Otter GPS Implant

Design Review

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Introduction

Wildlife biologists have recently started using advanced technology to monitor the behavior of animals in their natural habitat. In particular, the return of the North American river otter population in Illinois has piqued the interest of many local biologists. The otter was nearly considered extinct in Illinois around the 1800s due to human interactions. After a recent reintroduction of the otter to Illinois the animal seems to be doing well and populations are increasing. Scientists are now seeking the use of technology in order to learn why they are thriving and what effects they will have on the environment.

Scientists frequently use collar mounted GPS tracking systems in order to record the traveling habits of larger mammals. While these have proven useful for larger animals, animals such as the otter pose an interesting problem in that their heads are smaller than their necks. Any sort of collared device would simply slip off of the animal due to their active lifestyle. Similarly, harnesses or other exterior devices run the risk of getting caught underwater and potentially suffocating the animal. Biologists studying the otter are in need of sub-dermal tracking methods in order to safely monitor the animal without altering its usual behavior.

Thus, our group will develop a sub-dermal GPS implant for use with the North American River Otter, per our biologist contact Samantha Carpenter's request. This project serves as a great learning experience for our group as it involves many different areas of engineering such as wireless communications and the programing of hardware. It is also important to the biological community as it has the potential to give scientists new insight and access to data that was previously unattainable. Our close contact with Samantha will insure that our device will meet the specifications required by people in the biological community.

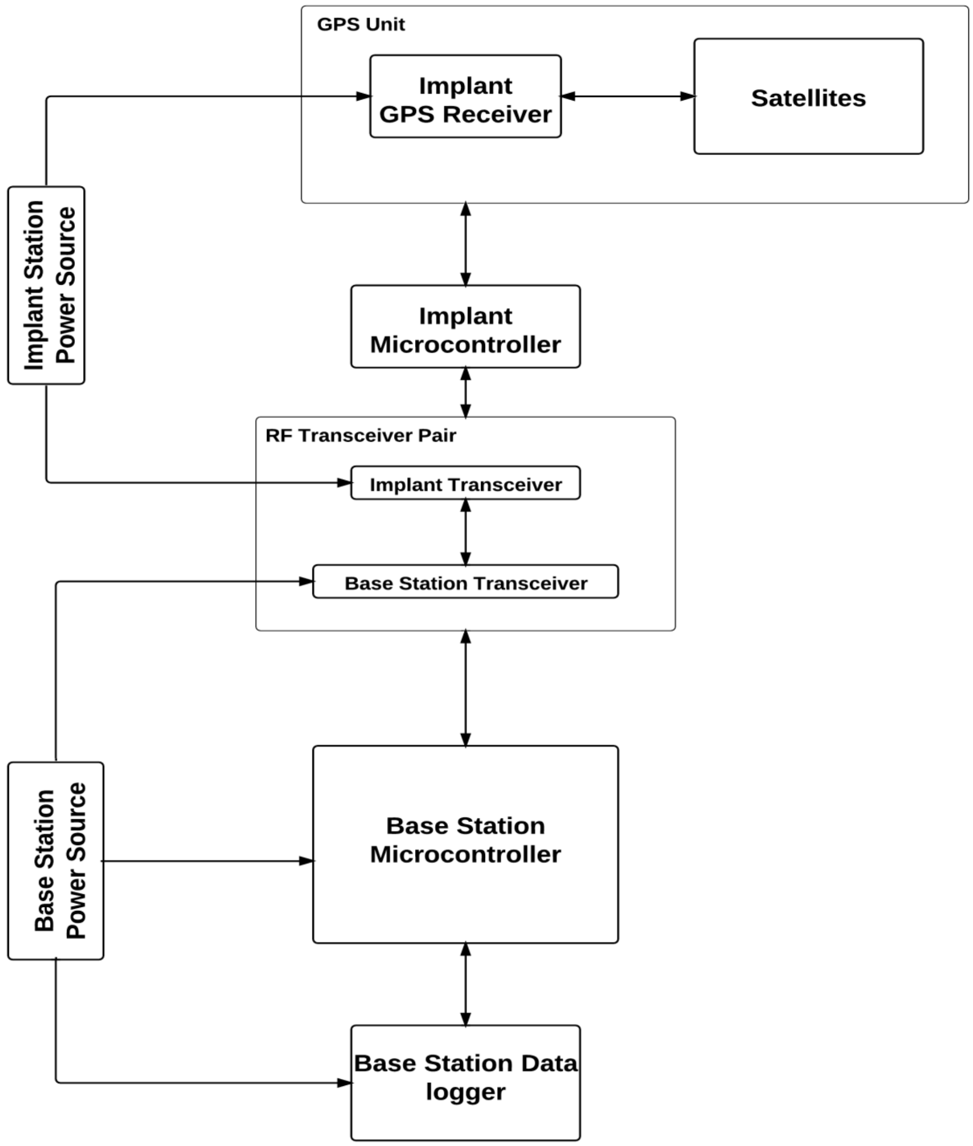
Benefits

- Energy efficient download station
- Provides accurate location data for use in analyzing otter's behavior
- Small, compact implant design with flexible antennae
- Automatic data collection

Features

- Solar panels for use with station
- Satellite GPS positioning
- Data stored to removable drive

Block Diagram



Description of Block Diagram

Satellite:
There are a minimum of 24 GPS satellites orbiting the globe at all times. These can be utilized by the GPS implants to obtain positional information on the otters.

