
WORCESTER POLYTECHNIC INSTITUTE
LEHR UND KUNST
1865
WPI

WPI

WAVE

Waterborne Autonomous VEhicle

A Modular Underwater Research Platform

Team Robosub

WAVE

Project Motivation

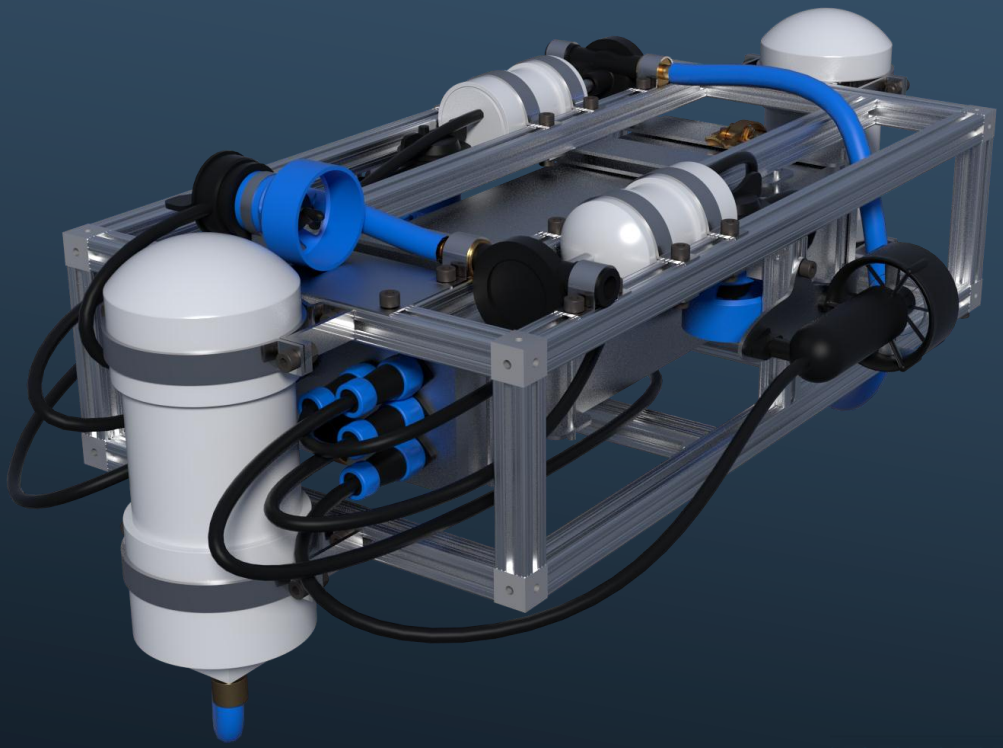
$40,000
SeaBotix LBV200

$1,000,000
Bluefin 9

- Existing Unmanned Underwater Vehicles (UUVs)
  - Expensive
  - Closed Source
  - Non-extensible

Design Goals

- Modular underwater robotic platform
- New research opportunities for WPI
- Open Source
  - Hardware
  - Software
- COTS



AUVSI "Robosub" Competition

Association for Unmanned Vehicle Systems International

- Annual competitions – Launched in 1997
- Typical competition includes:
  - Visual identification
  - Waypoint navigation
  - Object manipulation
  - Launch projectiles through targets

Design Specifications

- Max depth: 12 meters
- Run time: 20 minutes
- Desired speed: 0.5 m/s
- Max dimensions: 0.91m x 0.91m x 1.83m
- Depth control accuracy: 12 cm
- Max mass: 54 kg

Department Breakdown

Robotics Engineering

Mechanical	Electrical	Software
Professor Stephen Nestinger	Professor Susan Jarvis	Professor Craig Putnam
Professor Ken Stafford		Professor Mike Ciaraldi

Presentation Order

• Project Overview	2:30pm
▪ Mechanical	2:34pm
▪ Electrical	2:48pm
▪ Software	3:02pm
• Integration	3:16pm
• Final Questions	3:20pm

Mechanical Challenges

Sidney Batchelder, Anna Chase, Cory Lauer, Lisa Morris, Chris Overton





Problem Statement

To provide WAVE with a nimble chassis, capable of moving freely within a body of water, sheltering its electronic components, dissipating heat, while ensuring safe operation.

