

ECE 445
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Contents

Introduction

The motivation of this project is to give The Prairie Research Institute a system that can determine the time and ambient temperature when individual otters get in and out of a local pond. Very little behavioral research has been done on the North American River Otter in Illinois, and many commercially available tracking systems are extremely expensive. This system will provide a low cost alternative.

Due to their physiological aspects and environment, otters present an interesting challenge to monitor their behavior. Otters' heads are smaller than their necks; therefore, the most popular tracking device, a collar, is impractical. In addition, they spend significant time both in water and on land. This causes significant attenuation to a signal generated by a transmitter. In addition, otters will chew off devices attached to their paws or tails.

After extensively looking into the topic, we have found no other researchers who utilize RFID tags with otters. This project also has a unique goal in tracking specific behavior, rather than tracking real time location, such as by using GPS, which is also very expensive.

Objectives:

The end goal of this project is to sense and record the time and ambient temperature when an otter enters or exits the pond. An antenna will sense the tag inside the otter and communicate the tag ID to a central control unit. When the control unit receives this data, it will record the ID number, temperature, and time. The user can then extract the data via an SD card.

Benefits:

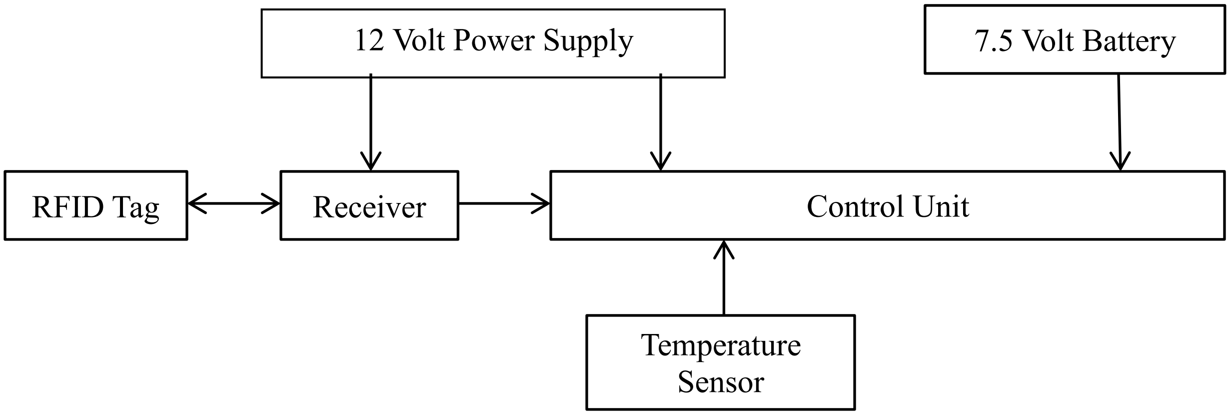
- Can track otter movement without requiring user presence
- Approximately one fifth the price of a commercial RFID reader
- Assists biologists' understanding of otter behavior
- Temperature dependent behavior tracking

Features:

- Recognition of RFID tag in outdoor environment
- Simultaneously records tag ID, time, and ambient temperature.
- Provides adequate onboard storage for tracking multiple individuals for 3 days
- Low power design for continuous use for up to 3 days
- Provides easy access through SD card

Design

Block Diagram



Block Descriptions

RFID Tag

The RFID tag is a BIOMARK HPT22 Passive Integrated Transponder (PIT) that embedded inside the otter's torso. It will be the key identifying component of the design, allowing the system to determine which otter has crossed the boundary. It reflects and modulates a 134.2 kHz carrier signal broadcast by inductive coupling with a loop antenna. The PIT tags utilize FDX-B protocol, which uses Amplitude Shift Key (ASK) modulation and differential biphase encoding. FDX-B is described within the ISO 11784 and 11785 standards.

ASK modulation is a digital form of modulation that turns the carrier frequency on and off, corresponding to a 1 and 0, respectively.

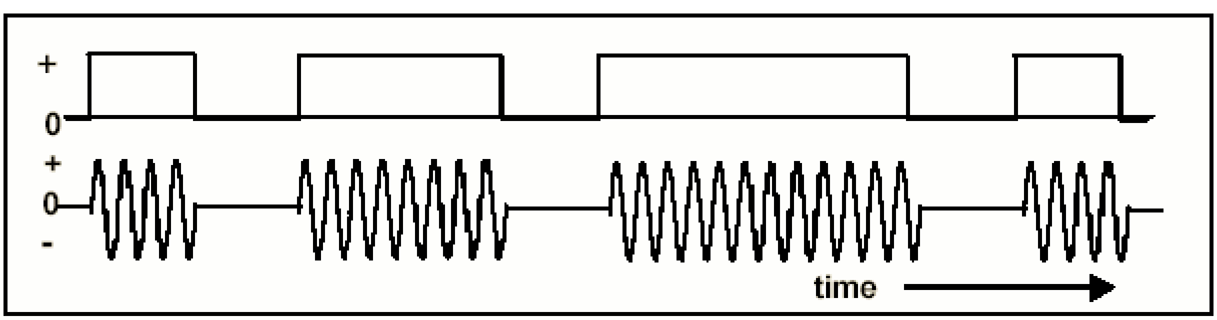


Figure 1: Amplitude Shift Key Modulation [1]

