Water quality Autonomous Robot
W.A.R Boat

Group 24
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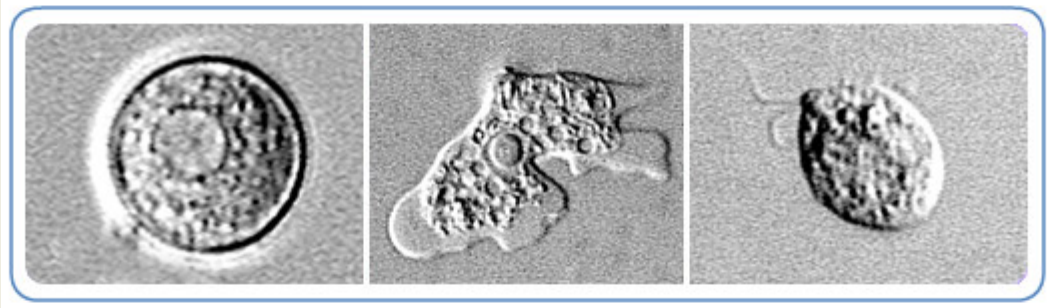
What is W.A.R Boat?

- Solar power is used to charge the lithium ion batteries that power all on board electronics.
- Autonomous motion is achieved through GPS and user inputted waypoint coordinates.
- Equipped with 5 water quality sensors: temperature, ORP, conductivity, pH, DO.
- Wirelessly transmits sensor data to an on shore laptop.

Motivation

- Naegleria Fowleri - Brain Eating Amoeba
- Found in warm fresh waters: lakes, rivers, hot springs.



- Amoeba becomes active and begins to reproduce at 25°C / 77°F.
- Make it easier for outdoor enthusiasts to test the water in safe and comfortable conditions.
- Testing the water for the following qualities: temperature, pH levels, conductivity, dissolved oxygen, and oxygen reduction potential.

Requirements

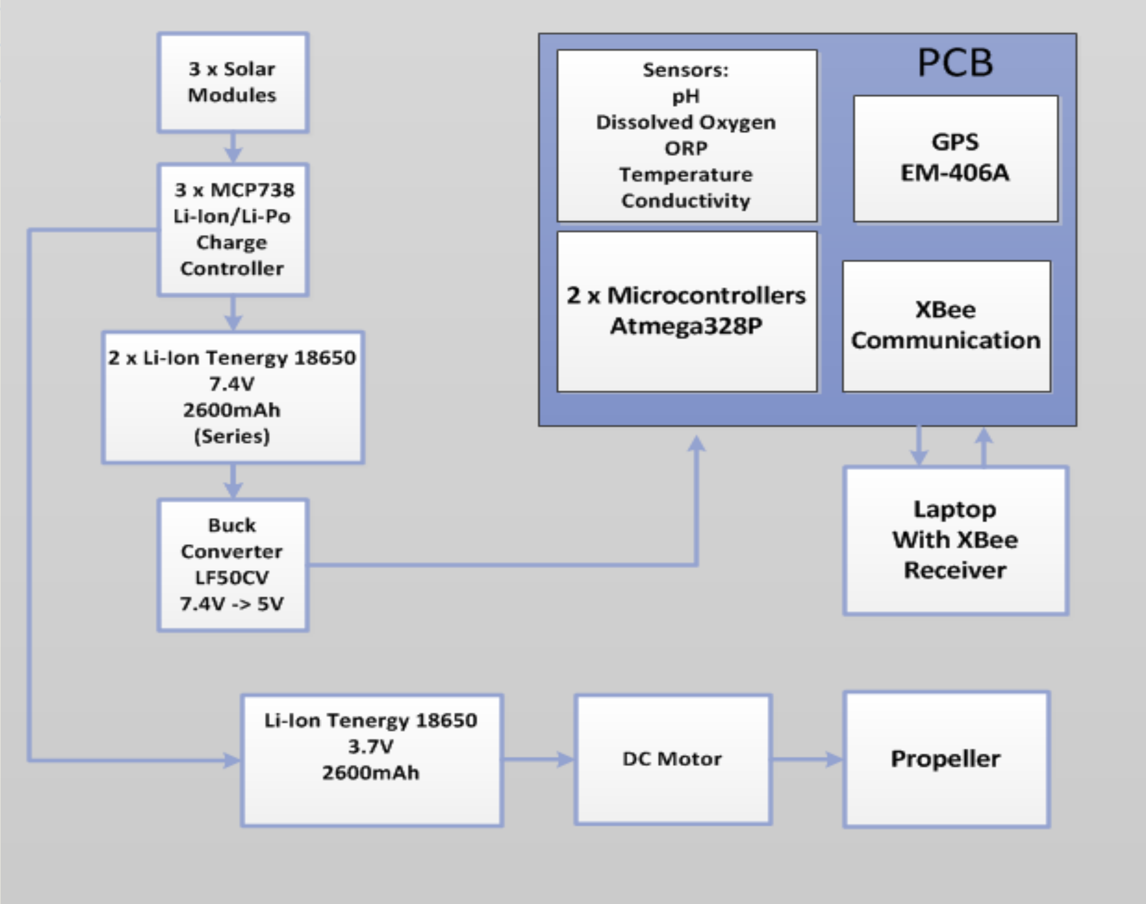
- The boat should be self sufficient by using solar energy and lithium ion batteries to power the entire system.
- Portable by being able to move and durable to withstand harsh water conditions.
- Autonomous by using GPS guidance.
- Able to read multiple water quality characteristics, i.e. Temperature, pH, Conductivity, etc.
- Wireless data transmission of water quality from boat while out in the water.

Specifications

Req. ID #	Parameter	Specification
W-01	Wireless Data Range	At least 50-100m range
W-02	Weight of Boat	Less than 5 lbs
W-03	Time Before Recharge	At least 1 hour of use
W-04	Solar Cell Power Output	Average 4.5W
W-05	Boat Dimensions	At most 3 ft x1ft x1ft
W-06	GPS Calculations	Every 0.25 seconds
W-07	All Sensor Data Acquisition and Transmission	Complete in under 5 minutes
W-08	Average Speed	5 mph
W-09	GPS Location Accuracy	Within 15 meters
W-10	GPS Time for First Fix	~ 60 seconds

Group Work Distribution

	Solar Cells	Charge Controller	MCU Programming	Wireless/ Sensors	Motor/Robot Platform	Navigation
Irina	**X**	**X**			**X**	
Dennis			**X**		**X**	**X**
Joey	**X**	**X**	**X**	**X**		



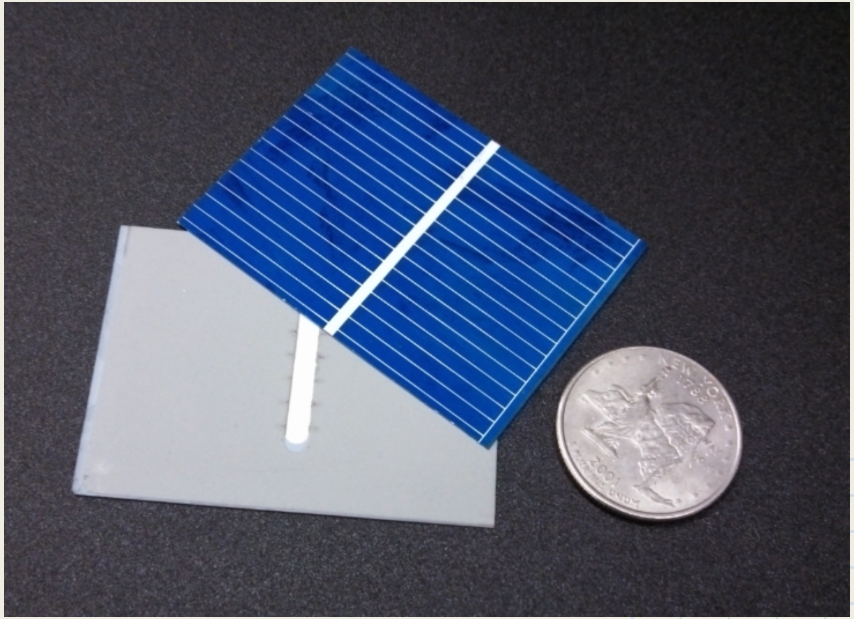
Overall Block Diagram

Power System

Solar Cells

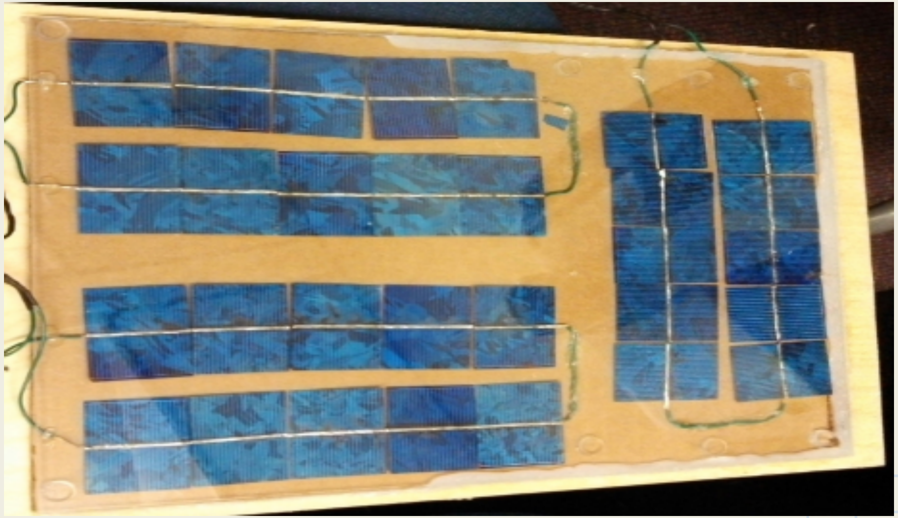
- Polycrystalline Solar Cells
- Cheap and fit the requirement
- Extremely fragile
- Allows for custom solar panel

Size	52x38mm
Power (max)	0.15 Watts
Current (max)	0.3 Amperes
Voltage (max)	0.5 Volts



Solar Cell Layout

- There are 10 PV cells connected in series.
- Each module of series PV cells charges one battery.
- One module produces roughly 5-5.5V at 1.5 watts of power.
- There are three modules in one solar panel, resulting in 4.5 watts of power.