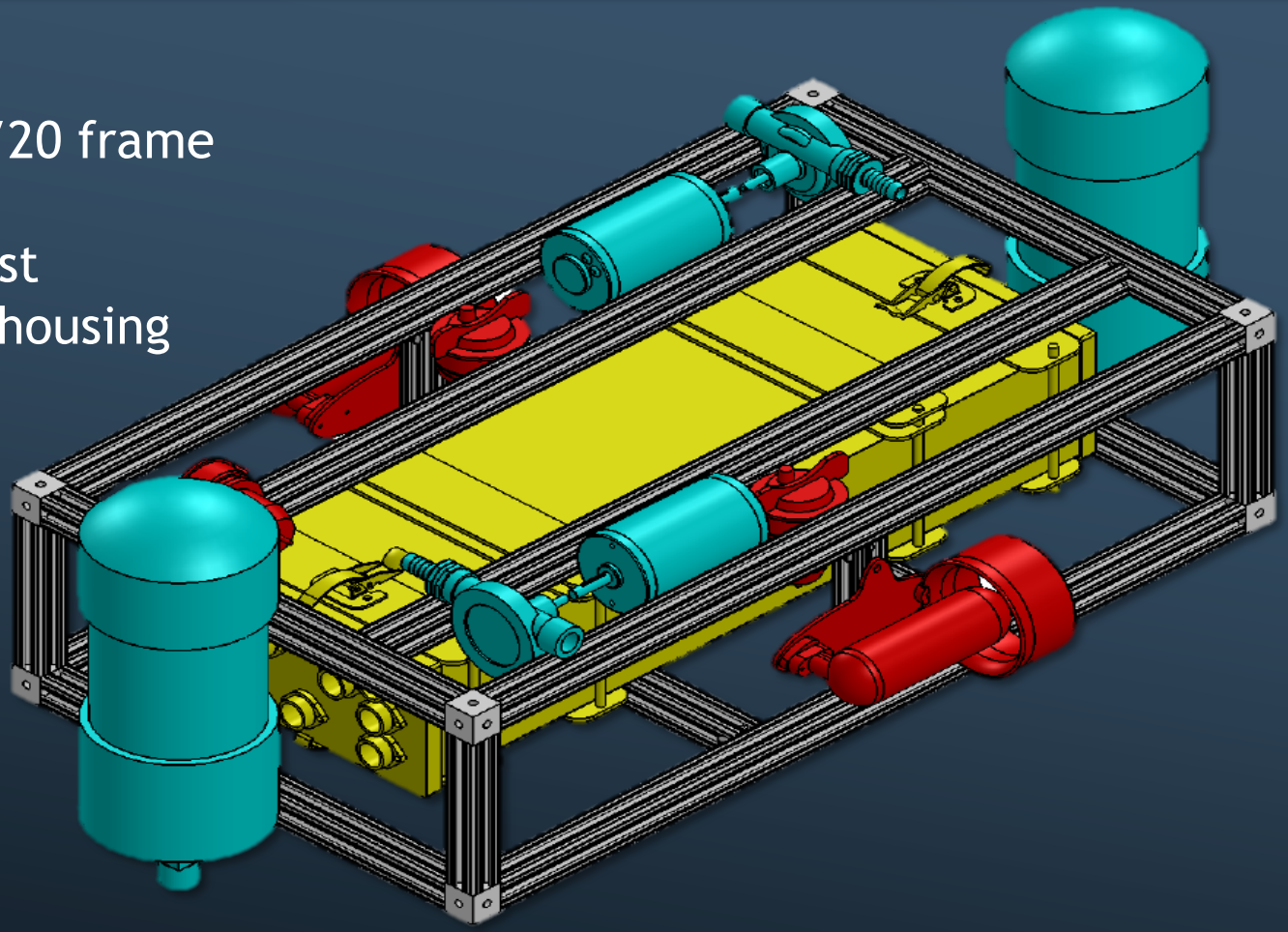
Objectives

- Hydrodynamics
  - Buoyancy Management
  - Minimum 0.5 m/s motion
- Minimum 4 degrees of freedom
- Electronics Housing
  - Watertight
  - Sufficient thermal dissipation

Design Overview

Key

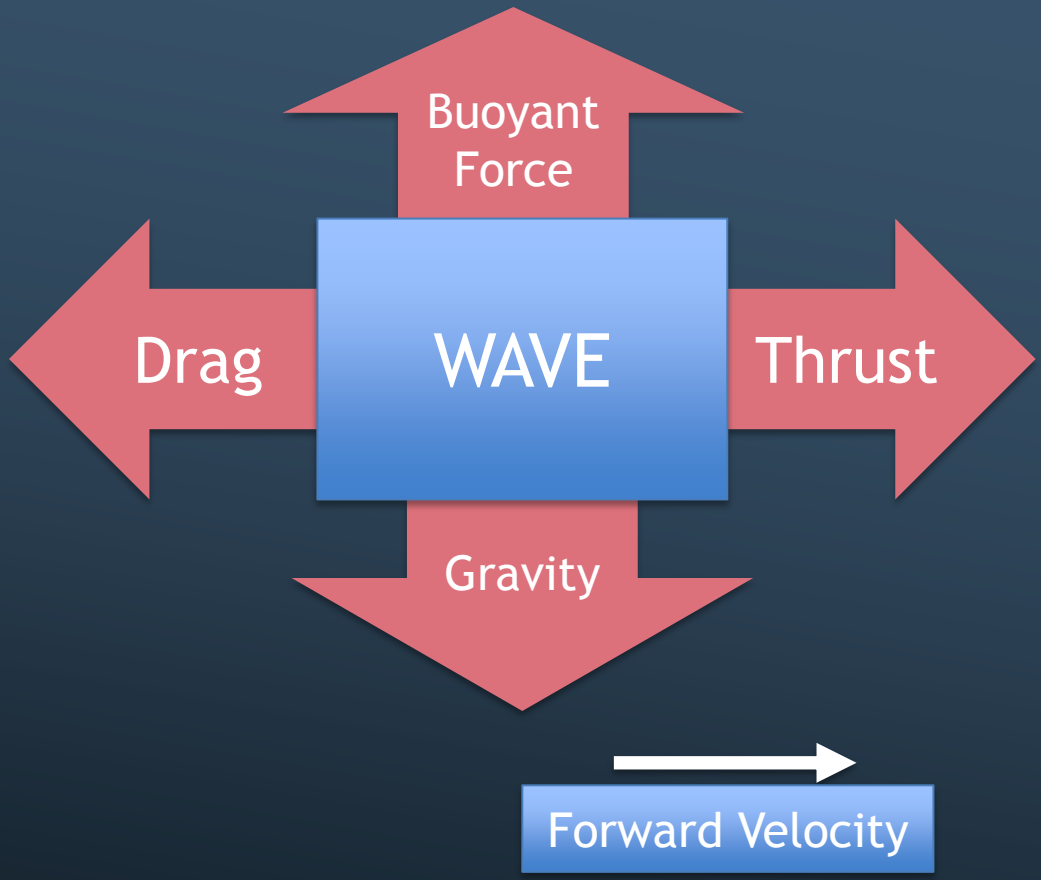
Silver - Modular 80/20 frame
Red - 6 thrusters
Cyan - Active ballast
Yellow - Electronics housing