Implant GPS Receiver:
The GPS unit will consist of a programmable GPS (D2523T) chip with onboard storage and read/write capability. This will be implanted into the otter. It will receive positional coordinates from the satellites available, at periodic intervals. Then, the information will be conveyed implant microcontroller.

Implant Microcontroller:
The implant microcontroller (Arduino Mini 04) will parse the GPS data and store the relevant information (location and timestamps) onto its onboard memory. The microcontroller will also receive signals from the transceiver in order to determine if it is within a transmittable range from the base station. If it is, the microcontroller will transmit the data to the base station via the transceiver and wipe its memory for future use.

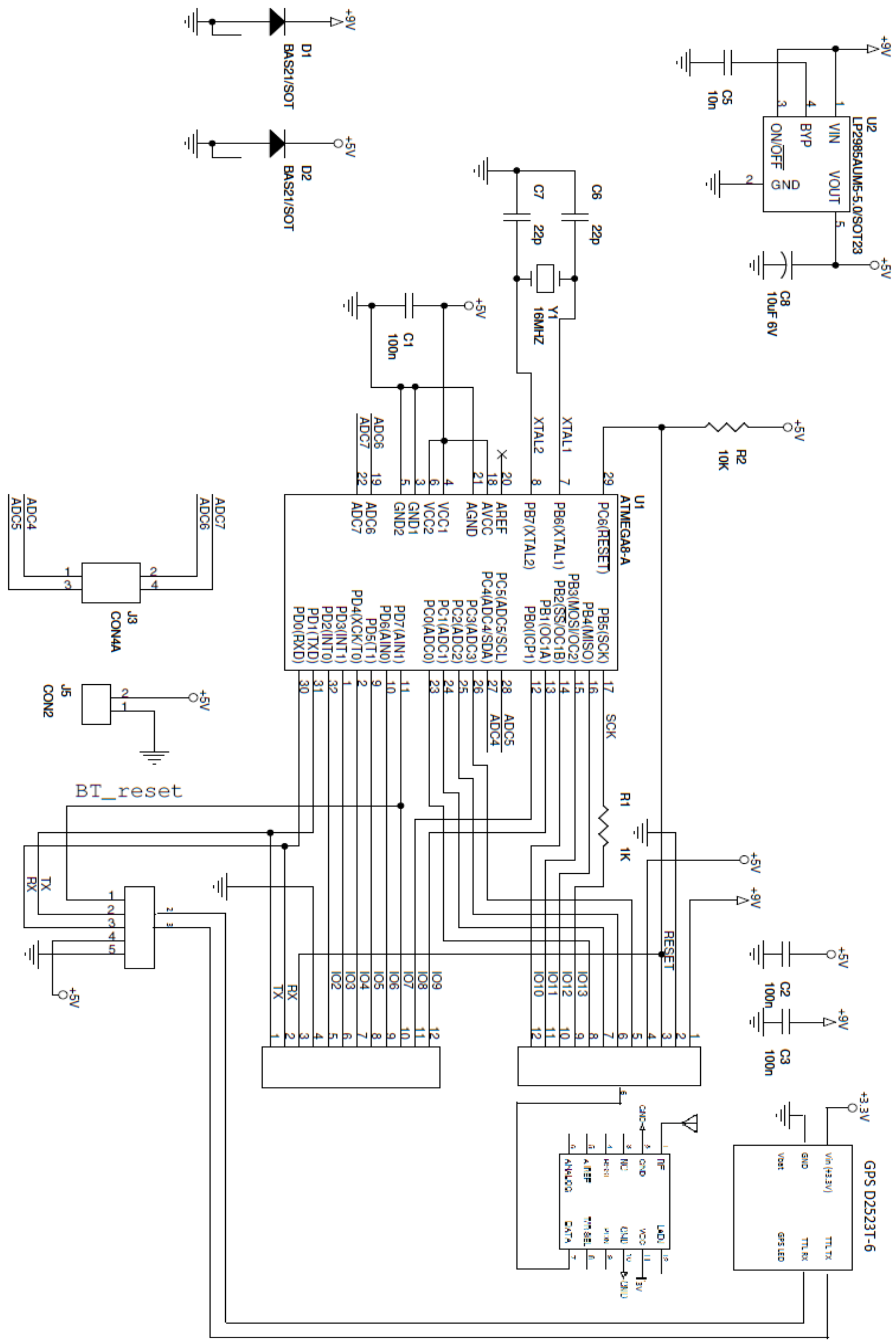
RF transceiver pair:
The implant and base station transceivers (Linx TRM-433-LT) act as intermediaries between the implant and base station microcontrollers. They, along with the antennas attached to them, govern the wireless communication between the base station and implant, and the maximum transmission range.

Base Microcontroller:
The microcontroller (Arduino Uno) will be used to control the RF transceiver to extract data from the implant when the otter is within an acceptable range, and finally store it in the data logger. The data logger will basically be a USB flash drive connected to the USB port of the Arduino Uno. The microcontroller will also send out a signal via the transceiver signaling that data transfer is complete.