Batteries

- Lithium Ion Tenergy 18650
- 3.7V Nominal Capacity 2600mAh
- Max Charge Current 1300mA
- Max Discharge Current 5200mA

- PCB Protective Circuit cuts off voltage if:
  - Above 4.3V
  - Below 2.5V (render it unchargeable)
  - Temperature exceeds 90°C/ 194°F

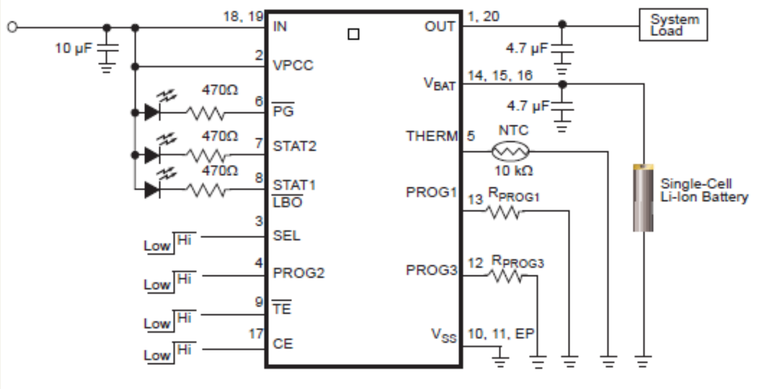
- *In theory* the following formula should predict the battery's discharge time

$$Discharge\ Time\ of\ Battery = \frac{Battery\ Amp\ Hour}{Discharge\ Current} = \frac{2.60\ Ah}{0.45A} = 5.78\ hours$$

- In practice we predict less than 5 hours due to inefficiencies in charge/discharge cycle

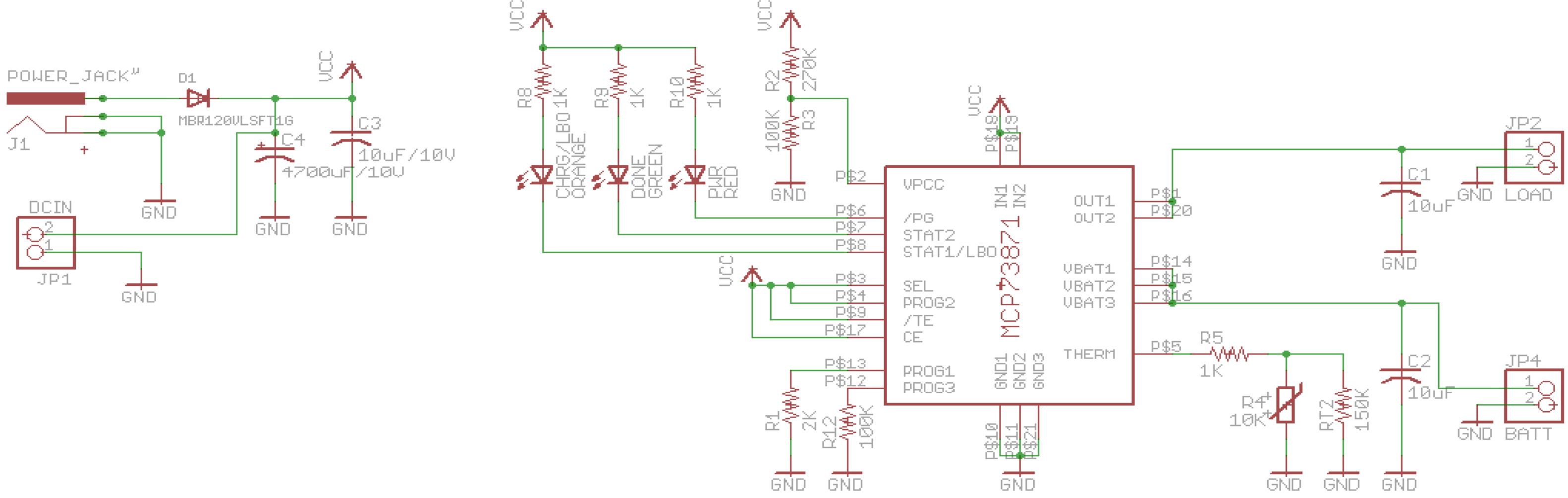
Charge Controllers

- MCP73871 Lithium Ion Stand Alone Charge Controller.
- One charge controller connects one module to one battery.
- Prevents over/under charging and provides a load sharing feature.
- Equipped with Voltage Proportional Charge Control.
- Input of 3.75V - 6.0V for one cell 3.7V battery.
- Provides a steady charge current flow up to 500mA.



Typical MCP73871 Application

Charge Controller Schematic



VPCC vs. MPPT

VPCC

- Low cost
- Simple design
- Uses a linear converter which dissipates heat in any excess voltage

MPPT

- Uses DC/DC converter which increases cost
- Complex design
- Not necessarily more efficient in low voltage and current settings

➢ The added diode voltage drop in the linear converter is approximately the same value as for the inefficiencies from the DC/DC converter

Charge Controllers

- The charge controller is connected to a 5 volt solar cell module, 3.7 volt Li-Ion battery, and output load.
- The load current is being directly drawn from the solar cell module.
- If the load current is less than the required current the battery will supplement the load current by up to 1.8 amperes.

- To increase efficiency the MCP73871 chip implements Voltage Proportional Charge Control (VPCC)

    - which reduces the current in order to proportionally increase the voltage to a preset matching voltage.
    - to set the matching voltage an R1 value is selected using a voltage divider equation.

$$V_{VPCC} = \left(\frac{R_2}{R_1 + R_2}\right) \times V_{IN} = 4.5V$$

$$4.5V = \left(\frac{110k\Omega}{110k\Omega + R_1}\right) \times 5V$$

$$R_1 = 12.22k\Omega$$

Charge Controllers

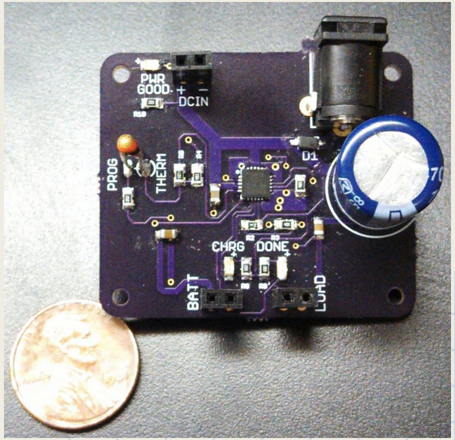
Four Connection Types:

- Three 2-pin headers
  1. Power Input - solar cell module output.
  2. Battery Input - connected to Li-Ion Battery.
  3. Load Output.

- One DC barrel jack
  - Shares the same connection as Power Input.
  - Provides a secure connection after testing.

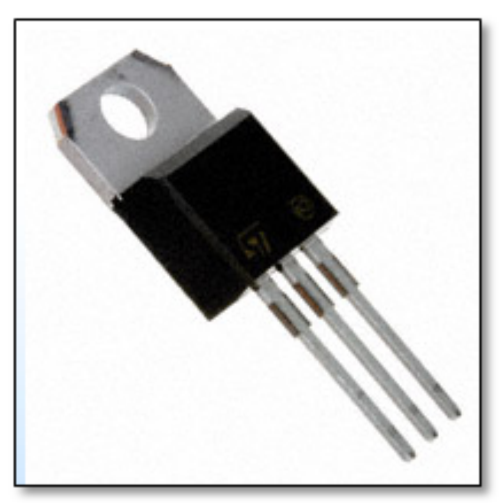
Three status LEDs:

- "PWR" - good power source.
- "CHRG" - battery charging.
- "DONE" - battery has reached full charge.



LF50CV Voltage Regulator

- STMicroelectronics Buck Converter.
- Converts up to 16 volts down to 5V that will power the sensors, microcontrollers, GPS, etc.



Parameter	Maximum Value
Input Voltage	16V
Output Voltage	4.95 - 5.05V
Output Current	500mA
Dropout Voltage	0.4 - 0.6V
Operating Temp.	-40° ~ 125° C

Microcontroller, Sensors, Wireless

Microcontroller

- Atmel ATmega328
  - 16 MHz clock
  - 8-bit RISC architecture
  - 2KB RAM
  - 32 KB Storage
  - 14 Digital I/O Pins
  - 6 Analog I/O Pins
- TI MSP430
  - 16 MHz clock
  - 16-bit RISC architecture
  - 512B RAM
  - 16KB Storage
  - 8 Digital I/O Pins
  - 8 Analog I/O Pins

Microcontroller

- ATmega328
  - Low power consumption
  - Plenty of online support for the microcontroller
  - Support between microcontroller and water quality equipment
  - Group wanted to learn how to use a new microcontroller
- Development Board
  - Arduino Uno
  - Atmel STK600

Types of Water Quality Equipment

- Market for Water Quality Equipment/Sensors is small costing hundreds to thousands of dollars.
- Most sensors are handheld devices only allowing the user to read water quality at a specific spot.
- All water quality equipment/sensors are finished products, which do not allow hobbyist to make their own equipment.

Atlas-Scientific

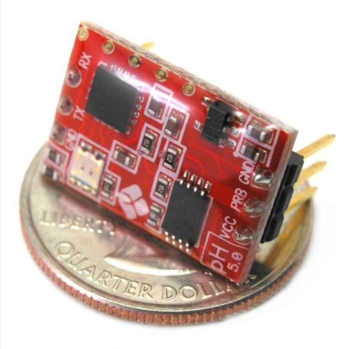
- Manufactures high quality sensors for environmental monitoring.
- Gives everyday people the ability to create their own water quality monitoring system.
- Creates sensors and embedded circuits for engineers to integrate into their own systems.
- Small team which provides a lot of support and answers questions.