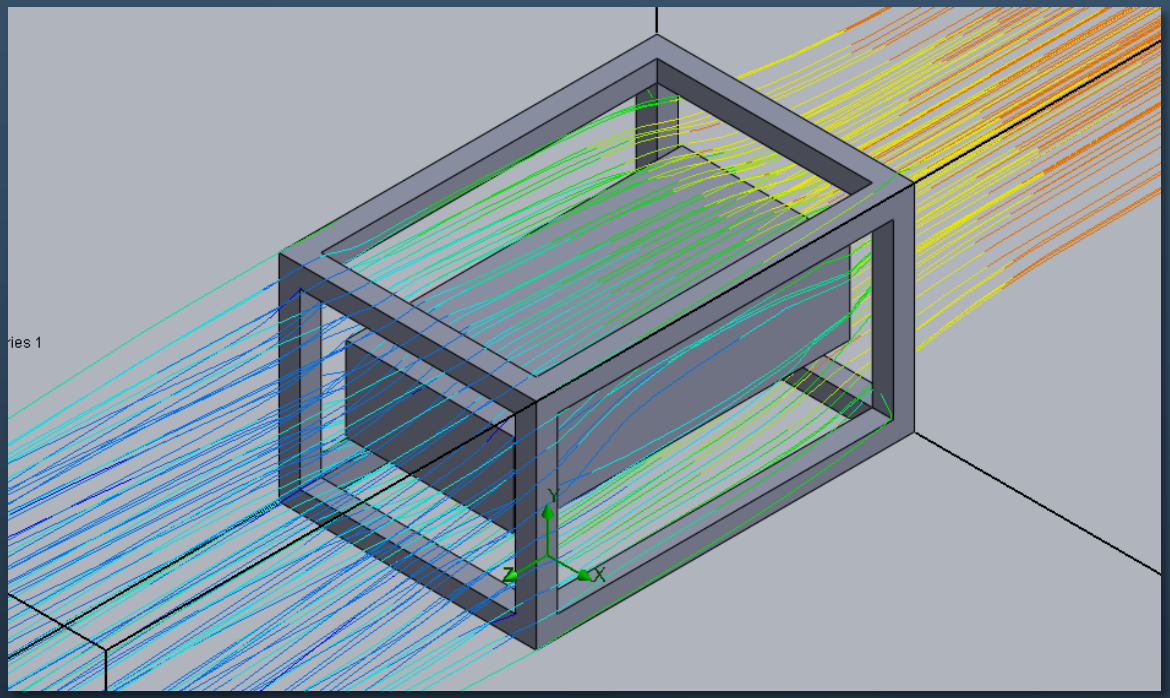
Hydrodynamics

Free Body Diagram of WAVE

- $F_g = mg$
- $F_B = \rho g V$
- $F_D = \frac{1}{2}\rho C_D A_c v^2$



Drag Force Analysis



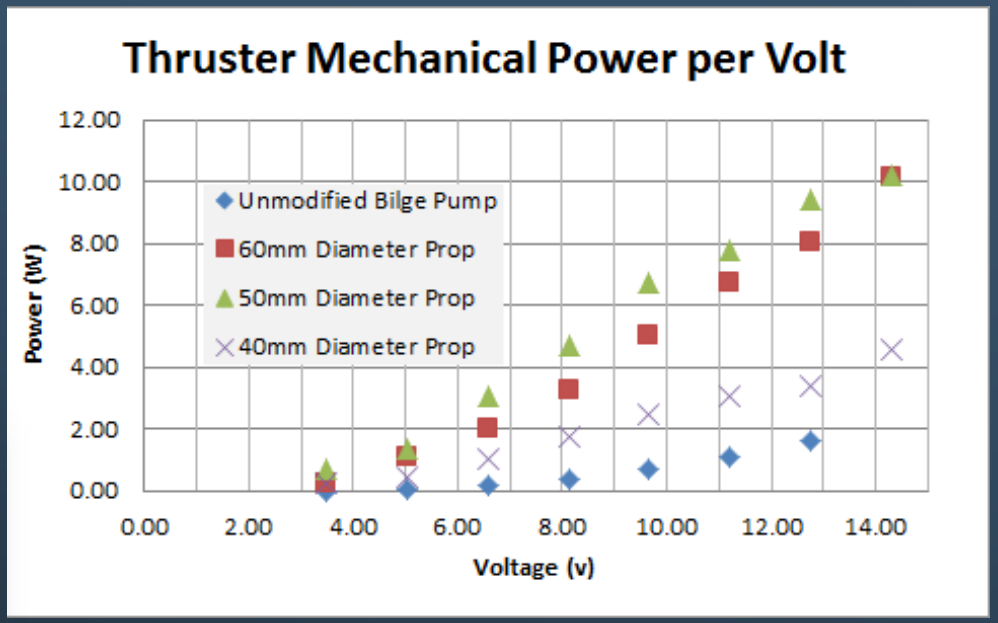
Drag Model

Total Forward Drag: **~10N**

Power to overcome drag at 0.5 m/s: **~ 5W**

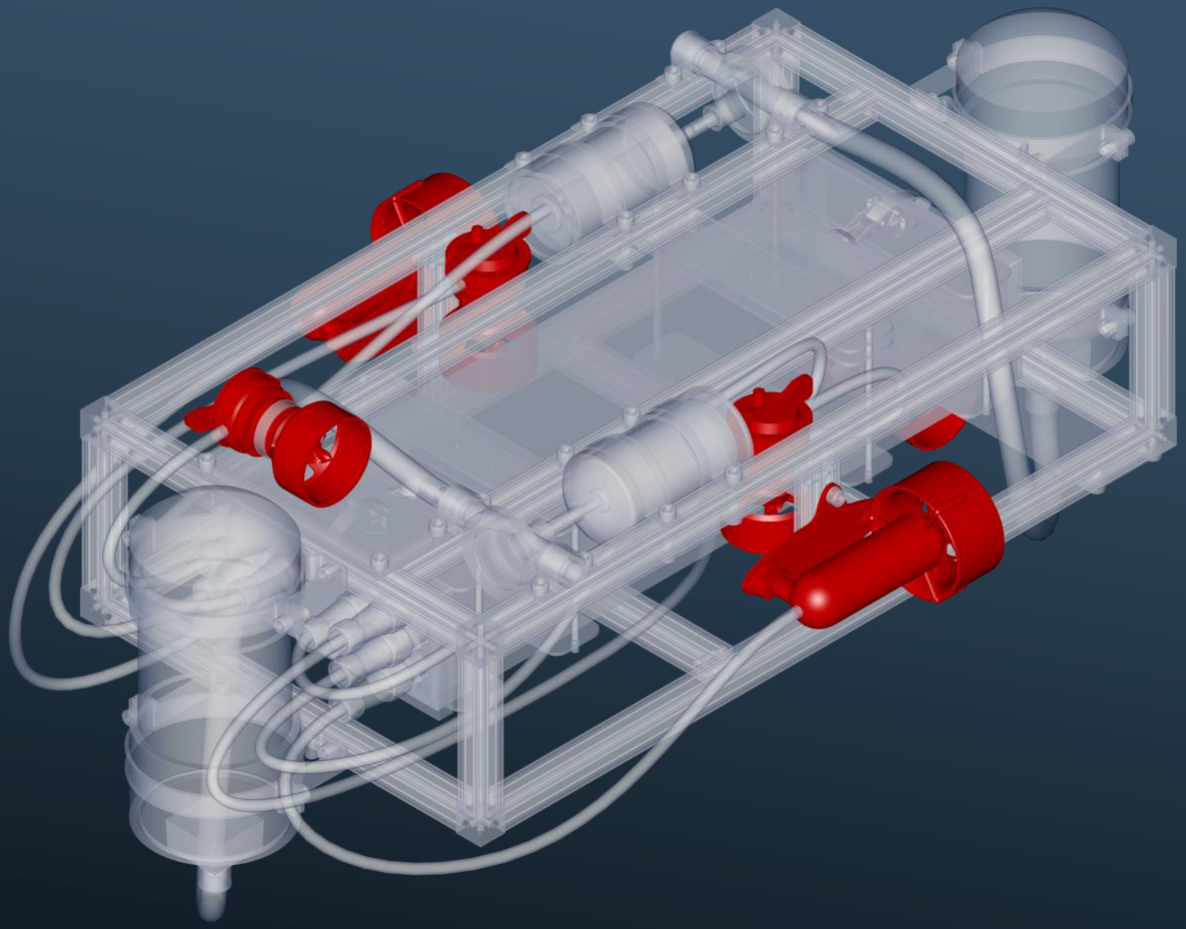
Thruster Testing