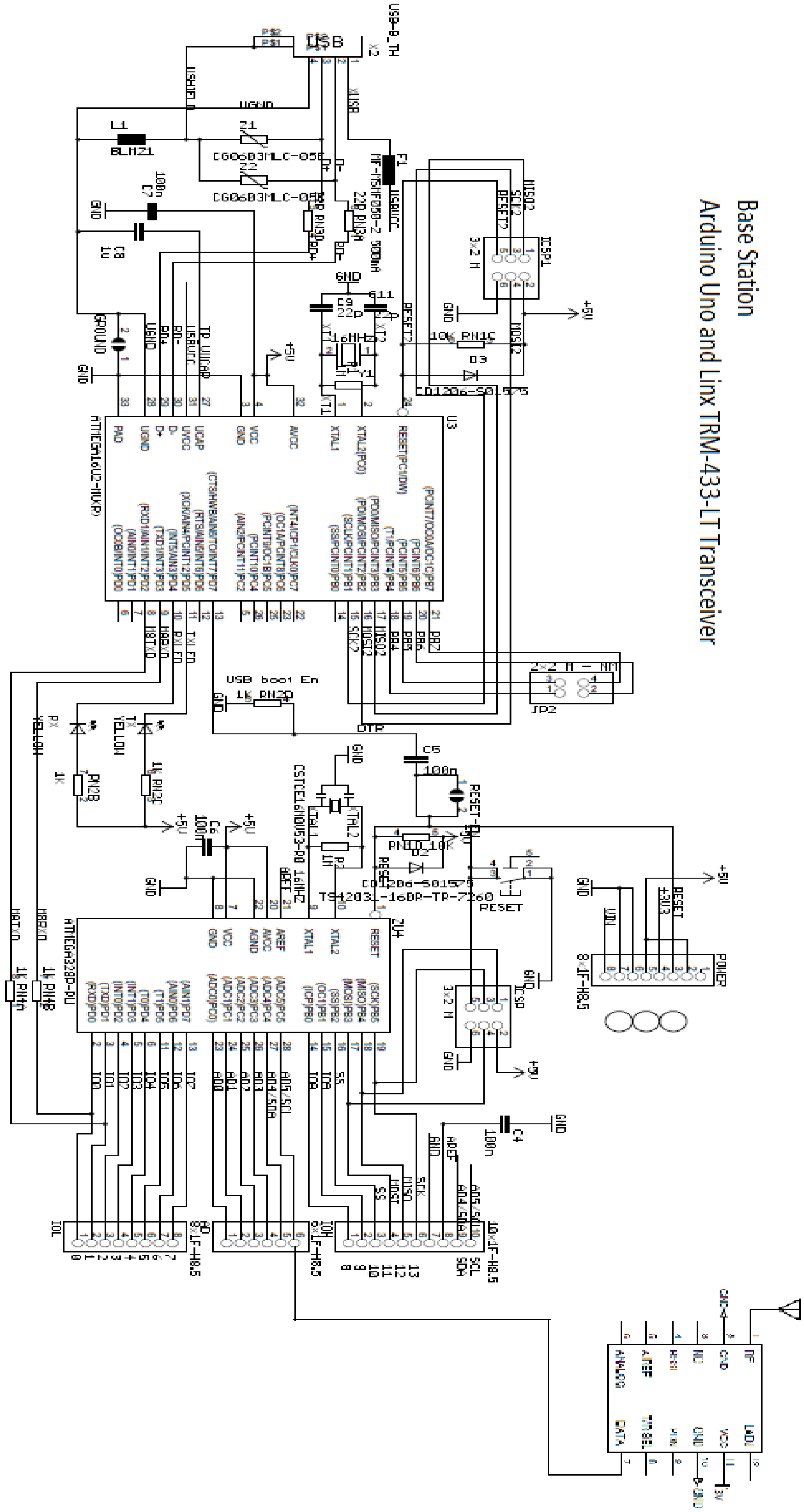
Power Sources:
All our devices will be battery powered, including the implanted unit. Two 3.7 Volt, 2000mAh Lithium Polymer batteries will be used to power the implant to ensure that the implanted unit will have a constant supply of power for at least 2 weeks. Biologists are interested in accurate location data that can only be provided by an actively powered unit. They assured us that they have no concerns with the inevitability of the unit requiring a battery replacement. For the base station, we are thinking of using solar panels as a power source and having 2 backup 9 Volt batteries. In order to provide the IC devices with the necessary input voltages, we are simply using resistors and making use of the voltage divider law governed by the equation:

$$V_{in} = V_{DC}\frac{R_1}{R_1 + R_2}$$

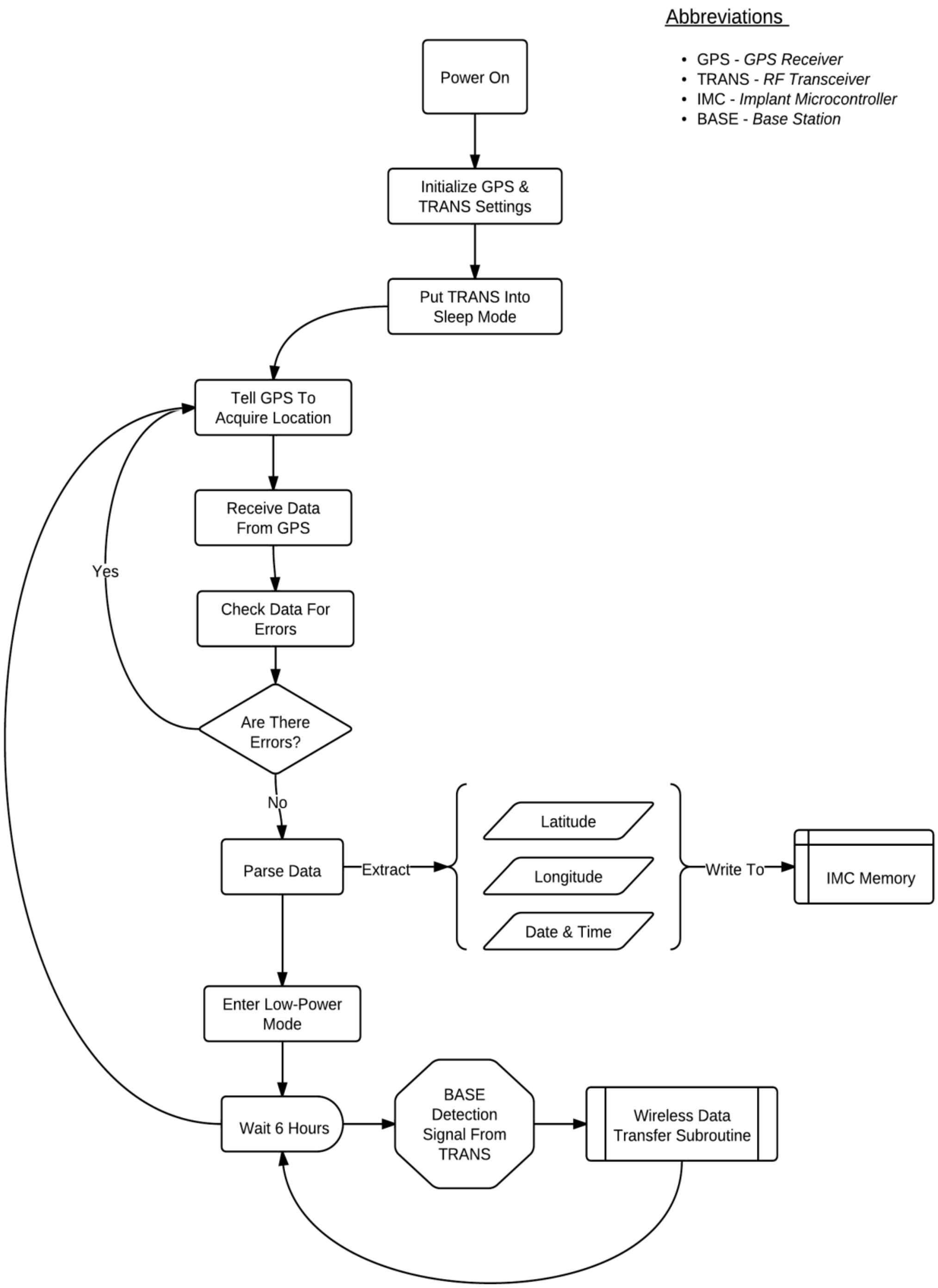
Implant Unit Schematic