Water Quality Circuits

- Atlas-Scientific pH Circuit
- Atlas-Scientific Oxidation Reduction Potential(ORP) Circuit
- Atlas-Scientific Dissolved Oxygen
- Atlas-Scientific Conductivity

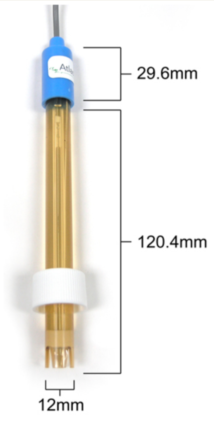
- Circuits are scientific grade monitoring devices designed to be used to with water quality sensors.
- All circuits transmit data using serial connectivity.
- Operates on 3.3V to 5.5V with low power consumption.
- Features multiple commands which allow the engineer to fine tune how the circuit operates (ON/OFF LEDs, continuous readings or single, baud rate changes, etc).

pH Circuit and Sensor

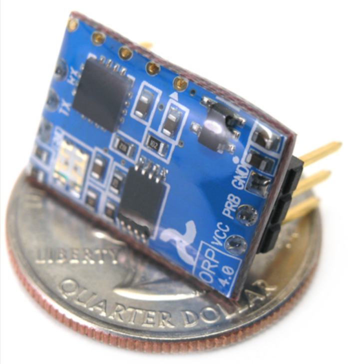


Circuit
- Full range pH readings from 0.01 to 14.00.
- Accuracy within two decimal points (XX.XX).
- Temperature dependant or independent readings.
- Automatic baud rate detection.
- Low power consumption using 4mA in active mode at 3.3V.

Sensor
- Speed of response: 95% in 1 second.
- Can be submerged indefinitely.
- Standard lab or in-field use.



ORP Circuit and Sensor

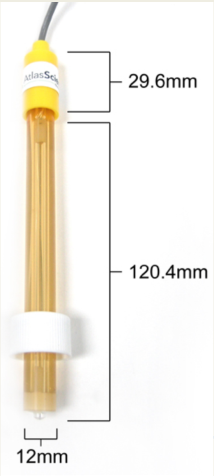


Circuit

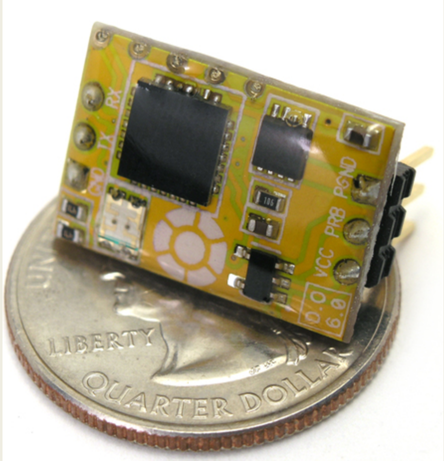
- Full range ORP readings from 0 to +1023.99 or -1023.99.
- Simple calibration of circuit.
- Automatic baud rate detection.
- Low power consumption using 10mA in active mode at 3.3V.

Sensor

- Speed of Response: 95% in 1 second.
- Range of measurement: +/- 2000mV.
- Can be submerged indefinitely.



Dissolved Oxygen Circuit and Sensor



Circuit

- Full range D.O. +/- 0.1
- Accuracy within two significant figures (XX.XX Mg/L).
- Freshwater/Saltwater/Brackish water readings.
- Low power consumption using 4.7mA at 3.3V.

Sensor

- Range: 0-20 mg/L
- Fresh and Saltwater compatible.
- Can be submerged indefinitely.

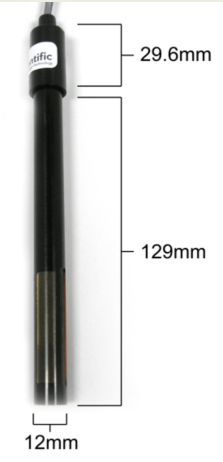
Conductivity Circuit and Sensor

Circuit

- Conductivity readings from +/- 5 μs/cm.
- Temperature dependant or independent readings.
- Also measures Total Dissolved Solids (TDL) and Salinity.
- Low power consumption using 4.2mA at 3.3V.

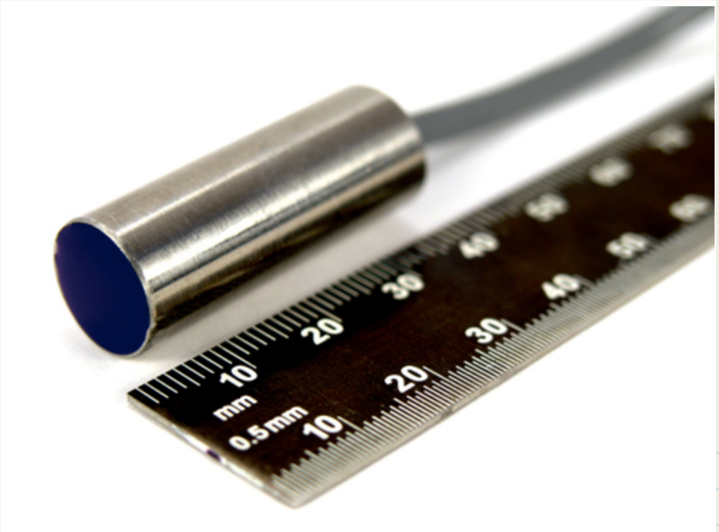
Sensor

- Corrosion resistant and extremely durable.
- Can be submerged indefinitely.
- Standard lab use or long term field use.



Field Ready Temperature Sensor

- Can be used in any weather.
- Wide temperature range: -20C to 133C
- Accuracy within +-1°C
- Fast reading time: <1ms
- Low operating current: <6μA
- Wide operating voltage: 3.1V - 5.5V



Wireless Data Transmission Choices

- Needed to support long range data transmission.
- Low power to conserve energy from batteries.
- Easy to connect and configure.
- Bandwidth not a concern.

Wireless Comparison

Parameter	Bluetooth 4.0	WiFi (802.11/g)	XBee-PRO (802.15.4)
Range (max, outdoors)	~300 ft	~460 ft	~1 Mile (perfect conditions)
Current Consumption (max)	Low (~25mA)	High	Low (215mA)
Frequency	2.4GHz	2.4GHz	2.4GHz
Cost	Cheap	Expensive	Expensive

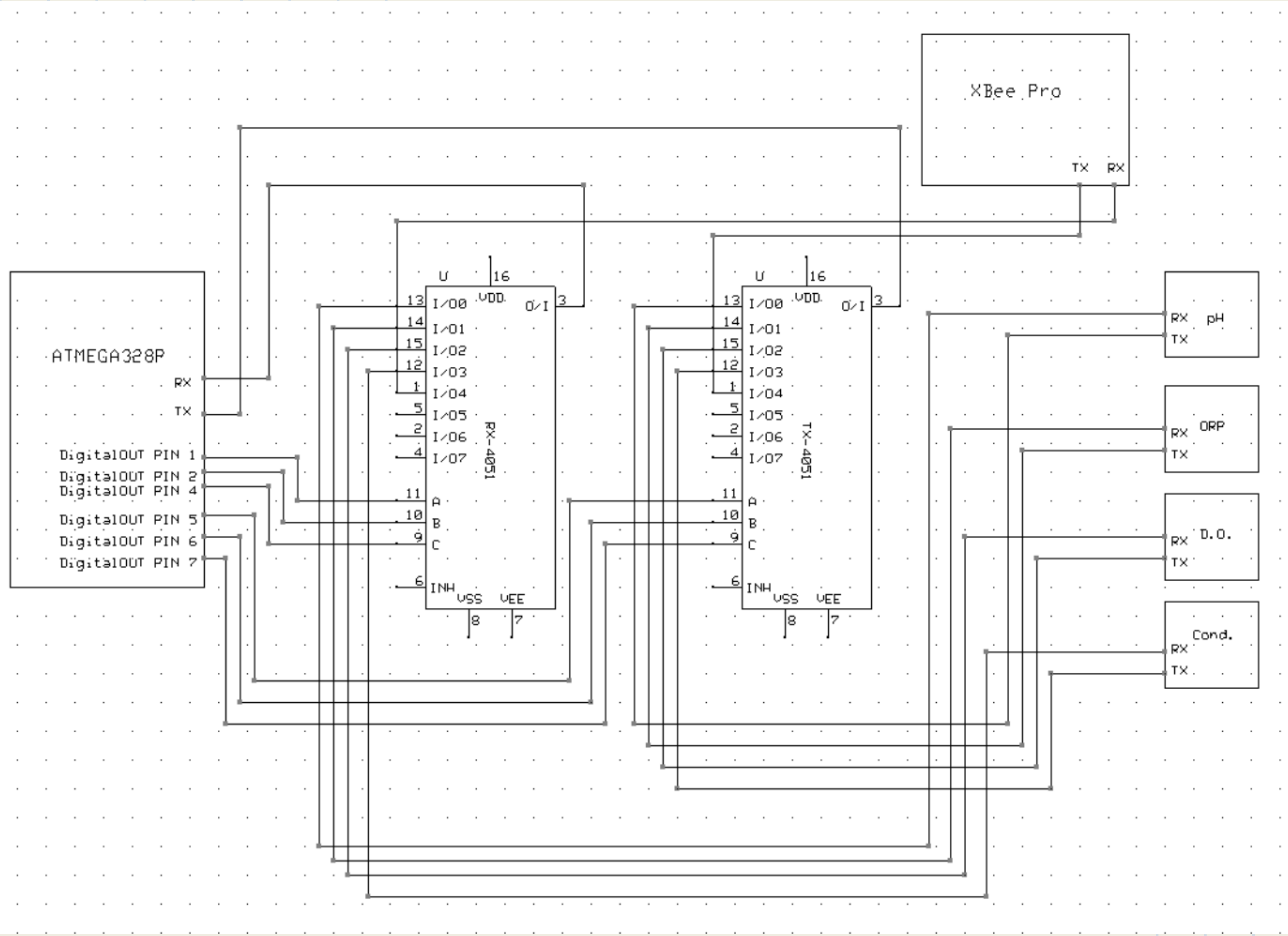
XBee Pro - Series 1 (802.15.4)

- Decided on using two XBee Pro modules for wireless data transmission.
- Low power consumption with great range.
- Easy configuration, one time “pairing” process.
- 1 mile range, outdoors line-of-sight.
- Two XBees will be used, one has a U.FL connector which will connect to an external antenna through a U.FL to RP-SMA cable on the boat and the other has a built on antenna that will be connected to the laptop.