In differential biphase encoding, 1's are represented as a change in value at the start of the clock, whereas 0's are represented by no change in value at the start of the clock. The value always changes in the middle of the clock cycle (falling edge), giving the coding scheme an inherent error detection.

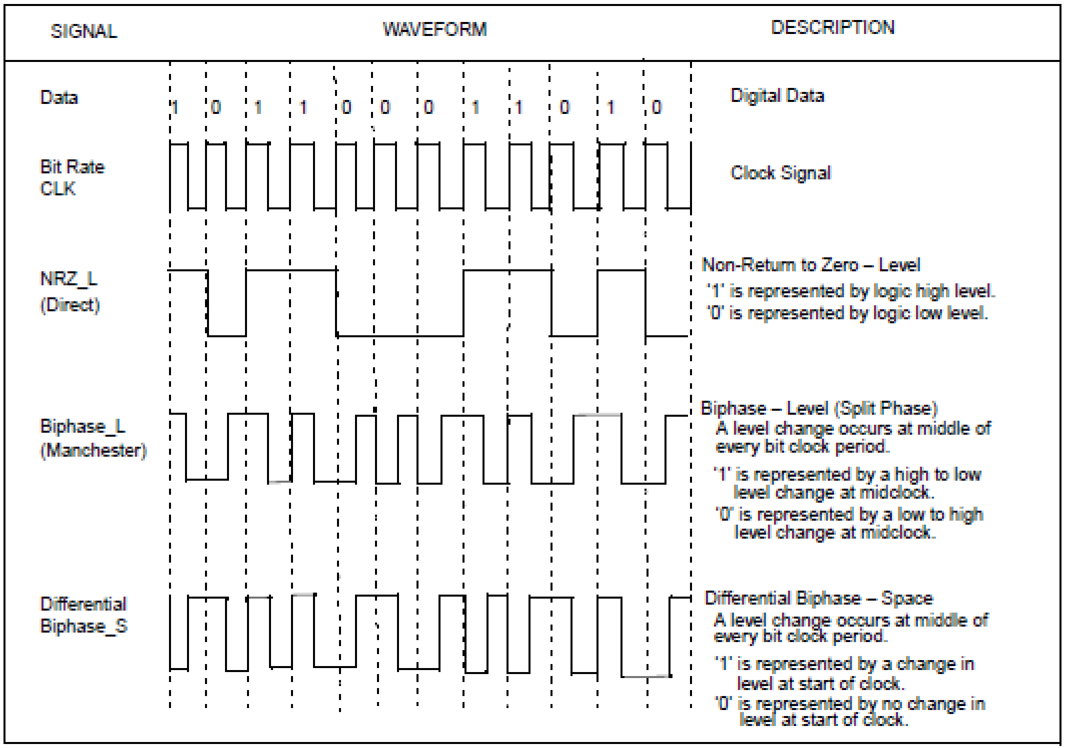


Figure 2: Differential Bi-phase Encoding [8]

The data structure consists of 128 bits, consisting of:

- 11 leading bits- 10000000000 (least significant bit first)
- 64 identification bits
- 16 Cyclic Redundancy Check (CRC) bits
- 24 bits of extended data
- 14 bits allocated for future use
- 13 control bits

MSB		LSB	
1 0	0	0 0 0 0 0 0 0 0	Header pattern. 11 bits.
	1	1 1 1 1 0 0 0 0	
	1	0 0 0 0 0 0 1 1	38 bit (12 digit) National code.
	1	0 0 0 0 0 0 0 0	eg. 000000001008 (decimal).
	1	0 0 0 0 0 0 0 0	
	1	1 1 0 0 0 0 0 0	10 bit (3 digit) Country code.
	1	1 1 1 1 1 0 0 1	eg. 999 (decimal).
	1	- - - - - - - 1	1 bit data block status flag.
	1	1 - - - - - - -	1 bit animal application indicator.
	1	1 1 0 1 0 1 1 0	16 bit checksum.
	1	0 1 0 1 1 1 0 1	
	1	0 1 0 1 0 1 1 0	24 bits of extra data if present.
	1	0 0 1 1 0 1 0 0	eg. $123456.
	1	0 0 0 1 0 0 1 0	

Figure 3: FDX-B Data Structure [1]

The header pattern indicates the beginning of the data structure, transmitting least significant bit first. The control bits are logic 1's following each set of 8 bits. The data is output in the order above.