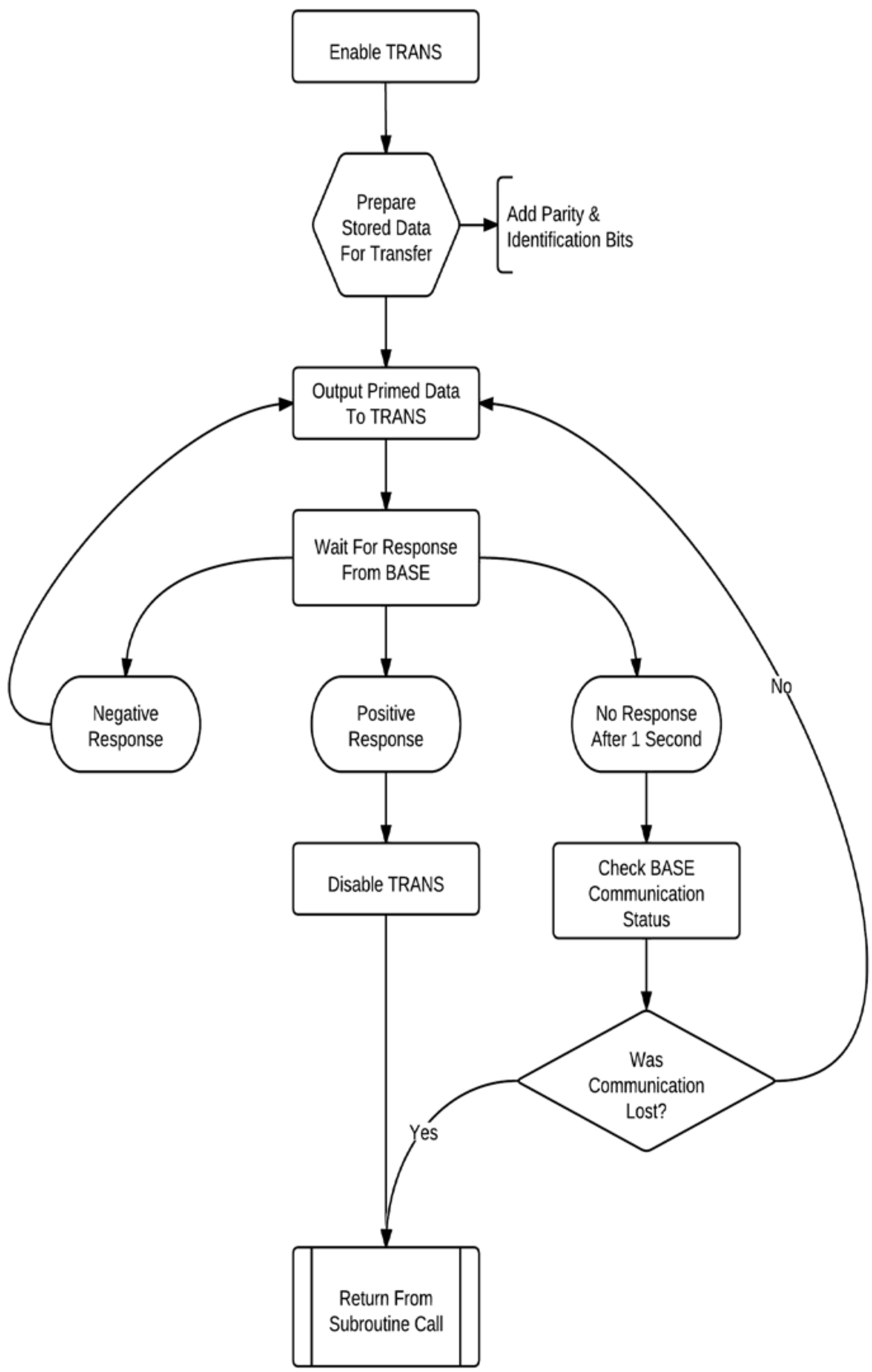
Base Station
Arduino Uno and Linx TRM-433-LT Transceiver