XBee Pro - Series 1 (802.15.4)

TI 74HCT4051 MUX/DEMUX

- The 74HCT4051 is an 8-channel multiplexer.
- We used two multiplexers for the microcontroller to communicate with all sensors and which allows us to expand to more sensors if needed.
- One multiplexer will handle all data that is transmitting to the user, while the other multiplexer will handle the data the user decides to send to the sensors.



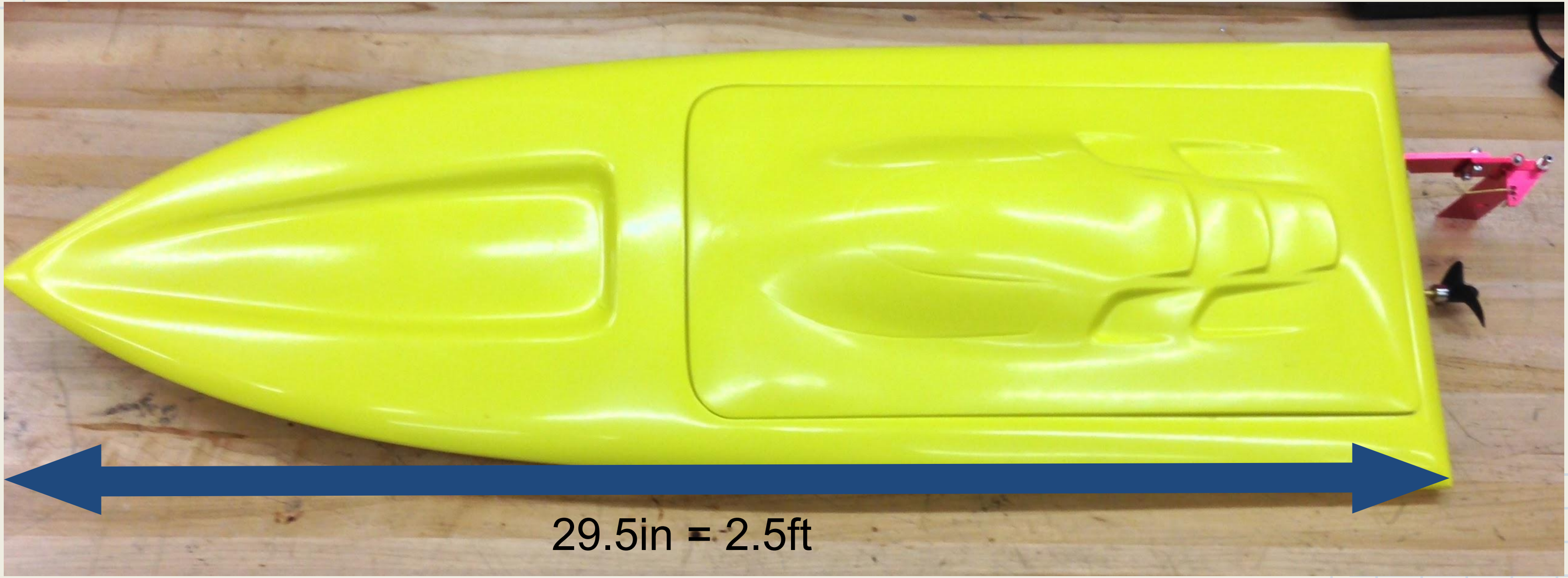
74HCT4051 Connection

Navigation

Robot Platform

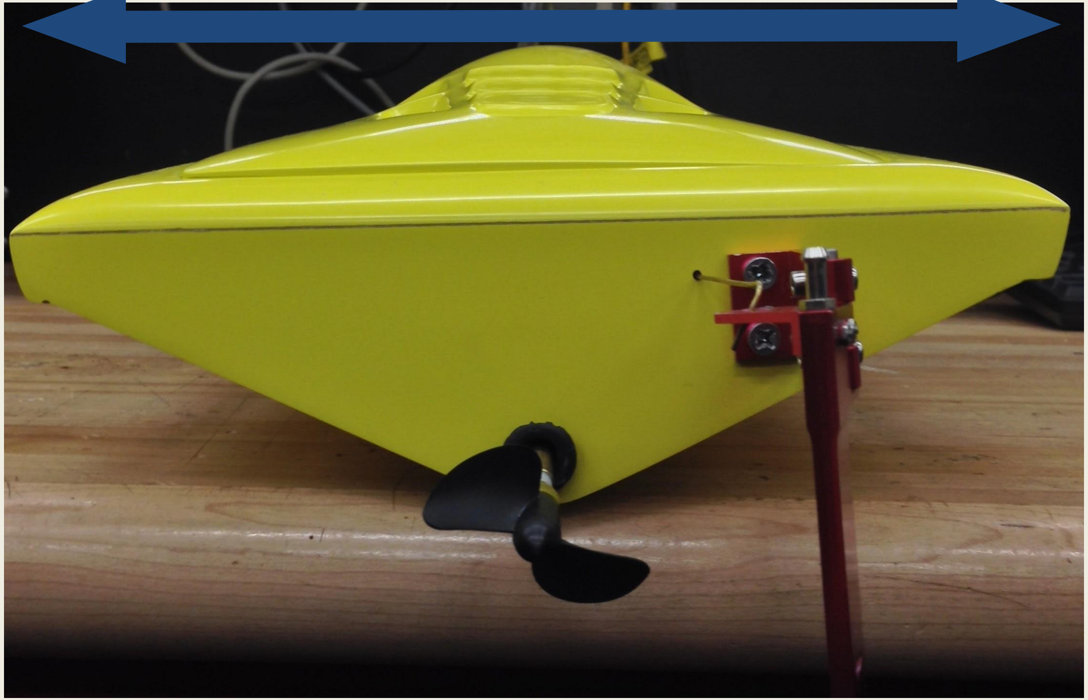
- Delta Force 29 Fiberglass Hull.
- Lightweight fiberglass built for speed.
- Measures 29.5in x 9.5in (about 2.5 ft x 0.8 ft)
- Designed as a Deep Vee with a small read pad for handling.
- Removable hatch for easy access to components.
- Moderately priced.
- Flat top for easy placement of solar cells.

Robot Platform



Robot Platform

9.5in = 0.8ft



DC Brushed vs Brushless Motor

Brushed Motor

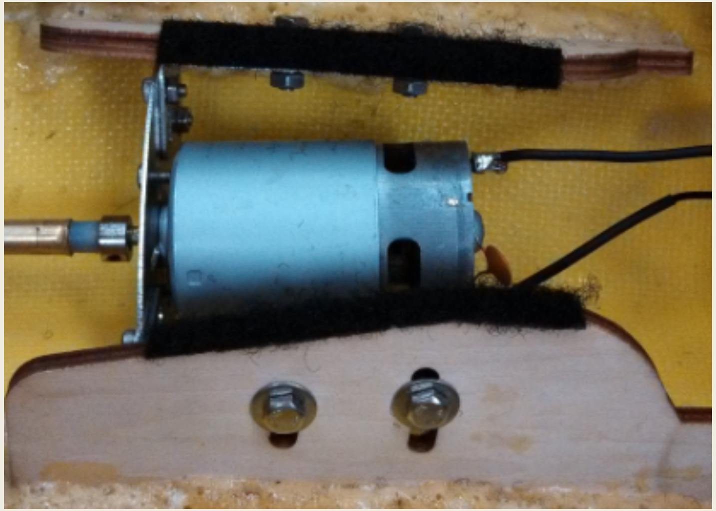
Pros	Cons
2 wire control	High rotor inertia
No controller for speed required	Lower max speed/torque
Cheap	Shorter lifespan
Operates in extreme environments	

Brushless Motor

Pros	Cons
Higher max speed/torque	Expensive
Operates at all speeds with rated load	Electric controller required to keep the motor running
High efficiency	Control is complex
Smaller in size	

DC Motor

- DC motor rated 3V-24V
- No load startup 3V at 0.2A
- 5V at 0.244A
- Loaded 3.7V at 0.45A
- Length: 40mm about 1.5in
- Diameter: 20mm about 0.78in



Electronic Speed Control

- Used to vary an electric motor’s speed.
- Most often used for brushless motors in radio controlled vehicles.

- W.A.R uses a 3-24V DC brushed motor.
- W.A.R is controlled by two microcontrollers.
- W.A.R utilizes a relay to switch the motor on and off.

- Originally planned to use an ESC if the boat moved too fast.