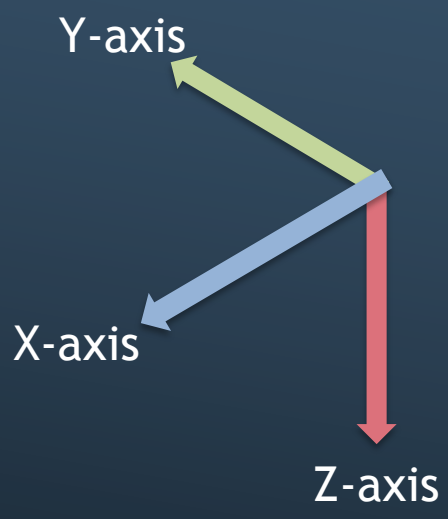
- Measured
  - Voltage, Current
  - Thrust, Flow



- Calculated
  - Power
  - Efficiency

Thruster Placement





Buoyancy

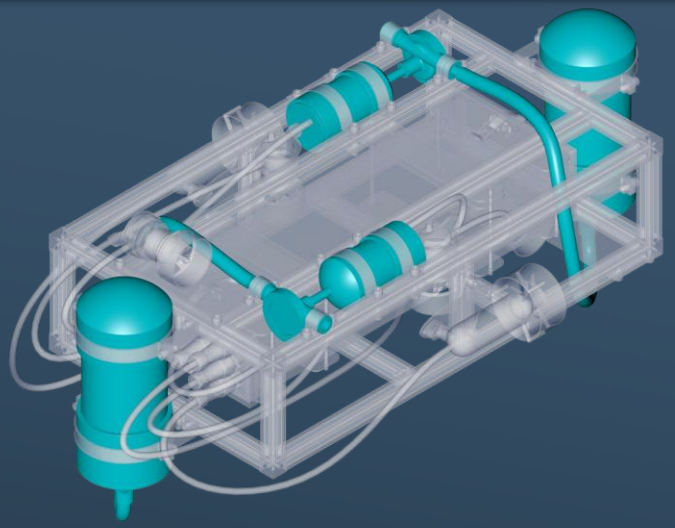
Element	Mass (kg)	Net Buoyancy (N)
Frame	1.86	-1.36
Electronics Housing	11.64	9.32
Motors	1.33	-5.65
Ballast	5.77	-0.39
TOTAL	**19.36**	**1.92**