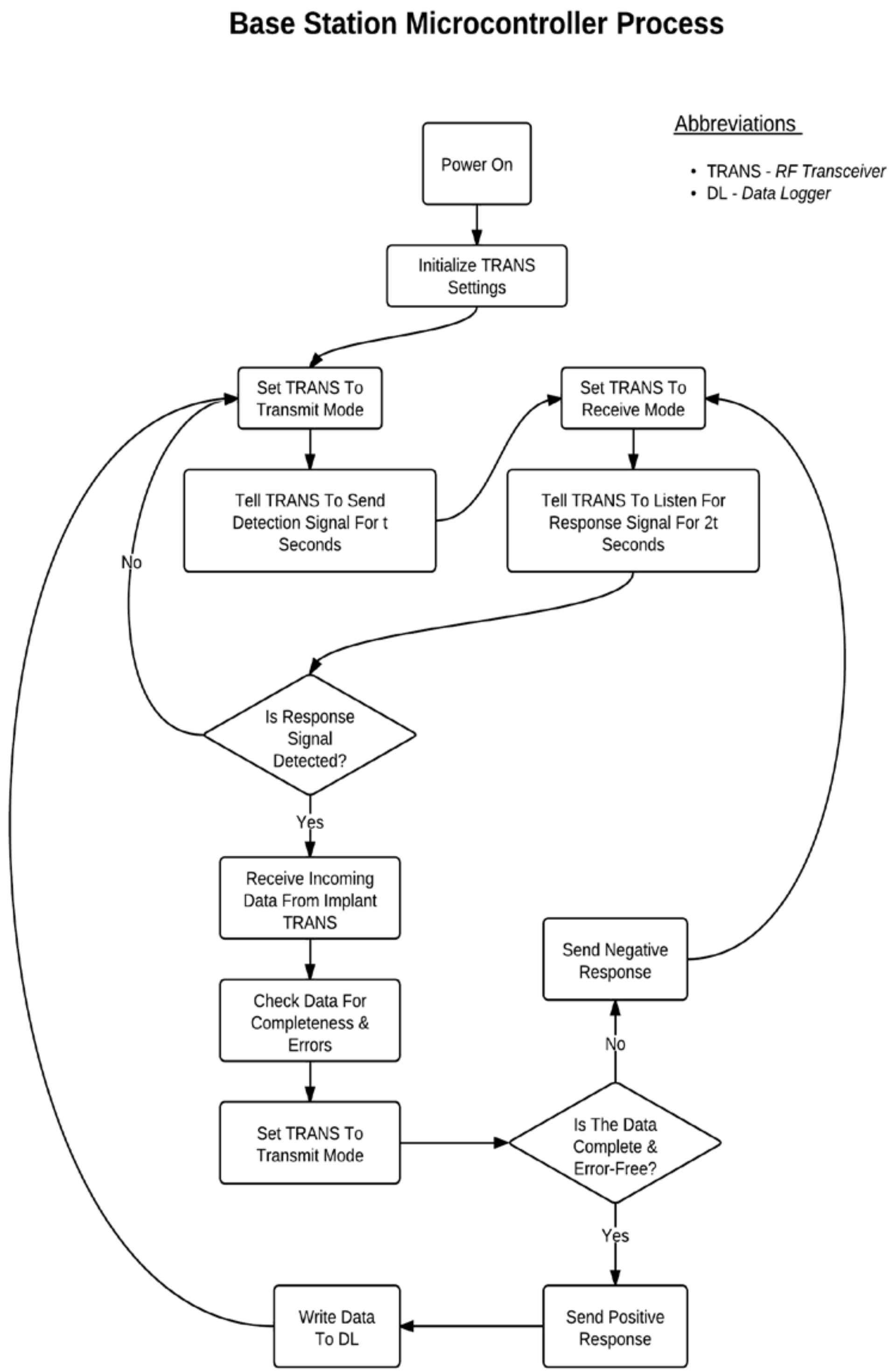


Microcontroller Process For Repeated GPS Detection



Wireless Data Transfer Subroutine




Base Station Microcontroller Process
Abbreviations
• TRANS - RF Transceiver
• DL - Data Logger
Power On
Initialize TRANS Settings
Set TRANS To Transmit Mode
Tell TRANS To Send Detection Signal For t Seconds
Set TRANS To Receive Mode
Tell TRANS To Listen For Response Signal For 2t Seconds
Is Response Signal Detected?
No
Yes
Receive Incoming Data From Implant TRANS
Check Data For Completeness & Errors
Set TRANS To Transmit Mode
Is The Data Complete & Error-Free?
No
Send Negative Response
Yes
Send Positive Response
Write Data To DL

Testing and Verification

Requirement	Verification
<u>1.GPS Unit</u> -Acquires signals from 4 satellites to gain positional information. a. Must acquire signals from satellites. b. Must get accurate data to within 10 meters of otter's actual location and provide a timestamp that is within 1 second of the actual time taken. c. Must be able to run on power saving mode and ping satellites defined by user programing. d. Must be able to communicate with microcontroller. e. Must weigh no more than 2.5 pounds (10% of otter's body weight).	1. The GPS unit is connected to the Arduino Mini. It receives instructions from the unit as well as parses data to the microcontroller. To test it, we can use a user interface provided by the manufacturer and monitor its outputs using a bread board. a. GPS unit will be turned on, connected to bread board and then to PC. We will then use the GPS analysis software "u-blox 6" to test to see what satellites the unit is capable of acquiring signals from. b. Data stream from GPS unit will be obtained using NMEA parsing software. The bit stream from the unit will then be examined to ensure that the location and timestamp given are accurate given our own location. c. User defined program will be uploaded using ublox-6 software to determine ping intervals and minimize power consumption. d. Serial input/output port (Tx, Rx) will be connected to Arduino Mini to test communication between then and data transfer rate. e. The final GPS unit to be implanted will be weighed using a digital scale.
<u>2. Arduino Mini (Implant Microcontroller)</u> -Arduino mini will receive location data and time stamp from GPS and store it onto onboard memory. Then it will convey the information to RF transceiver when it is in range of the base station. a. Must parse NHEA data received and store only relevant information, namely timestamp and location. b. Must receive signal from Linx	2. The Arduino Mini will be attached to a bread board and connected to an Arduino Uno (already owned). The Uno is recommended by Arduino as a solid debugging/programing tool as it can connect to the Mini and use its USB port to connect to a computer for a user interface. The GPS will be connected to the Arduino via the serial input/output pins (Rx, Tx) and the Arduino mini will be connected to a PC through the Arduino Uno's USB port. The Linx transceiver will be connected to