Receiver

The receiver includes the antenna to sense the RFID tag, an Atmel U2270B Read/Write Base Station, and complementing circuitry. The antenna is a resonant loop designed to operate at 134.2 kHz. Because of the extremely long wavelength, it utilizes inductive coupling to sense a load (PIT tag). When the tag passes over, the antenna's signal is ASK modulated. The receiver circuit then demodulates the signal and routes it to the U2270B. The base station then digitizes the signal and sends the encoded data to the microcontroller. Using a capacitance of 1nF and a frequency of 134.2 kHz, the required inductance, L, can be calculated:

(Eq. 1)

$$L = \frac{1}{(2\pi f)^2 C} = \frac{1}{(2\pi \times 134.2kHz)^2 \times 1nF} = 1.406mH$$

The number of turns is then calculated using the inductance and a radius of 8 cm

(Eq. 2)

$$N = \sqrt{\frac{L}{\pi \mu_0 r}} = \sqrt{\frac{1.406mH}{\pi \mu_0 \times 8cm}} = 66.7\ turns$$

12 Volt Power Supply

The first power supply will provide more power than the one powering the main controller. It will need to power multiple antennas and withstand a large current draw. The rating needed can be determined by calculating the power consumption of the receiver, microcontroller, and the temperature sensor.

(Eq. 3)

$$Microcontroller\ Power\ [W] = Max\ Current\ Draw\ [mA] \times 12V = 200mA \times 12V = 2.4W$$

(Eq. 4)

$$Temperature\ Sensor\ Power\ [W] = Temperature\ Sensor\ Current\ Draw\ [mA] \times 3.3V = 0.05mA \times 3.3V = 1.65 \times 10^{-4}W$$

(Eq. 5)

$$Base\ Station\ Power\ [W] = 0.38W$$

(Eq. 6)

$$12V\ Battery\ Rating\ [Ah] = \frac{Total\ Power\ Used\ [W] \times 72\ hrs}{12V} = \frac{(Microcontroller + Temp\ Sensor + Base\ Station) \times 72hrs}{12V} = \frac{(2.4W + 1.65 \times 10^{-4}W + 0.38W) \times 72hrs}{12V} = 16.68Ah$$

7.2 Volt Battery Pack

This battery pack solely supplies the Adafruit Data Logger. It is a pack of 6 Nickel Metal Hydride (NiMH) AA batteries. The rating needed on the pack can be determined by calculating the power dissipation of the data logger, including the SD card.

(Eq. 7)

$$Data\ Logger\ Power\ [W] = SD\ Card\ Current\ Draw\ [mA] \times 3.3V + Data\ Logger\ Current\ Draw[mA] \times 7.2V = 40mA \times 3.3V + 5mA \times 7.2V = 0.168W$$

This can then be put into the battery rating equation:

(Eq. 8)

$$7.2V\ Battery\ Rating\ [Ah] = \frac{Total\ Power\ Used\ [W] \times 72\ hrs}{7.2V} = \frac{Data\ Logger\ Power\ [W] \times 72hrs}{7.2V} = \frac{0.168W \times 72hrs}{7.2V} = 1.68Ah$$

Typically, NiMH AA batteries come rated at 2Ah, which is perfect for this device.

Control Unit
The control unit consists of the microcontroller, the data logger, and the SD card. The microcontroller is an Arduino Mega 2560 board based on the ATmega2560. It has 56 digital I/O, 16 analog inputs, 4 serial ports, a 16 MHz oscillator, and operates at 5 VDC. This the central control unit that processes the data from the receiver, the temperature sensor, and the real time clock on the data logger. When the receiver senses a tag, the microcontroller will decode, process, and send the data to the data logger for recording.

The data logger is an Adafruit Data Logging Shield for Arduino. It comes with an SD card interface for large storage capacity and easy accessibility. It also provides the Real Time Clock used to determine when an otter crosses. The data is saved on the SD card in .csv format, which can be opened using Microsoft Excel (or similar program).

Temperature Sensor
The temperature sensor is an Analog Devices TMP36 Temperature Sensor. At -50°C, it outputs 0V, and at 125 °C it outputs 1.75V. This signal will be processed by the microcontroller and recorded by the data logger when needed. To determine the temperature in Celsius, the following equation is used:

(Eq.9)

$$Temperature\ [°C] = \frac{V_{out}[mV] - 500mV}{10mV/°\mathrm{C}}$$

The V_{out} can be determined by using the 10 bit value of the Analog to Digital Converter (ADC) on the microcontroller and the supply voltage:

(Eq.10)

$$Voltage\ at\ Pin\ [mV] = \frac{ADC\ Reading}{1024} \times 3300mV$$

Schematics

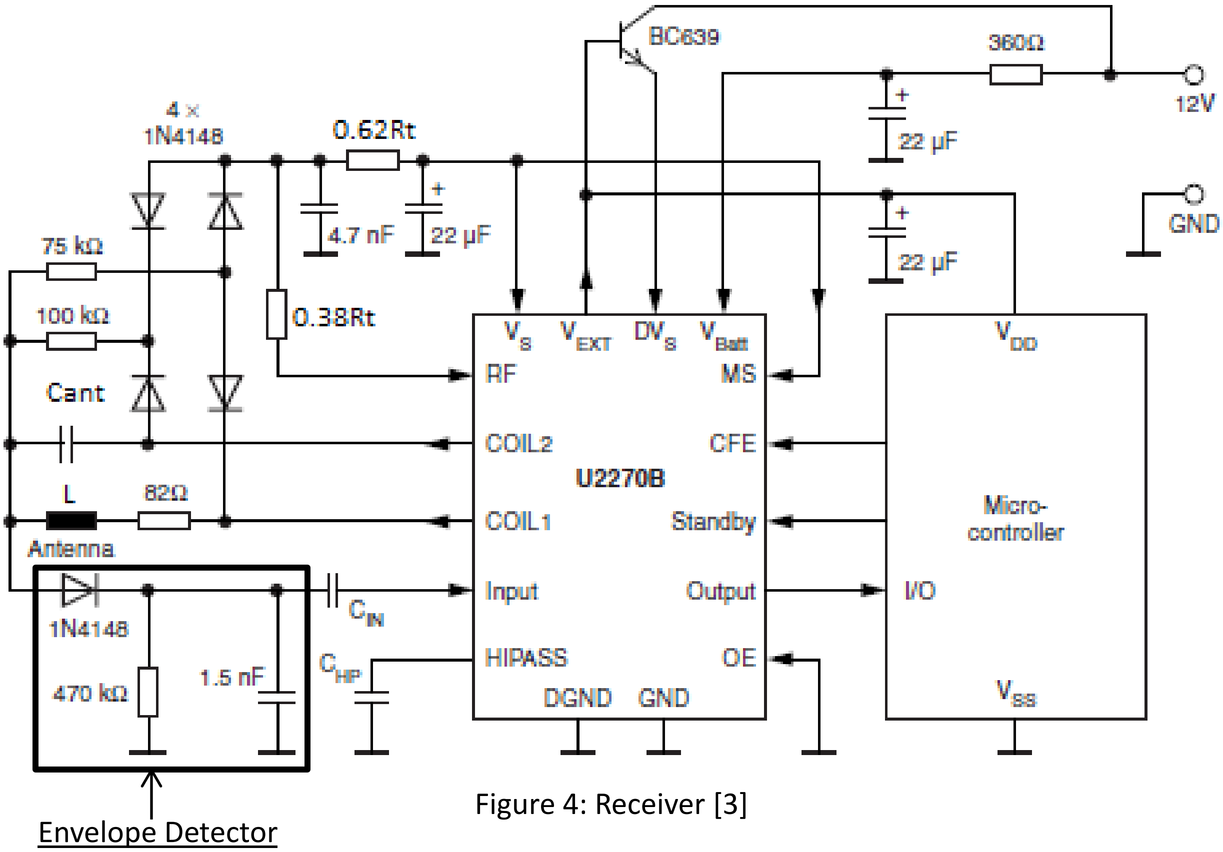


Figure 4: Receiver [3]

$L = 1.406mH$
$C_{ant} = 1nF$
$C_{IN} = 680pF$
$C_{HP} = 100nF$

(Eq. 11)

$$R_t[k\Omega] = \frac{14375}{f[kHz]} - 5 = \frac{14375}{134.2kHz} - 5 = 102k\Omega$$