Conclusion

Lots of available weight for modules and trim ballast weights

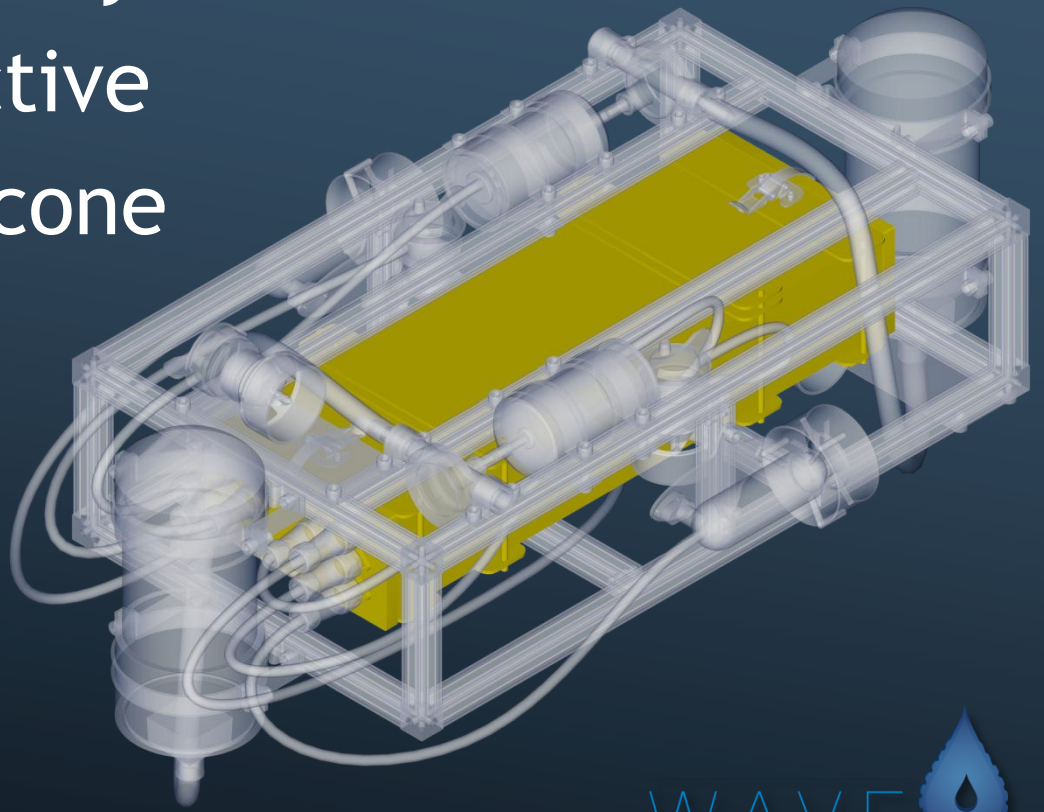
Ballast

- Two vertical 4"x10" PVC tanks
- Controlled by two reversible, positive displacement pumps
- Gives pitch and buoyancy control

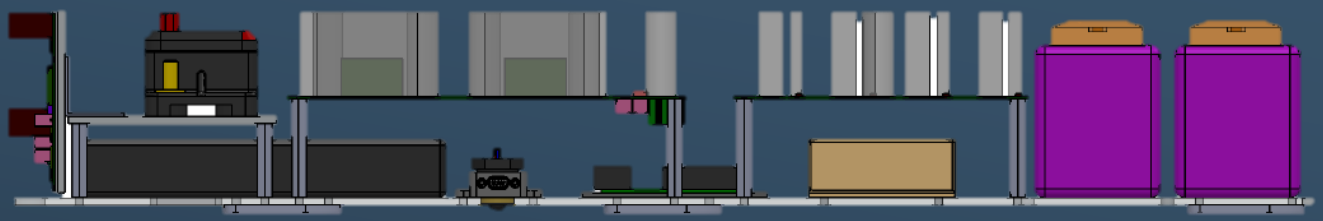


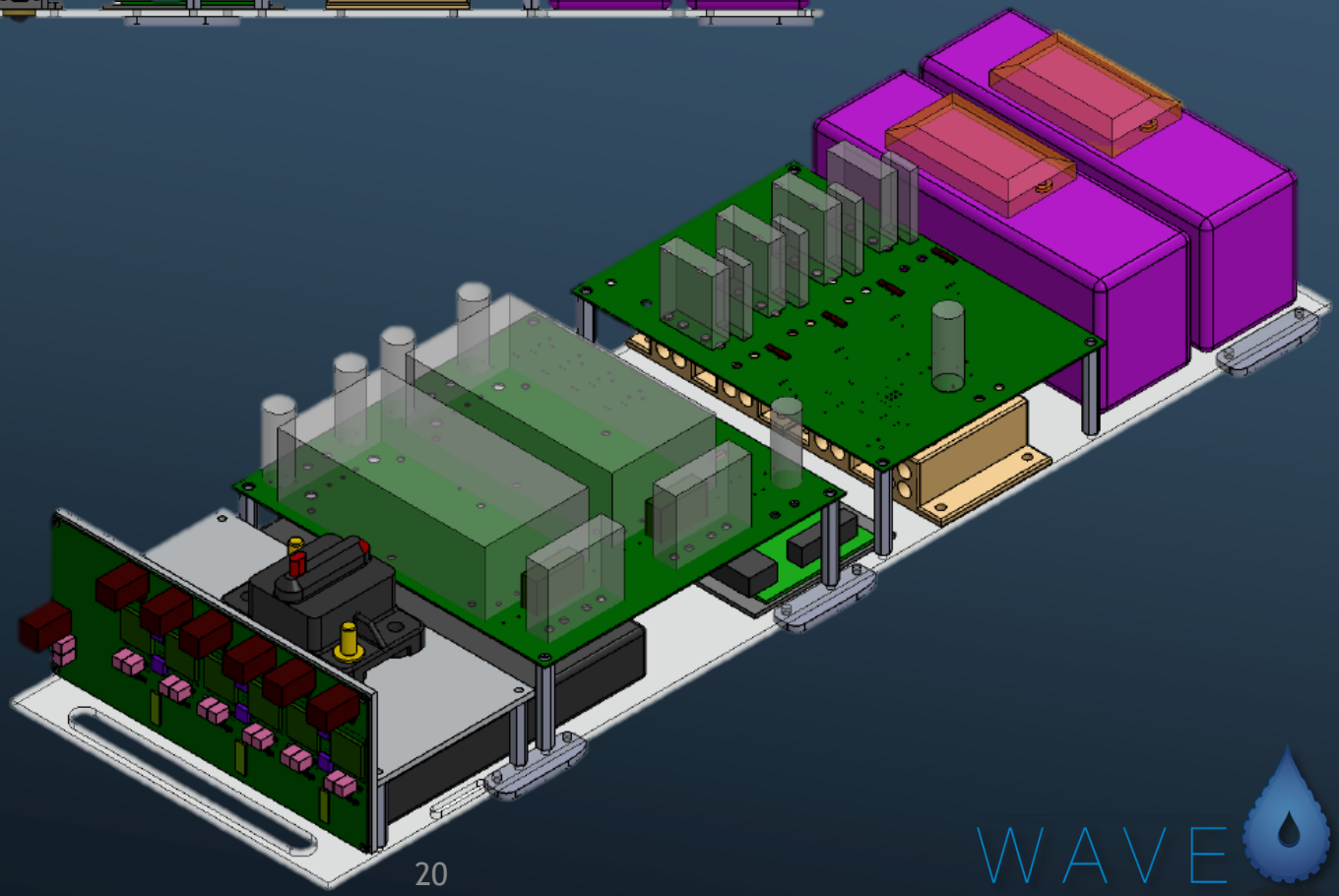
Electronics Housing

- 2ft of 4”x8” aluminum tubing
- Keeps electronics dry
- Thermally conductive
- End caps with silicone gaskets