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module confirming range and pass data to it for transmission. Then it must wipe the transmitted data from memory.
c. Has to run in power save mode to minimize power consumption.
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the Arduino Mini via the bidirectional digital pin.
a. Will use bread board and upload NMEA parsing program and collect test data to see if accurate location and time information is stored onto memory without using too much memory space (no more than the 32 KB total flash memory on board).
b. Connect Linx module to microcontroller and see if it can recognize its input signal to confirm transmittable range and then send out the information back to it at a matched data transfer rate. We will also ensure that the data that has been transferred will be wiped from memory once stop signal is received from RF transceiver.
c. Will upload program that puts the microcontroller to sleep mode and verify that it turns on only when the GPS module is about to ping the satellites by making use of the start bit sent out by the GPS module.
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<u>3. RF Transceiver Pair</u>
-The transceiver pair must be able to communicate with each other and transfer data accurately. The Linx patch and standard monopole antennas must be able to communicate within a reasonable range of at approximately 5ft so that we can get the data from the otter.
a. Range of transmission must be about 5ft.
b. Sends data between each pair and convey the data received to their respective microcontrollers.
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3. The transceivers can be wired to the Arduino Mini/Uno on a bread board and the inputs/outputs monitored to ensure it will send or receive the location data from the GPS. We also will have a manufacturer made evaluation kit to ensure our antenna’s transmission range will be correct.
a. Put the transceivers 5ft apart and adjust the output power level of the transceiver using the LADJ pin to see if a minimum of -5dBm signal is obtained by connecting the output pin of the receiving transceiver to an oscilloscope or network analyzer.
b. Will program Arduino Mini to send out an arbitrary message and see if it can be received and transferred to the Arduino Uno.
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<u>4. Station Microcontroller (Arduino Uno)</u> -Must receive data from implant and store/send it to the Data Logger protocol to be written to the USB drive. a. Must be able to communicate with transceiver in order to receive information and change transmitting/receiving mode. b. Must be able to send data to Data Logger block.	4. The microcontroller can be powered and analyzed using a simple bread board. It has a USB port so that it can be easily programmed using manufacturer provided user interface. a. Will serially upload information to Linx and see if the microcontroller can receive the data. We will also monitor the Linx transceiver and make sure that the Uno is correctly managing the transceiver's send/receive protocols; i.e. that it changes from transmit to receive when the implant is in range, and that it changes from receive to transmit when the data is downloaded in order to send out a confirmation so that the Mini will delete its stored data. This is done by feeding the T/R select pin of the transceiver a 0 for receive and a 1 for transmit. b. Will send data to Data Logger (Flash Drive) which will be connected via the USB port onboard the Arduino Uno and ensure that the correct data appears on that end by checking the data on the flash drive on a PC.
<u>5. Data Logger</u> -Must receive data from Arduino Uno and write data to the USB. a. Will write data the USB in an easy to understand format for use by the biologists.	5. The Data Logger block is within the microcontroller. It is programmed the same way the Uno will be. a. Will send arbitrary data to the microcontroller's writing protocol and ensure that it stores the data we sent on memory.
<u>6. GPS Power Source</u> - Implant must record location data at a high enough frequency that it will provide	6. Unit will be "stress tested" using different satellite pinging rates. We can then use voltmeter to see how long the

an accurate representation of the traveling habits of the otter. At the same time, the more often the chip pings satellites, the faster we will drain the battery. **a.** Must provide at least 2 locations per day and will last approximately 2 weeks.	required voltage can be maintained. a. Will test battery life starting with at least 2 data collections each day, and slowly increase until we find a reasonable balance.
<u>7. Station Power Source (Solar Panels)</u> -Solar powered station allows us to continually send RF waves to scan for the implant at the station site while using a free power source. **a.** Must provide sufficient power to station.	7. Station must be able to be continually powered by the solar panels. We cannot afford to lose power at the station where we are downloading our data. a. Will take panels out to leyline to ensure that they receive adequate sunlight during the day by adjusting the tilt angles. The output of the solar panels will be connected to a voltage regulator to provide stable voltage. We will probe the terminals of this regulator to ensure that a stable voltage is maintained throughout the required operational time.

Contingency Plans

1. None. The GPS Unit must get accurate data.
2. If the Arduino Mini does not have enough onboard memory to store the amount of data we will be collecting we can look into getting extra memory for the implant, but it’s a solution we’d like to avoid given our size constraints.
3. If we are unable to establish two way connection and get the implant to receive messages from the station we will be unable to know exactly when to wipe the data. If this is the case we will simply program the microcontroller to wipe its memory after a certain amount of time (say 2 days). Given the unpredictable nature of the otter, we’d prefer not to go with this option. If we determine the antenna is the issue, we will use a manufacturer’s evaluation kit to determine the gains of the antennas and their receiving and gain capabilities to see if they are the issue. The basic equation that governs transmission range could be used to perform calculations and is shown on the next page. In the case that these antennas are incapable of providing this range due to their gains or maximum power handling capabilities, there are many other options that we can look

towards.

$$P_R = P_T G_T G_R \left(\frac{1}{d}\right)^n$$

4. Microcontroller must work. We have several PIC's we can use as backups if necessary.
5. The Microcontroller has a built in USB port so it should be capable of writing to a drive. If not, we know of compatible data logger modules that we can get for only $20 that is guaranteed to read/write.
6. If collecting data at a high frequency is extremely detrimental to our battery life, we are willing to sacrifice the amount of data collected for battery longevity. As long as we are providing more than 2 locations each day (a frequency at which researchers were able to achieve just using binoculars in a recent report), we will be providing a vast improvement to current methods.
7. We are willing to abandon the solar panels in exchange for traditional batteries or even rechargeable ones.

Performance Requirement

Perhaps the single most important feature of our project is the fact that it tracks the otter without need for a biologist to be on site at the time. Thus the most crucial component we need to optimize is our power supply for the GPS implant. The battery in the implant must be small and unobtrusive so we cannot change the amount of power we will have available. Thus we will optimize the number of times that the implant will take the otters location in order to provide both a good idea of its traveling habits and a reasonable battery life. We are also going to alter the number of satellites the GPS receiver pings simultaneously in order to reduce the overall signal acquisition and tracking currents. Our goal is to provide at least 2 weeks of battery life.