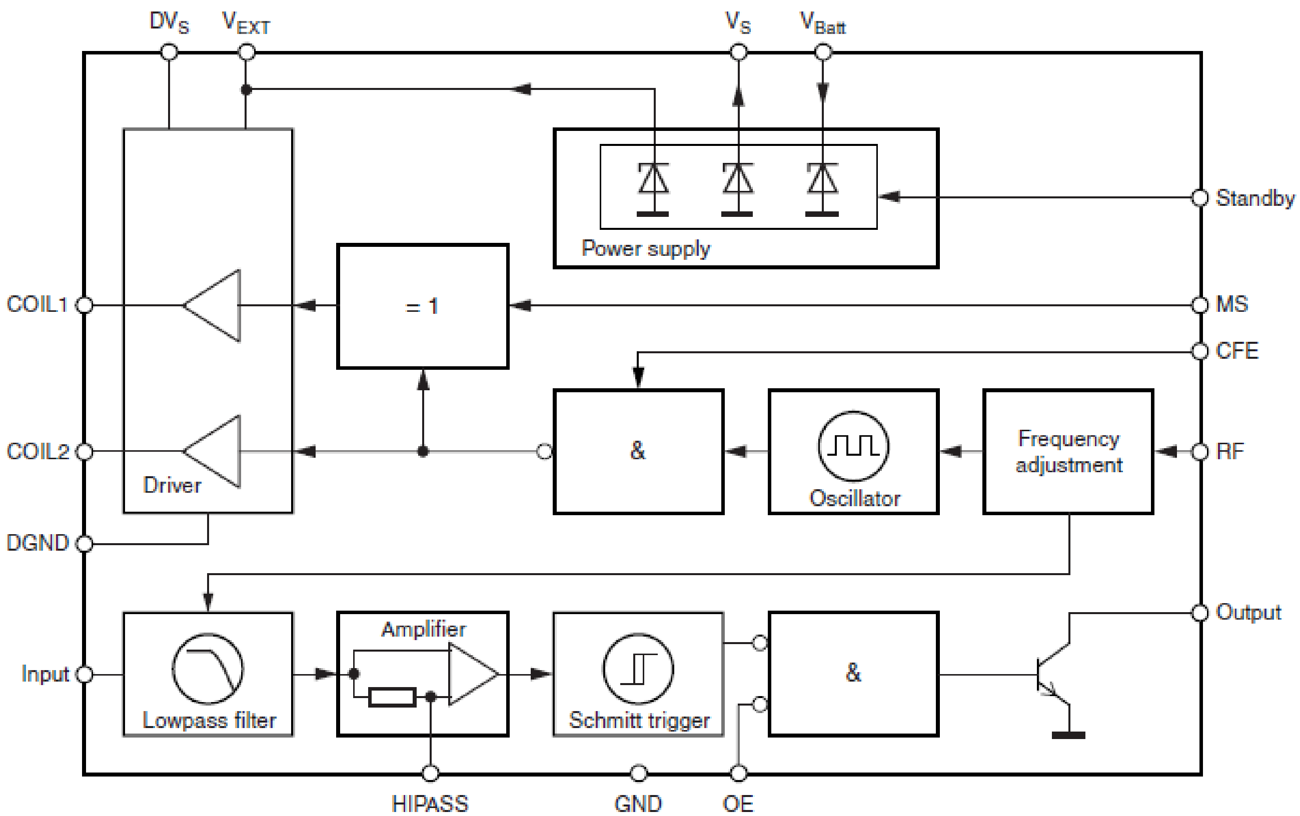


Figure 5: U2270B [3]

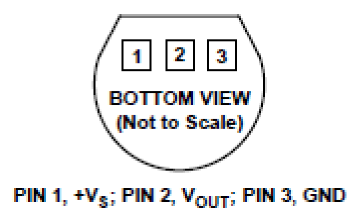


Figure 6: TMP-36 Temperature Sensor [7]