Servo/Propeller/Rudder

Servo

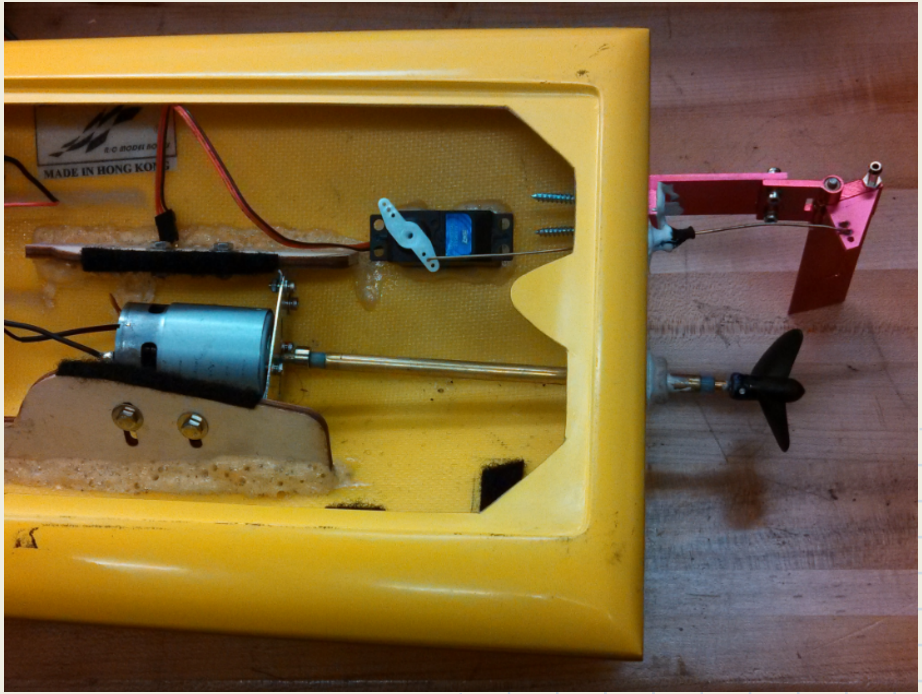
- Losi B0818 Digital Servo.
- Torque: At 6V, 45 oz-in.
- Speed: 60 degrees/0.17sec.

Propeller and Shaft

- Approximately 2 inch Diameter.
- Waterproofed stuffing box.

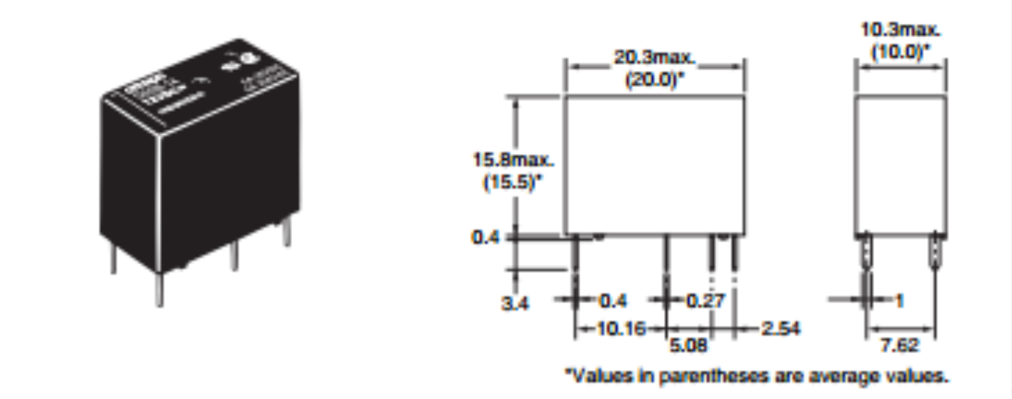
Rudder

- Rudder and Strut (red) from ProBoat.
- 4.4in x 4in x 1.1in



Motor Relay

- Omron G5SB-14, A compact SPDT relay.
- Used to turn the motor on/off.
- Rated coil voltage of 5V and max switching current of 5A.
- The coil of the relay is powered by the PCB.
- 1 lithium ion battery is used to power the motor.



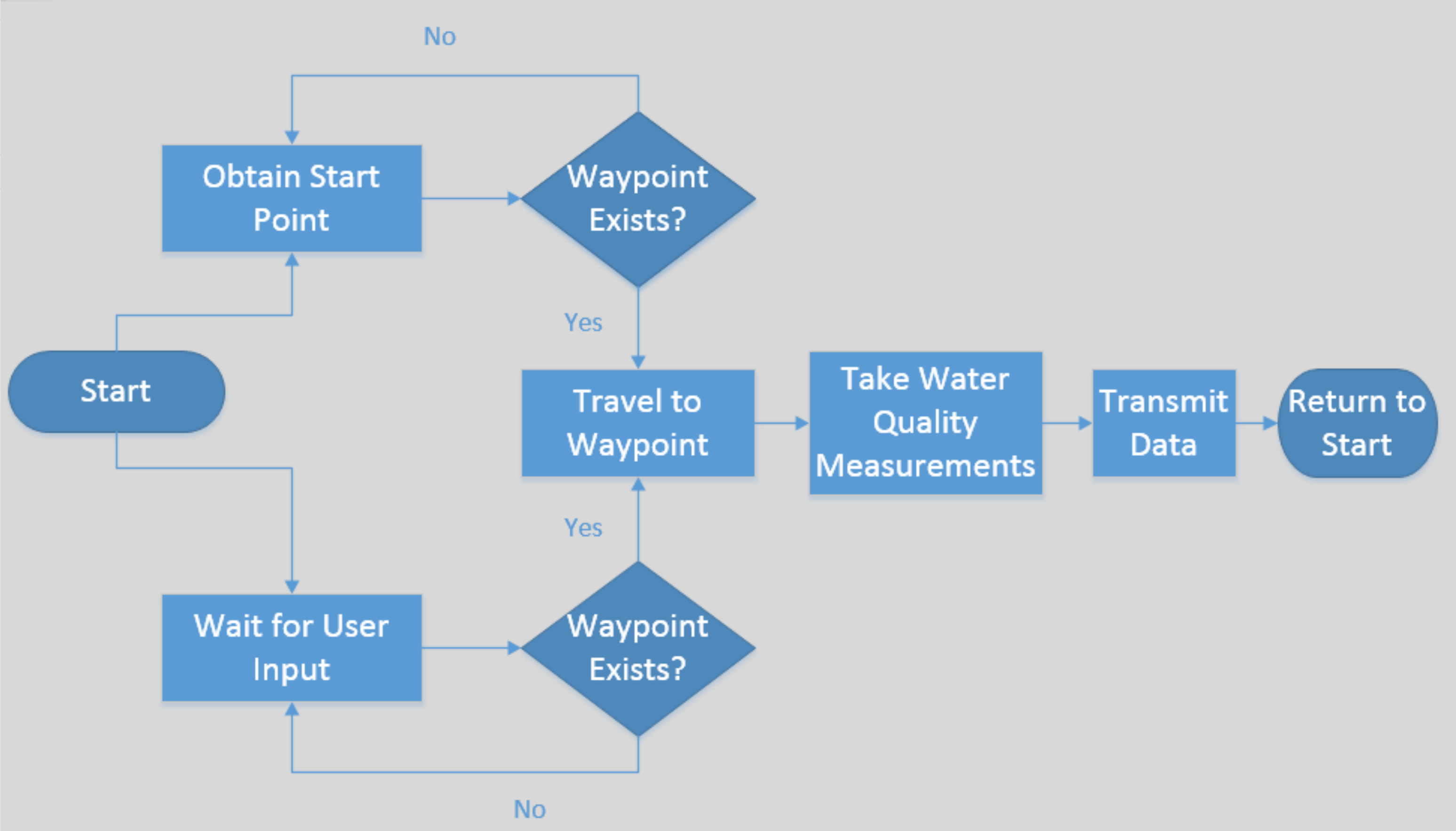
Comparison of GPS

Parameter	EM-406A SiRF III	LS20031 GPS
Frequency	L1, 1575.42MHz	L1, 1575.42MHz
Sensitivity	159dBm	159dBm
Update Rate	1Hz	1Hz default, up to 10Hz
Hot Start	1s	<2s
Current Consumption	44mA	29mA
Power Input	4.5V - 6.5V	3V - 4.3V
Price	$39.95	$59.95

EM-406A SiRF III

- 20 Channel Receiver.
- High Sensitivity: -159dbm
- Accuracy (<10m)
- Hot Start :1 second
- Time to First Fix : 42 seconds
- 49 mA at 5V
- Outputs both NMEA 0183 and SiRF binary protocol.

Software



Software Flow Chart

Navigation Calculations

Distance

Haversine formula:

$$a = \sin^2(\Delta\varphi/2) + \cos(\varphi_1).\cos(\varphi_2).\sin^2(\Delta\lambda/2)$$