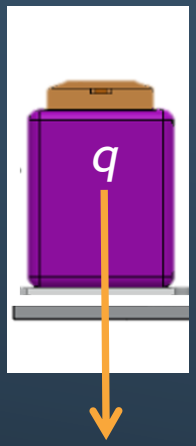


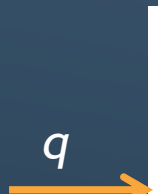
Electronics Rack

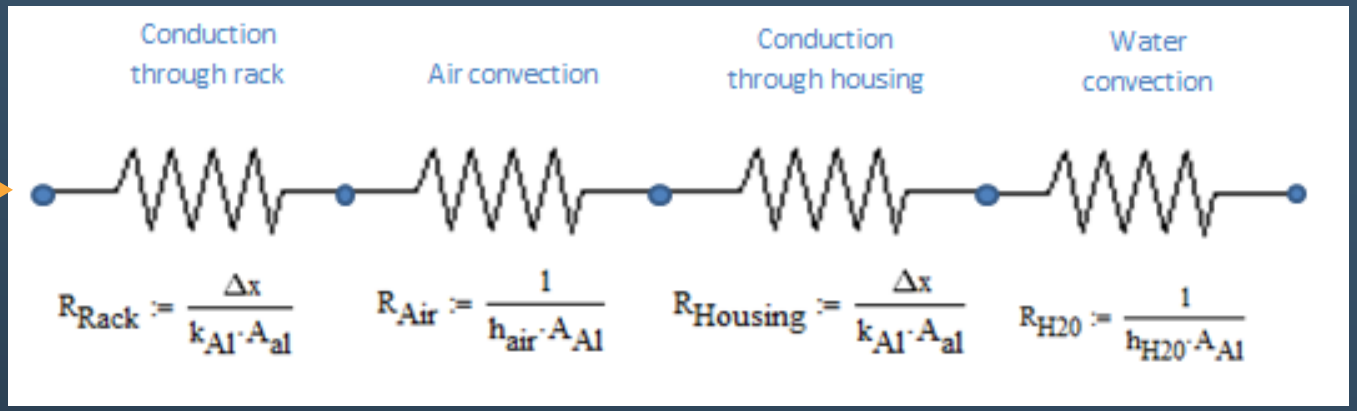




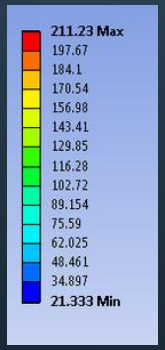
Thermal Analysis

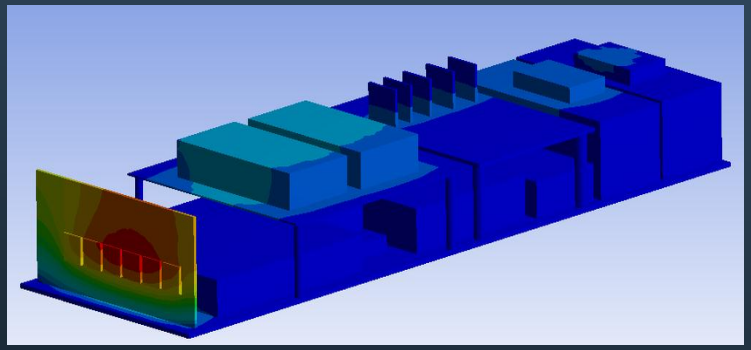






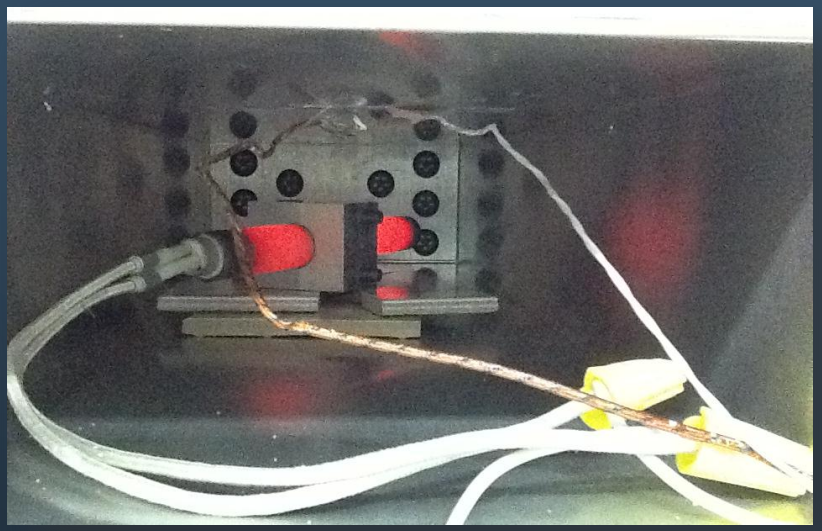
- Heat transfer
  - Using series circuit to model heat transfer, *q*, through walls.
  - Conduction and convection heat flow from battery to water.
- ANSYS Thermal Simulation
  - Identified hotspots





Thermal Tests

- Thermal Testing
  - 300 W heating element
  - 20 Minutes
  - 180 °C
    - In air