Schedule and Responsibilities

Date	Task	Group Member(s)
6-Feb	Finish Proposal	All
	Research RF Transceiver / Parts	Sugato
	Research GPS Chip and Antennae / Parts	Nick
	Research Microcontroller and Programing / Parts	Andy
13-Feb	Finish Design Review	All
	Implant Design	Nick
	Microcontroller and RF Design	Andy
	Power and RF Design	Sugato
20-Feb	Design Review	All
	Testing/Requirements andDesign Review Creation	Nick
	FinalizingStation Parts / Circuit Simulations	Andy
	Finalizing GPS parts / Circuit Simulations	Sugato
27-Feb	Build Implant (GPS - Antennae)	Nick
	Build Implant (Power System/Microcontroller)	Sugato
	Build Implant (Programming/Connection Setup)	Andy
5-Mar	Build Station (RF Unit)	Nick
	Build Station (Power System)	Sugato
	Build Station (Programming)	Andy
12-Mar	Finish Implant/Test GPS Satellite Connection	Nick
	Finish Station/ Station Power Systems	Sugato
	Finish Programming Components	Andy
19-Mar	Spring Break	All
26-Mar	Prepare for Mock-up Presentation	All
	Testing Battery Life to Transmission Ratio	Nick, Andy
	Testing Transmission Range	Sugato
2-Apr	Mock-up Presentation	All
	Test Proper Storage on Removable Drive	Andy
	Test Battery Life to Transmission Ratio	Sugato, Nick
9-Apr	Preparation for Demo/Presentation	Nick
	Last Minute Debugging/Testing	Sugato, Andy
16-Apr	Preparation for Demo/Presentation	Nick
23-Apr	Demo/Presentation	Andy
30-Apr	Demo/Presentation/Checkout	Sugato

Note: All group members are responsible for each part of the project. While someone may be given lead of a task, everyone is expected to contribute to each part.

Estimated Cost Analysis

Parts	Link	Description	Cost per Unit	# of Units	Total Cost of Units	Status
GPS Receiver	http://www.canakit.com/50-channel-gs407-helical-gps-receiver-gps-09436.html	50 Channel D2523T with Helical Antenna	$100.80	1	$100.80	To be ordered
RF Transceiver	http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&itemSeq=110971744&uq=634653574214452789	Linx Technologies LT Series - 433 MHz	$15.47	2	$30.94	To be ordered
RF Antenna	http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail&itemSeq=110972129&uq=634653579730283748	Linx Technologies SP Series "The Splatch" - Grounded Line ¼-Wave Monopole Antenna - 433 MHz	$2.26	2	$4.52	To be ordered
Microconroller (implant)	http://www.sparkfun.com/products/8164	Arduino Mini 04 for use inside the implant	$33.95	1	$33.95	To be ordered
Microcontroller (base station)	http://www.sparkfun.com/products/11021	Arduino Uno R3 for use inside the base station	$29.95	1	$29.95	To be ordered
Housing (implant)	http://www.amazon.com/Shrink-Wrap-Wide-Yard-Roll-Clear/dp/B00168264S/ref=sr_1_1?ie=UTF8&qid=1329774800&sr=8-1	Clear heat-shrink wrap	$4.82	1	$4.82	To be ordered
Housing (station)	http://www.radioshack.com/product/index.jsp?productId=2062285	Project enclosure box (8x6x3")	$7.39	1	$7.39	To be ordered
P7.2-75 Flexible Solar Panel	http://flexsolarcells.com/index_files/OEM_Components/Flex_Cells/pages/Flex_Cells_Individual_17_P72_75.php	Roughly 7.2V @ 100mA solar cell	$39.95	1	$39.95	To be ordered

Lithium Battery (implant)	http://www.sparkfun.com/products/8483	3.7-volt battery at 2000mAh	$16.95	2	$33.90	To be ordered
Duracell 9-Volt Alkaline Battery (station back-up)	http://www.staples.com/Duracell-9-Volt-Alkaline-Batteries-2-Pack/product_318972	A 9-Volt battery, which can be easily replaced by the biologists (comes in a 2-pack)	$7.99	1	$7.99	To be ordered

Total Parts Cost = $294.21

Labor

Engineers	Rate	Hours/Week	Total # of Weeks	Multiplier	Total
Sugato Ray	$40/hr	10	13	2.5	$13,000
Nick Gruebnau	$40/hr	10	13	2.5	$13,000
Andrew Beugelsdijk	$40/hr	10	13	2.5	$13,000

Total Labor Cost = $39,000

Grand Total = Labor + Parts = $39,000 + $265.29 = $39,294.21

Ethical Considerations

Because our project directly involves a live animal, we have several important ethical guidelines to keep in mind:

From the IEEE Code of Ethics:

"1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;"

It is important that our GPS design in no way endanger the life or quality of life of the otter in which it will be implanted. We must make sure that our design is compact enough so as not to agitate the otter in its day to day activities. Part of this is ensuring that our implant is only 5%-10% of the otters total body weight. Considering an otter weighs approximately 25 pounds, our device needs to weight no more than 2.5 pounds.

"3. To be honest and realistic in stating claims or estimates based on available data;"

We must be sure to fully disclose the capabilities of our device. This means providing data related to worst case battery life and shortest possible RF transmission range. It is important to be realistic about the functionality of our device.

Citations:

Schematics of Arduino boards from http://arduino.cc