$$c = 2.\mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

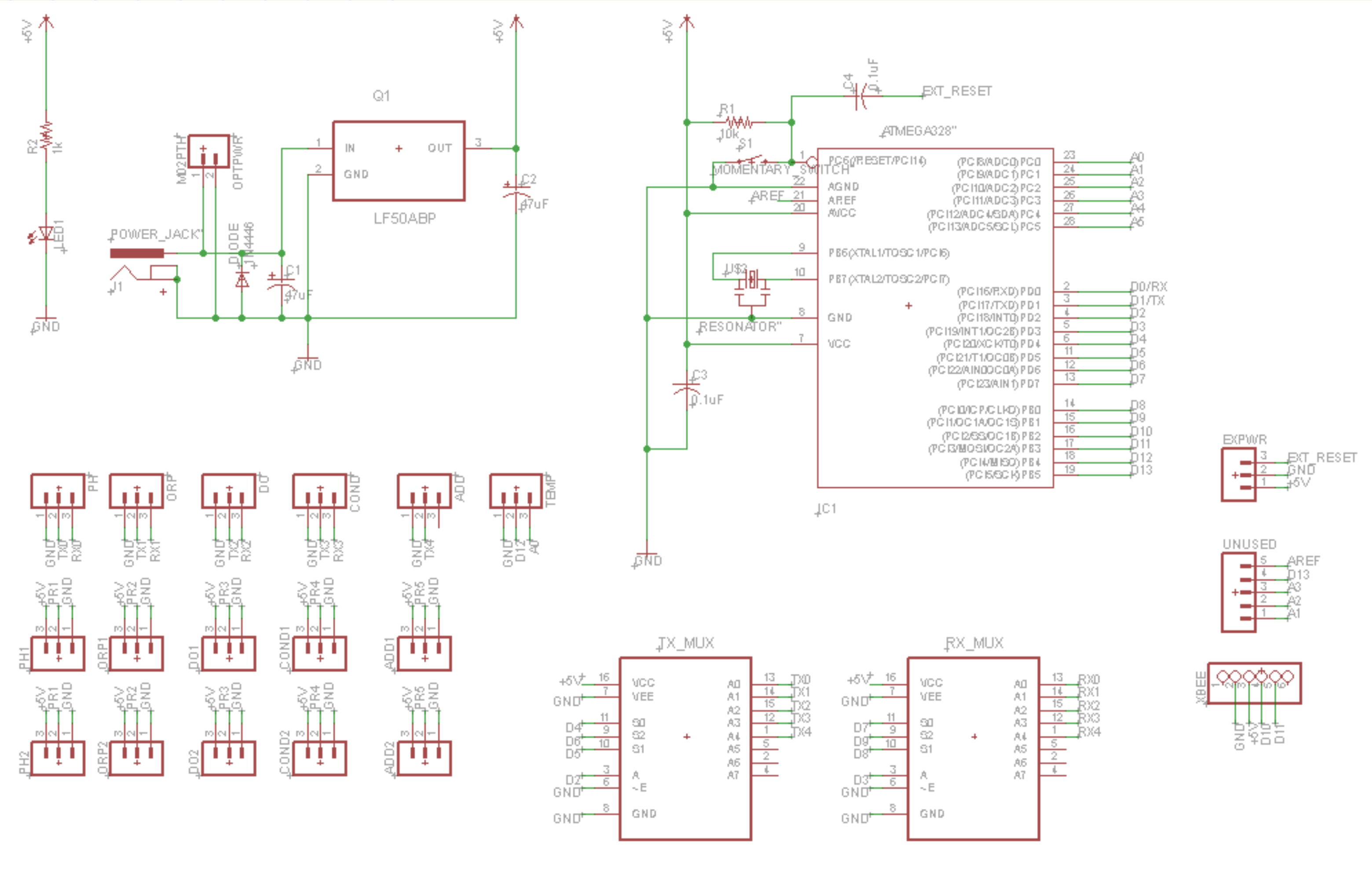
$$d = R.c$$

where φ is latitude, λ is longitude, R is earth's radius (mean radius = 6,371km)

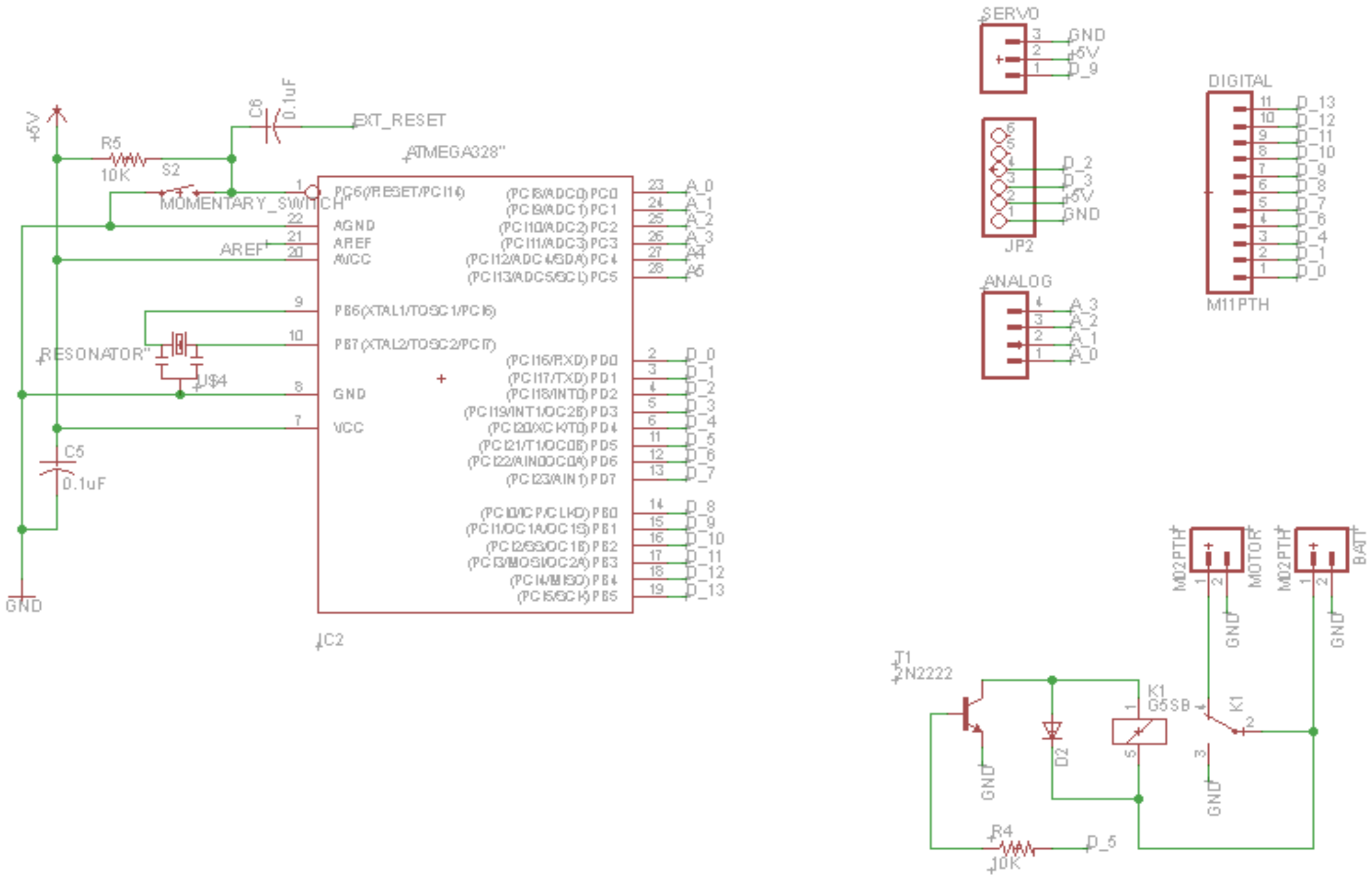
Bearing

Formula:

$$\theta = \mathrm{atan2}(\ \sin(\Delta\lambda).\cos(\varphi_2),\ \cos(\varphi_1).\sin(\varphi_2) - \sin(\varphi_1).\cos(\varphi_2).\cos(\Delta\lambda)\ )$$

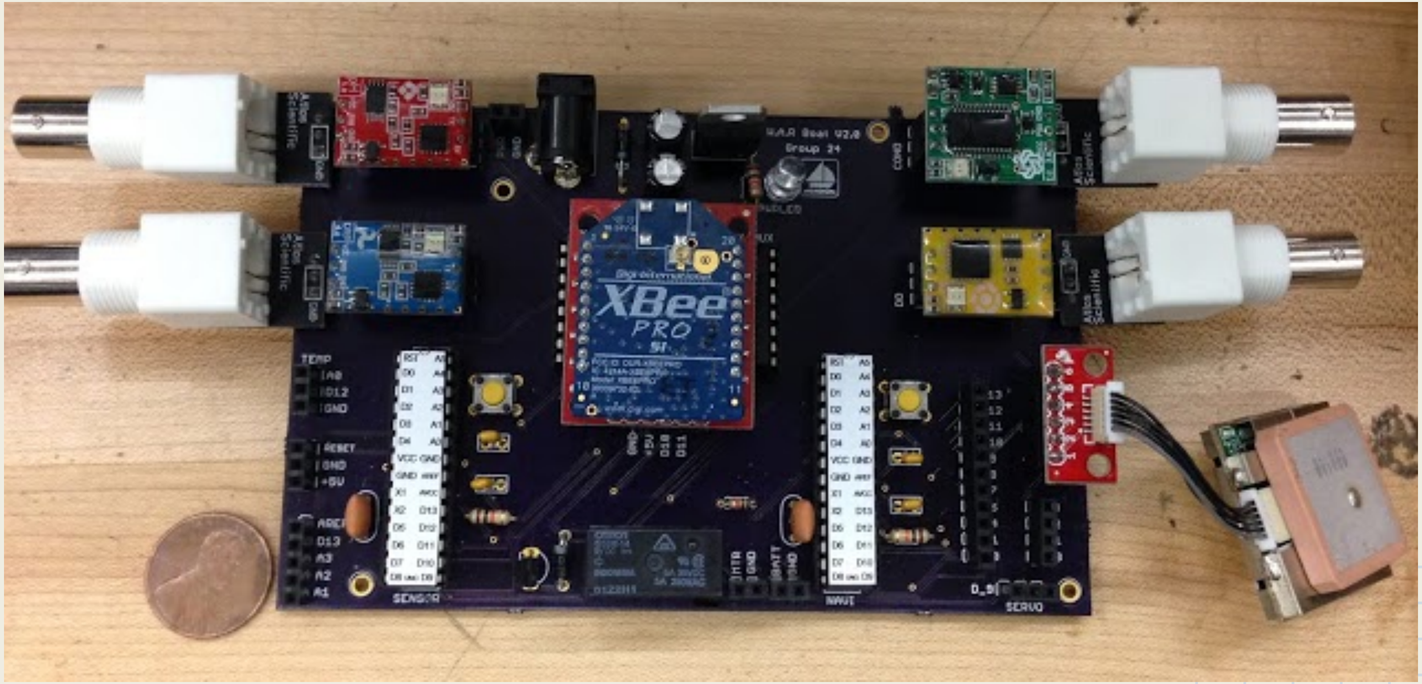


+5V
R2
1k
LED1
GND
Q1
LF50ABP
IN
OUT
GND
M02PTH
OPTPWR
POWER_JACK"
J1
DIODE
1N4446
C1
47uF
C2
47uF
R1
10k
S1
MOMENTARY_SWITCH"
C4
0.1uF
EXT_RESET
ATMEGA328"
PC6(/RESET/PCI14)
AGND
AREF
AVCC
PB6(XTAL1/TOSC1/PCI6)
PB7(XTAL2/TOSC2/PCI7)
GND
VCC
U$3
RESONATOR"
C3
0.1uF
(PCI8/ADC0)PC0
(PCI9/ADC1)PC1
(PCI10/ADC2)PC2
(PCI11/ADC3)PC3
(PCI12/ADC4/SDA)PC4
(PCI13/ADC5/SCL)PC5
(PCI16/RXD)PD0
(PCI17/TXD)PD1
(PCI18/INT0)PD2
(PCI19/INT1/OC2B)PD3
(PCI20/XCK/T0)PD4
(PCI21/T1/OC0B)PD5
(PCI22/AIN0/OC0A)PD6
(PCI23/AIN1)PD7
(PCI0/ICP/CLKO)PB0
(PCI1/OC1A/OC1B)PB1
(PCI2/SS/OC1B)PB2
(PCI3/MOSI/OC2A)PB3
(PCI4/MISO)PB4
(PCI5/SCK)PB5
A0
A1
A2
A3
A4
A5
D0/RX
D1/TX
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
D13
IC1
EXPWR
EXT_RESET
GND
+5V
UNUSED
AREF
D13
A3
A2
A1
PH
ORP
DO
COND
ADD
TEMP
GND TX0 RX0
GND TX1 RX1
GND TX2 RX2
GND TX3 RX3
GND TX4
GND D12 A0
+5V PR1 GND
+5V PR2 GND
+5V PR3 GND
+5V PR4 GND
+5V PR5 GND
PH1
ORP1
DO1
COND1
ADD1
PH2
ORP2
DO2
COND2
ADD2
TX_MUX
RX_MUX
VCC
VEE
S0
S2
S1
A
~E
GND
TX0
TX1
TX2
TX3
TX4
RX0
RX1
RX2
RX3
RX4
D4
D6
D5
D2
D7
D9
D8
D3
XBEE
GND +5V D10 D11