Pin Layout

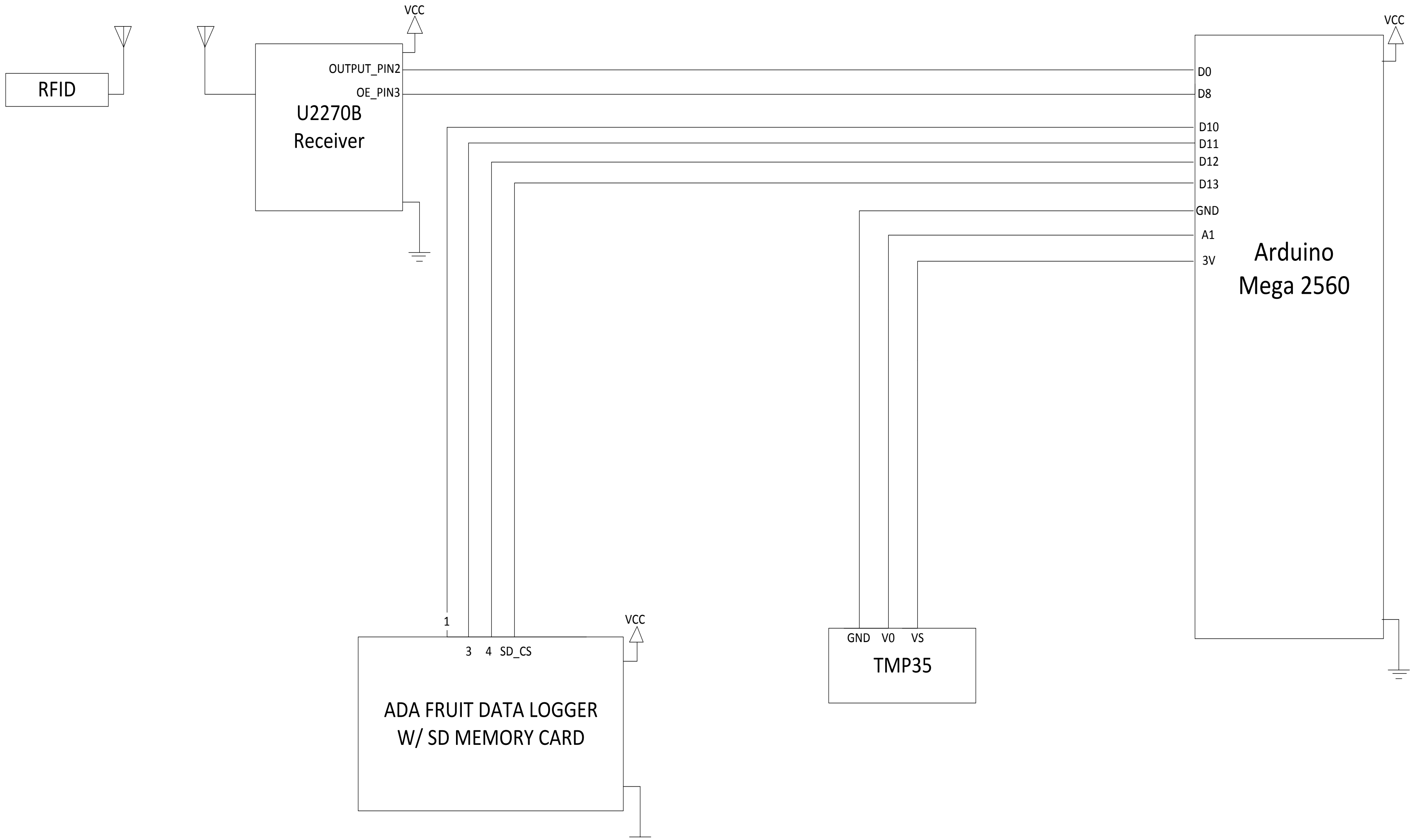


Figure 7: General Pin Layout

Flow Chart

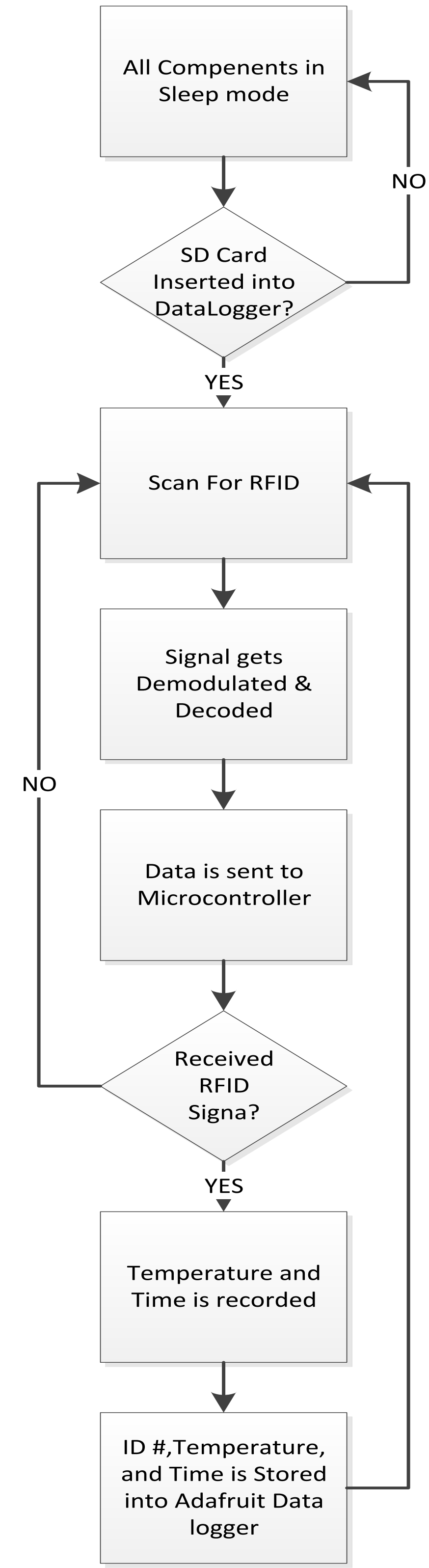


Figure 8: Flow Chart

Requirements and Verification

System Requirements

On the highest level, the system must meet the following requirements:

- Senses otter 100% of the time
- Sensor range of 6 inches
- Records time, tag ID, and ambient temperature for 10 otters entering and leaving the pond 15 times a day
- Power life of 3 days

These tests will require the device itself, the RFID tag, a commercial RFID reader, a commercial thermometer, and a computer with Microsoft Excel and an SD card slot. The lower level verification tests will additionally require an oscilloscope, a digital multimeter (DMM), and a function generator.