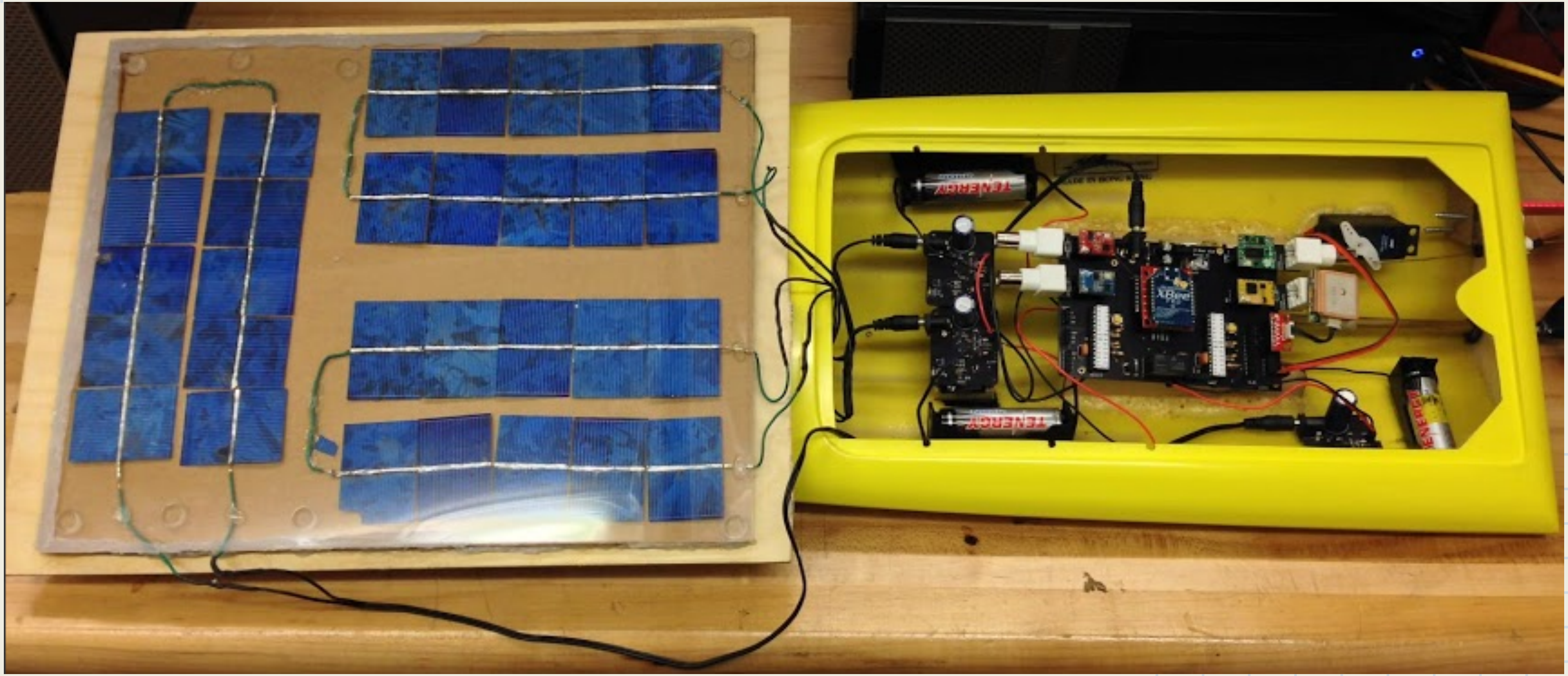


+5V
R5
10K
S2
MOMENTARY_SWITCH"
C6
0.1uF
EXT_RESET
ATMEGA328"
PC6(RESET/PCI14)
AGND
AREF
AVCC
PB6(XTAL1/TOSC1/PCI6)
PB7(XTAL2/TOSC2/PCI7)
GND
VCC
RESONATOR"
U$4
C5
0.1uF
GND
IC2
(PCI8/ADC0)PC0
(PCI9/ADC1)PC1
(PCI10/ADC2)PC2
(PCI11/ADC3)PC3
(PCI12/ADC4/SDA)PC4
(PCI13/ADC5/SCL)PC5
(PCI16/RXD)PD0
(PCI17/TXD)PD1
(PCI18/INT0)PD2
(PCI19/INT1/OC2B)PD3
(PCI20/XCK/T0)PD4
(PCI21/T1/OC0B)PD5
(PCI22/AIN0/OC0A)PD6
(PCI23/AIN1)PD7
(PCI0/ICP/CLKO)PB0
(PCI1/OC1A/OC1S)PB1
(PCI2/SS/OC1B)PB2
(PCI3/MOSI/OC2A)PB3
(PCI4/MISO)PB4
(PCI5/SCK)PB5
A_0
A_1
A_2
A_3
A4
A5
D_0
D_1
D_2
D_3
D_4
D_5
D_6
D_7
D_8
D_9
D_10
D_11
D_12
D_13
SERVO
GND
+5V
D_9
JP2
D_2
D_3
+5V
GND
ANALOG
A_3
A_2
A_1
A_0
DIGITAL
M11PTH
M02PTH
MOTOR
BATT
T1
2N2222
K1
G5SB
D2
R4
10K
D_5

Populated PCB



Finished Project



Part	Cost Per Unit	Quantity	Total Cost
Scientific Grade pH Sensor -------------------------------- pH Circuit	$60 ------------------------ $28	1	$88.00
Field Ready Temperature Sensor	$18	1	$18.00
Dissolved Oxygen Sensor ---------------- D.O Circuit	$160 ------------------------ $33.00	1	$193.00
Oxidation Reduction Potential Sensor -------------------------------- ORP Circuit	$90.00 ------------------------ $28.00	1	$118.00
Conductivity Sensor -------------------------------- Conductivity Circuit	$105.00 ------------------------ $43	1	$148.00
Microcontroller	$15.00	2	$30.00
Microcontroller Development Board	$50.00	1	$50.00
GPS unit	$40.00	1	$40.00
1-to-8 MUX - 74HCT4051	$1.00	5	$5.00
Diode	Free*	4	$0.00
PV Cells	$20.00	1	$20.00
Lithium-Ion Battery	$80.00	1	$80.00
DC to DC Power Converter	$15.00	1	$15.00
Breadboard	$30.00	1	$30.00
Wiring	$10.00	1	$10.00
PCB Manufacturing	$100.00	1	$100.00
Rudder	$20.00	1	$20.00
Rudder Servo	$15.00	1	$15.00
Propeller	$5.00	1	$5.00
Motor	$20.00	1	$20.00
Robot Frame/Platform	$120.00	1	$120.00
Total Cost of W.A.R Boat			**$1120.00**