Verification

Requirement	Verification
1. Receiver outputs correct TTL levels of the demodulated signal from RFID tag a. Antenna is properly tuned to 134.2kHz in order to detect the PIT tag from 6 inches away. b. Envelope detector circuit properly rectifies and removes carrier signal from the antenna terminals. c. Post-envelope signal must be approximately 170mV for the Schmitt Trigger to work, including through otter flesh. d. U2207B filters the remaining carrier signal and amplifies the data to proper TTL levels. e. Receiver draws correct amount of current from source	1. Knowing the tag's ID number beforehand, the method of FDX-B transmission, and that the data is differential bi-phase encoded, the correct signal can be determine analytically. The output of the receiver will then be connected to the oscilloscope while sensing the RFID tag. The two waveforms will then be compared. The logic levels of the highs must be between 2.2V and 5V, while the lows must be between 0V and 0.8V (TTL). a. An oscilloscope will measure the antenna voltage. If the voltage signal has a frequency approximately equal to $134.2 \pm kHz$ and ASK modulation occurs when a PIT tag is held 6 inches above the antenna, the antenna is properly tuned and working. b. The oscilloscope will show the basic shape of the ASK signal, yet with almost the entire carrier signal removed except for a small capacitance ripple. The voltage must be c. Check output of envelope detector

	with oscilloscope. Confirm voltage highs are above 170mV and voltage lows are below 163mV. Repeat test with tag embedded in otter model d. The output waveform as shown on the oscilloscope should have a frequency of fc/32=4.19kHz and a proper TTL logic levels (a logic high is 2.2-5V and a logic low is 0-0.8V). Carrier characteristics should be completely removed. e. Connect receiver to 12V supply and DMM. Confirm maximum current draw of $31.67mA$
2. Temperature Sensor senses correct temperature within 3℃. a. Sensor draws 0.05 mA from 3.3V supply	2. Connect sensor to 3.3V supply and DMM. Confirm output voltage to $\pm 30mV$ by observing voltage, performing voltage-Celsius conversion, and comparing to thermostat room temperature. a. Connect sensor to 3.3V source and hook up to DMM. Confirm current draw at 0. $0.05 \pm 0.005mA$
3. Control unit records correct tag ID, time, and temperature onto SD card. a. SD card capacity is sufficient to hold the required amount of data (150 entries) b. Microcontroller correctly decodes bi-phased signal c. Correctly identify RFID d. Microcontroller draws max of 200mA at 12V e. Data logger draws max of 45 mA	3. Pass tag over receiver 10 separate times under different temperatures and manually record time, temperature, and tag ID. Remove SD card from slot and open the loaded file in Microsoft Excel. Confirm 10 entries in file with correct values. a. Using arbitrary inputs in program, create 150 entries to log onto the SD card. Remove SD card and read the file with Excel. Confirm 150 entries. b. Input known encoded value to the microcontroller and have it output the decoded signal. Have program print data to a text file. Compare file to known value with 100% match. c. Assuming data is successfully decoded, use a signal generator to simulate a typical demodulated and decoded 128-bit signal that

	would be read off a RFID and make sure that the microcontroller stores the tag ID using FDX-B check bit standards with 100% bit match. d. Connect Microcontroller to 12V supply and DMM. Confirm a maximum of 200mA current draw when at full operation (recording data) e. Connect data logger to 7.2V supply and DMM. Confirm a maximum of 45 mA current draw
4. Power supplies output desired voltages for operation	4. Connect power supplies to DMM and read voltage. Confirm output voltage of $12 \pm 0.5V$ for the 12V supply and $7.2 \pm 0.2V$ for the 7.2V supply

Contingency Plan:

There are multiple parts of this project that can possibly fail. Proper antenna design and tuning may prove to be too difficult for self-design. In this case, there are many commercially available loop antennas with nominal inductance that can be purchased. If the receiver is not sensitive enough, extra gain may be applied outside the U2270B chip, or the antenna parameters (such as quality factor) can be adjusted.

If multiple otters cross at the same time, the two signals will interfere with each other. However, this would require them to cross *exactly* at the same time. If they are separated by a time of at least 40ms, the device will be able to process both signals.

If all parts of the project operate correctly, more receivers can be added to the system. Using simple Boolean logic, the microcontroller can determine when a tag is being read. Each receiver will add a 2.28Ah requirement to the power supply.

Tolerance Analysis:

Block Name & Basic Description	Testing Focus	Acceptable Result Ranges
Receiver- senses RFID tag, demodulates and amplifies signal	Sensing range and proper envelope detector voltage	Range of 6 ± 1 inches Envelope high $\geq$ 170mV Envelope low $\leq$ 163mV
Temperature sensor- outputs analog voltage as a function of temperature	Output voltage	Temperature read within ± 3°C of actual temperature Voltage within $\pm$30mV of expected value

In order to abide by TTL logic in the final output stage of the receiver, the minimum input from the envelope detector must be 170mV to read a logic 1. A logic 0 requires the input be less than 163mV.

These values are calculated by using the voltage gain of the Op-Amp inside the receiver and the minimum trigger level of the Schmitt trigger, also inside the receiver.

$$Minimum\ Envelope\ High\ Detector\ Voltage = \frac{5 + hysteresis\ lvl}{Voltage\ gain\ of\ Op - Amp} = \frac{5.1}{30} = 170mV$$

$$Maximum\ Envelope\ Low\ Detector\ Voltage = \frac{5 - hysteresis\ lvl}{Voltage\ gain\ of\ Op - Amp} = \frac{4.9}{30} = 163mV$$

By measuring this voltage when a PIT tag is place by the antenna, we can formulate a tolerance sensing distance of the antenna. The optimal antenna sensing distance of an otter should be 6 inches with a tolerance of ±1 inch. We can improve the sensing distance by adding cascade gain and adjusting the antenna parameters.

The temperature sensor's tolerance can be tested by connecting the sensor to a DMM and a DC supply. Using a commercial thermometer and the sensor's Celsius-voltage conversion, the two values can be compared at room temperature, in a freezer, and in front of a heater.

Ethical Considerations

This project does not come into contact with many of the ethical considerations in the IEEE Code of Ethics. It will present no danger to the public, but it must not interfere or present a danger to the animals it observes. Since there are no moving parts and all electrical components are enclosed, the otters will not be in any danger. With sufficient consideration, the device will not interrupt their daily routines either. Otters are very sociable and are not afraid of humans or man-made devices, as can be seen by the biologists' current camera setup.

The other concerns include full disclosure of technical limitations and to be honest in stating claims. With proper communication with the Prairie Research Institute and honest work throughout the semester, these will not present a problem.

Cost and Schedule

Cost Analysis:

Labor:

Name	Hourly Rate	Total Hours	Total = Hourly Rate x 2.5 x Total Hours
Jared Lesicko	$40	200	$20000
Kenji Nanto	$40	200	$20000
Miceal Rooney	$40	200	$20000
Total			$60000

Parts:

Part Number	Description	Cost	Quantity	Total
Arduino Mega 2560	Microcontroller Board	$58	1	$58
Adafruit Data Logger	Data Logger	$20	1	$20
Analog Devices TMP36GT9	Temperature Sensor	$2	1	$2
Patriot PSF2G40SD	2 GB SD Card	$5	2	$10
LA-12V20-NB	12V SLA Battery 20Ah	$50	2	$100
-	Resistors	$5	-	$5
-	Capacitors	$5	-	$5
-	Antenna Casing	$25	-	$25
-	PCB	$15	1	$15
-	Antenna Wire	$10	-	$10
1N4148	Diode	$1	5	$5
BC639	NPN Transistor	$1	1	$1
Atmel U2270B	Receiver	$2	1	$2
	Total			$258

Grand Total:

Section	Total
Labor	$60000
Parts	$258
Grand Total	**$60258**

Schedule:

Week	Task	Member
2/6	Complete Proposal	Kenji
	Research RFID	Jared
2/13	Sign-up for Design Review	Miceal
	Use DAQ to Implement Modulation	Jared
	Research Microcontroller	Kenji
	Research Timer	Jared
	Research Thermometer	Miceal
	Research Memory	Kenji
2/20	Design Review	-
	Build Antenna	Miceal
	Order Parts	Kenji
2/27	Sense PIT tag with antenna	Jared
	Design and research decoding scheme	Kenji
	Test Temperature sensor	Miceal

3/5	Begin building Receiver	Jared
	Finalize decoding scheme	Kenji
	Learn/Research microcontroller programming and SD card interface	Miceal
3/12	Finalize Receiver, begin working on receiver tolerance, efficiencies	Jared
	Test decoder	Kenji
	Programming microcontroller-TMP sensor interface and SD card interface	Miceal
	Individual Progress Reports	-
3/19	Spring Break	-
3/26	Finish testing receiver	Jared
	Finish testing decoder	Kenji
	Sign-up for Mock-up Demos Mock Presentation	Kenji
	Programming microcontroller-Receiver/Decoder interface	Miceal
4/2	Interface receiver and decoder	Jared
	Test and Confirm power consumption	Kenji
	Test overarching code, test SD card capacity	Miceal
4/16	Test at Otter Location, begin presentation	Jared
	Sign-up for Demo & Presentation, final report	Miceal
	Connect all modules and place in a weatherproof box	Kenji
4/23	Demo/Presentation	-
	Final Paper proofread, practice presentation	Miceal
	Ensure device is ready for demo, practice presentation	Kenji
	Finalize Presentation, practice presentation	Jared

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