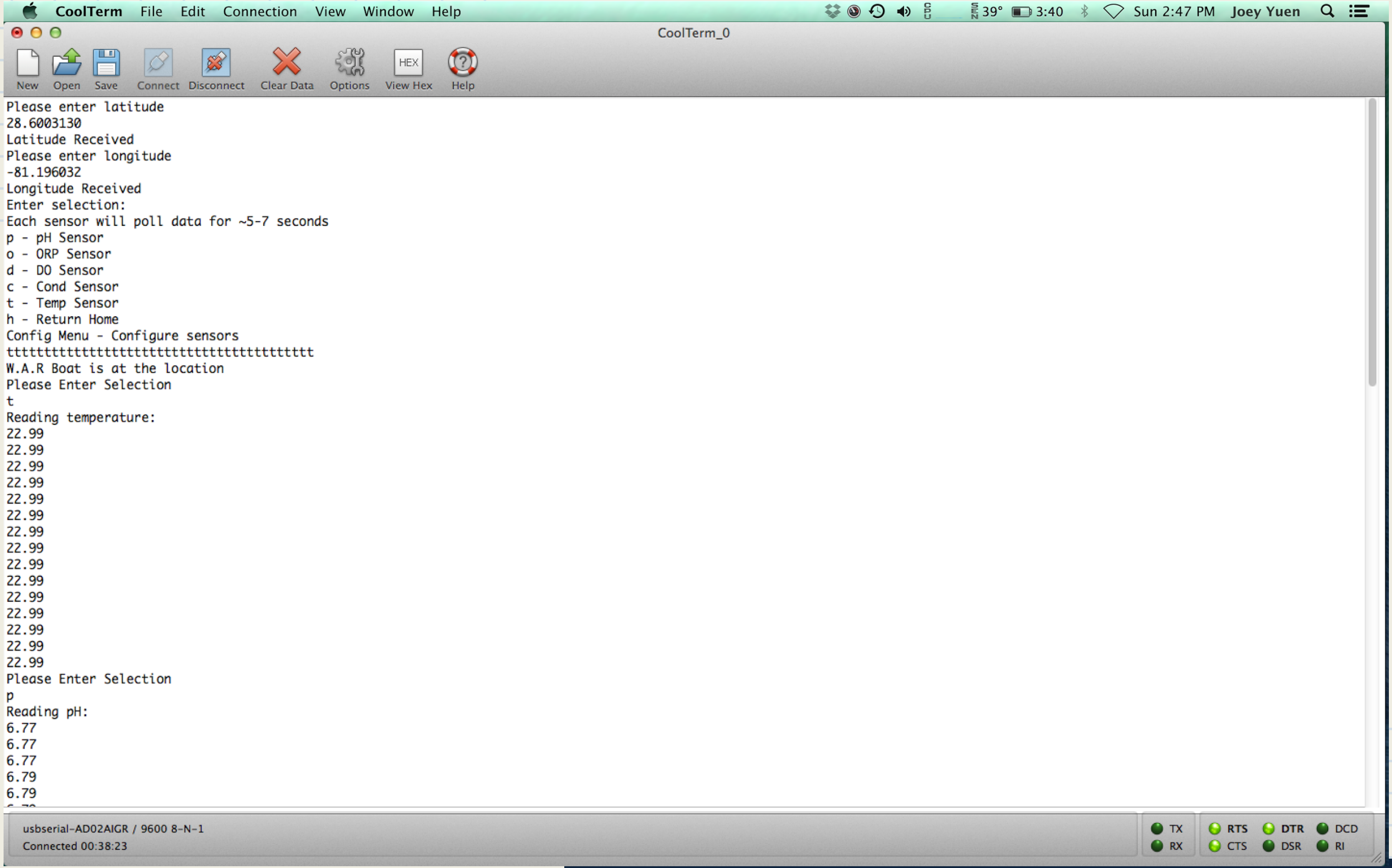
Budget

Challenges

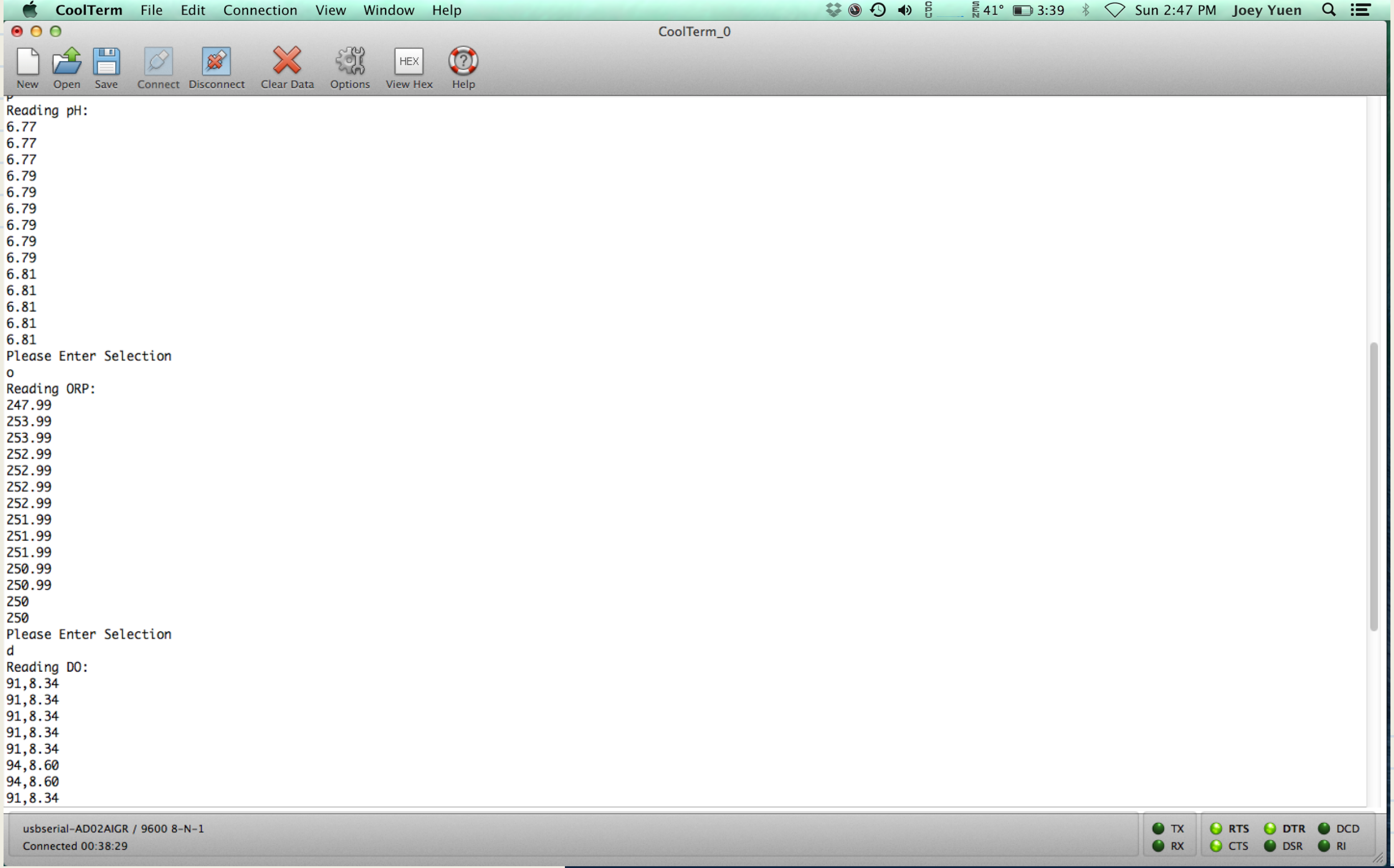
- Charging batteries from solar panels.
- Making the boat waterproof/creating propeller shaft.
- Wireless range.
- Original motor need too much current to start.
- Software libraries clashing.

Video Demo

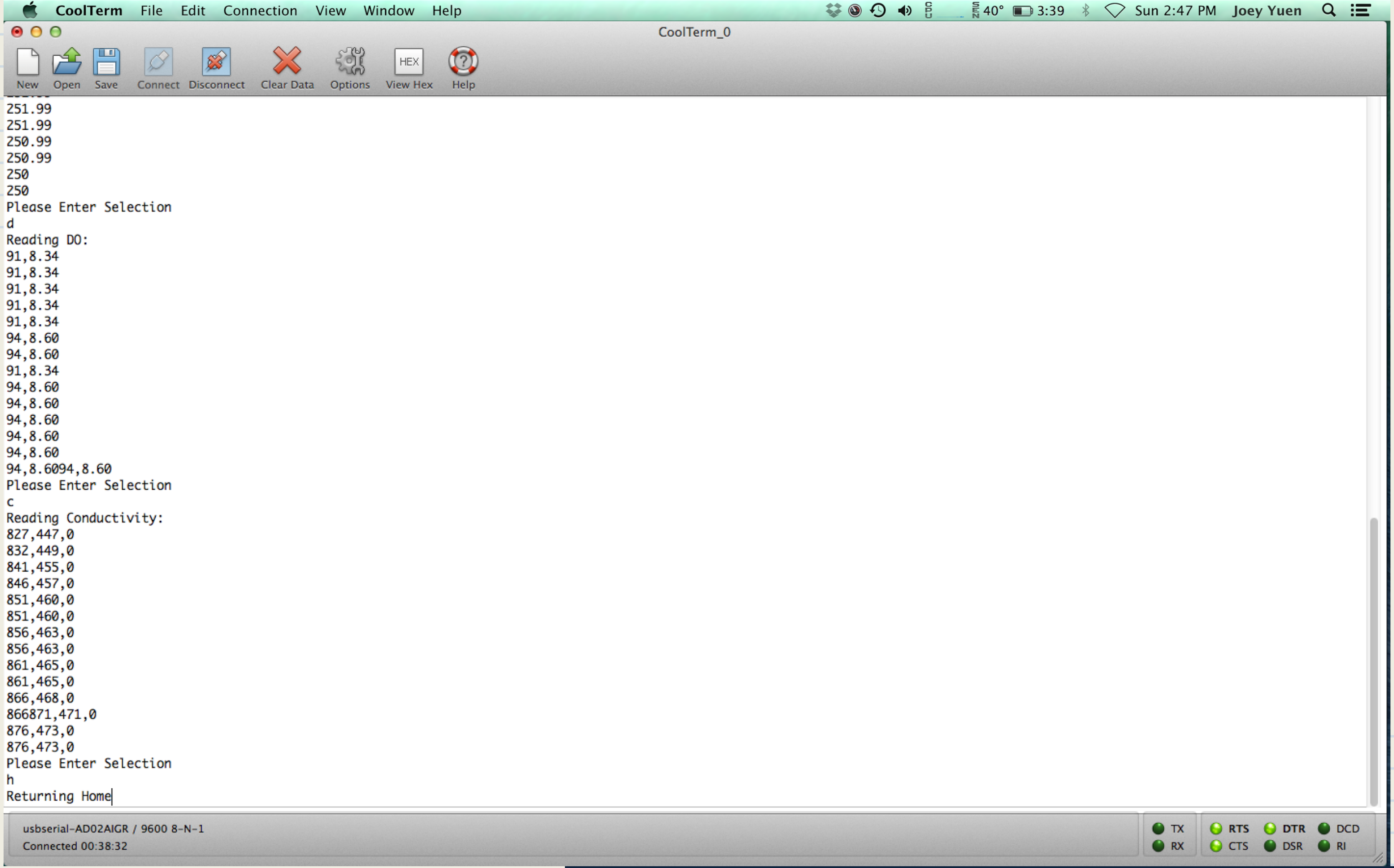
W.A.R Boat Testing/Demo Video



Water Quality Data of Lake Claire



Water Quality Data of Lake Claire



Water Quality Data of Lake Claire

Thanks to

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WHO WE SERVE

Questions?