Questions

Electrical Challenges

Ijeoma Ezeonyebuchi

Breanna E. McElroy

Neal Sacks

Adam Vadala-Roth

Problem Statement

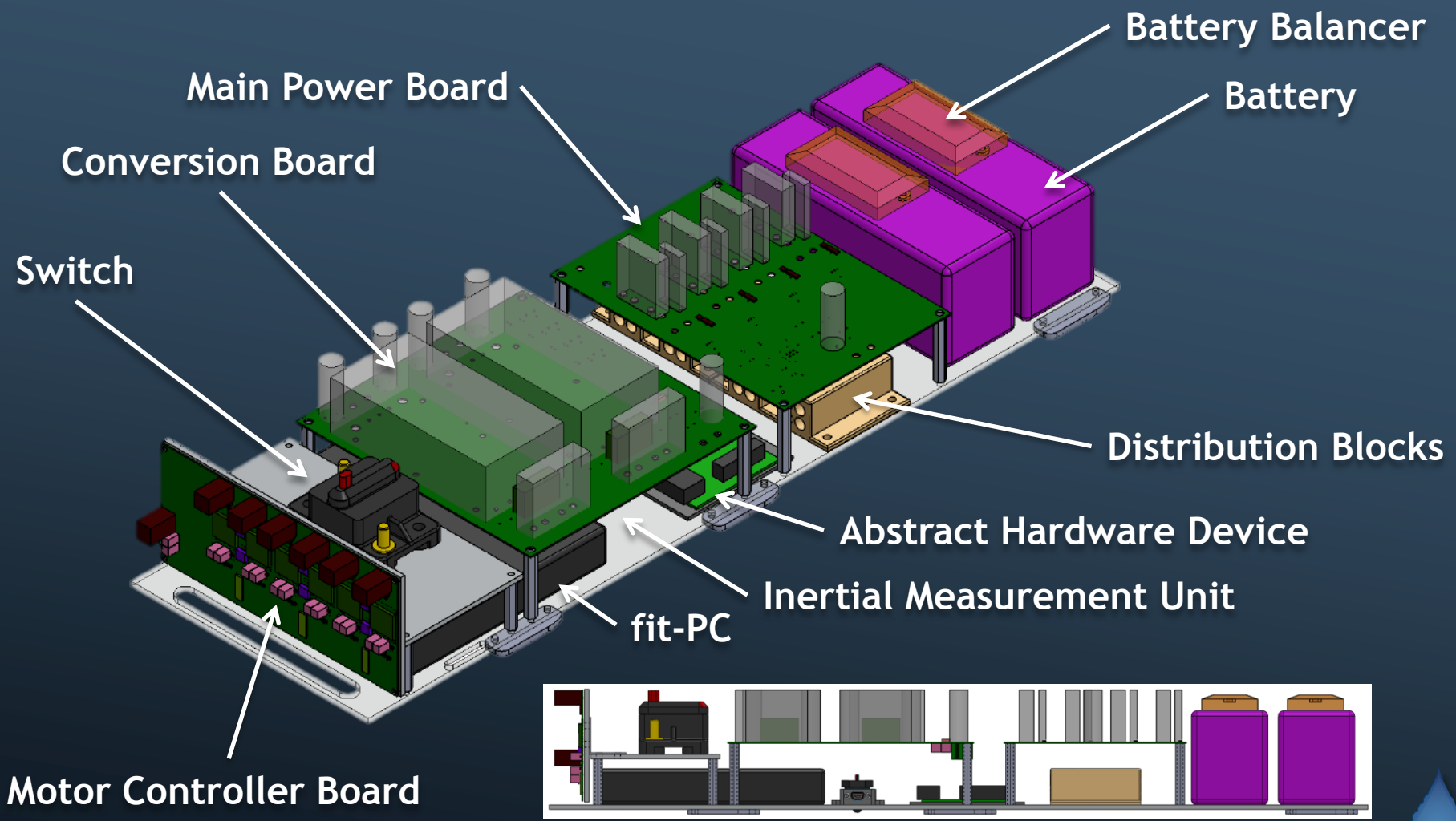
To provide WAVE with a modular, electrical infrastructure that will distribute power throughout the system, provide a standardized embedded computing platform for control, drive the platform, and gather sensor information.

Objectives

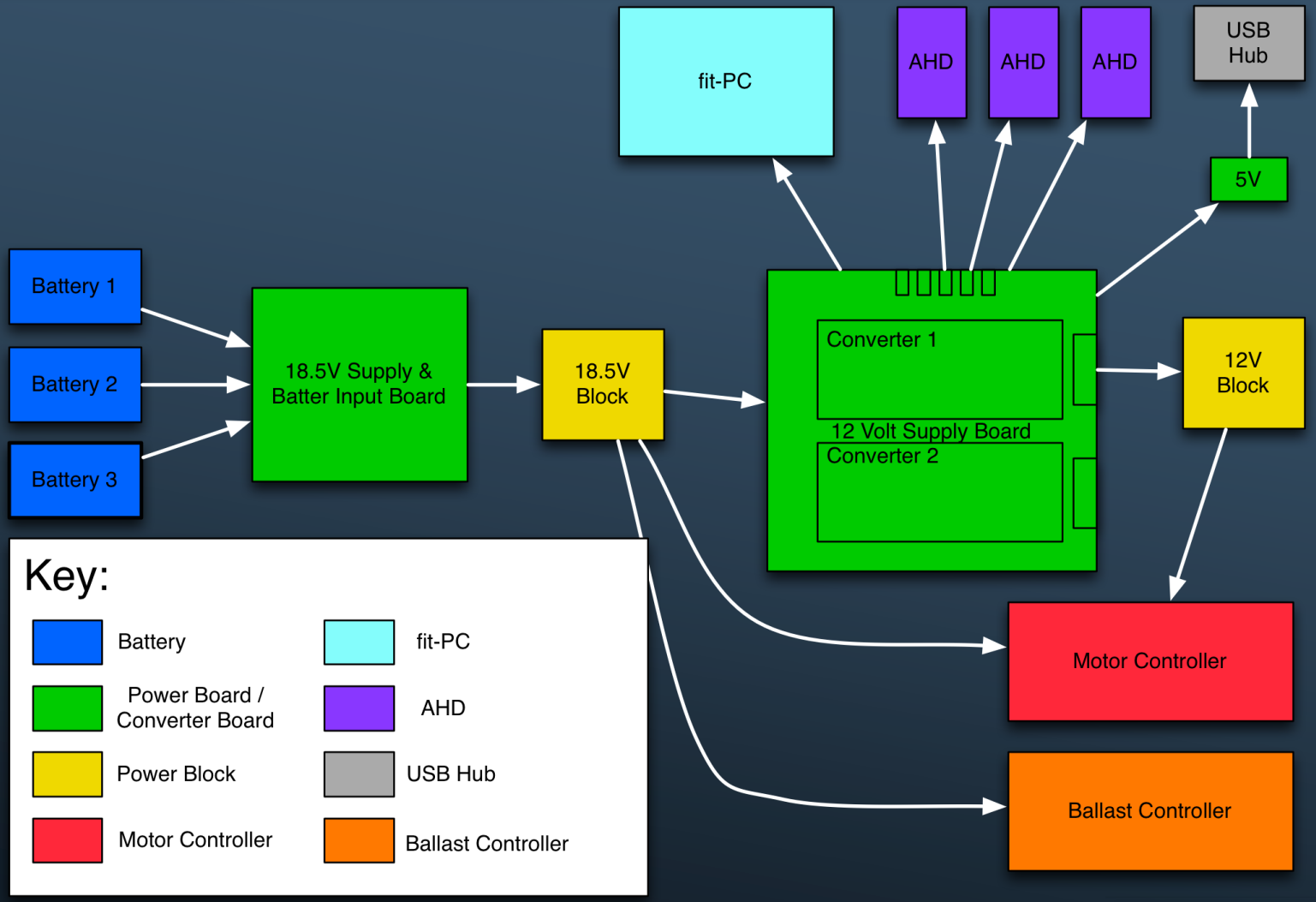
Modular Infrastructure Consisting of:

- Power Distribution
- Standardized Embedded Computing Platform
- Sensing
- Control of actuators for locomotion and additional accessory modules.

Overview


Battery Balancer
Battery
Main Power Board
Conversion Board
Switch
Distribution Blocks
Abstract Hardware Device
Inertial Measurement Unit
fit-PC
Motor Controller Board

Power Distribution Diagram



Worst-Case Current Analysis

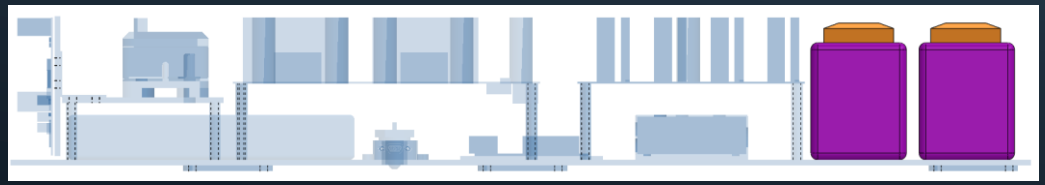
Components	Max Current Draw (Amps)
4 Bilge Motor	24
2 Seabotix Motors	11.6
6 AHDs	6
2 Ballast Motors	5
USB Hub	4.9
fit-PC	1.5

Worst-Case Current Draw
53A

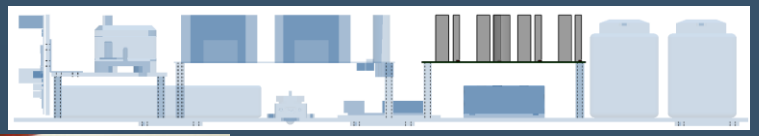
Worst-Case Runtime

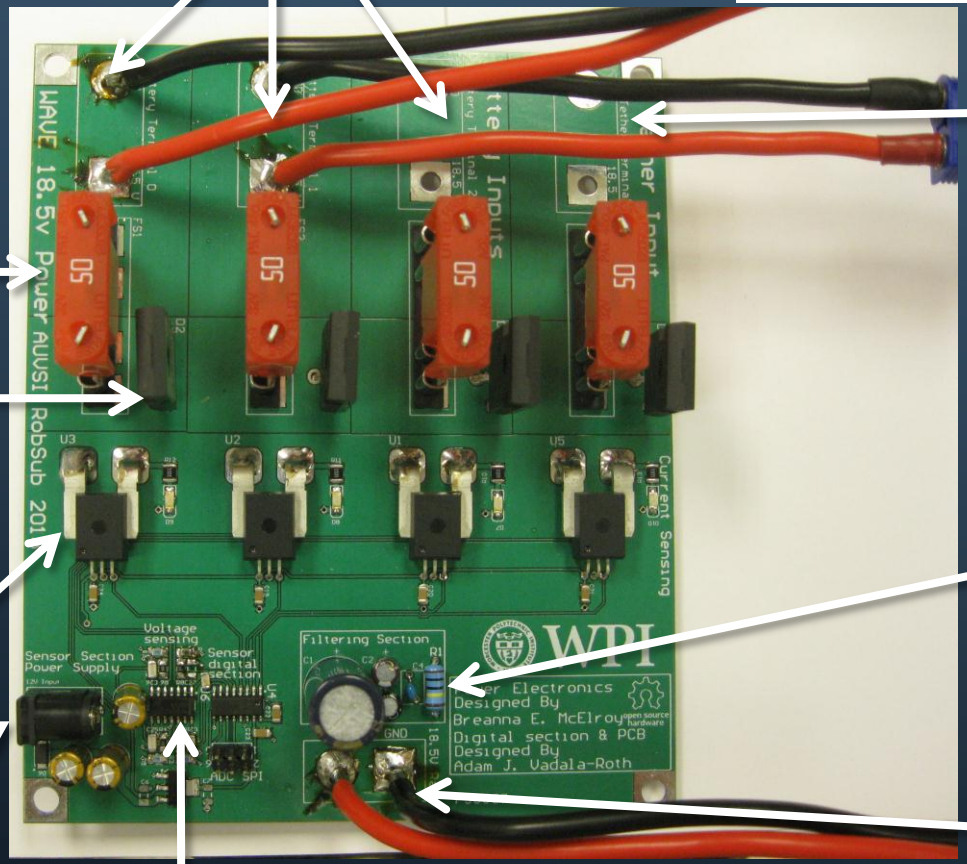
- Need High Capacity Battery
- Must meet maximum current requirements

(Capacity of Battery / Current Draw) *Capacity Discharge	Worst Case Run Time for 2 Batteries
(10Ah / 53A) * 0.7	16 Min



Main Power Board





Battery Inputs

Tether Input

Fuse

Schottky Diode

Current Sensing

Filtering Capacitors

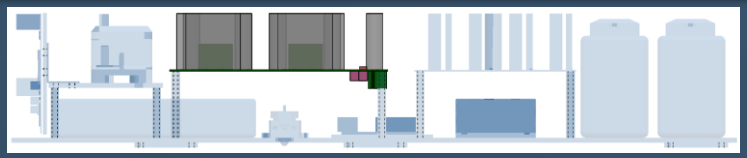
18.5V (nom) Output

12V Supply Input

Voltage Sensing

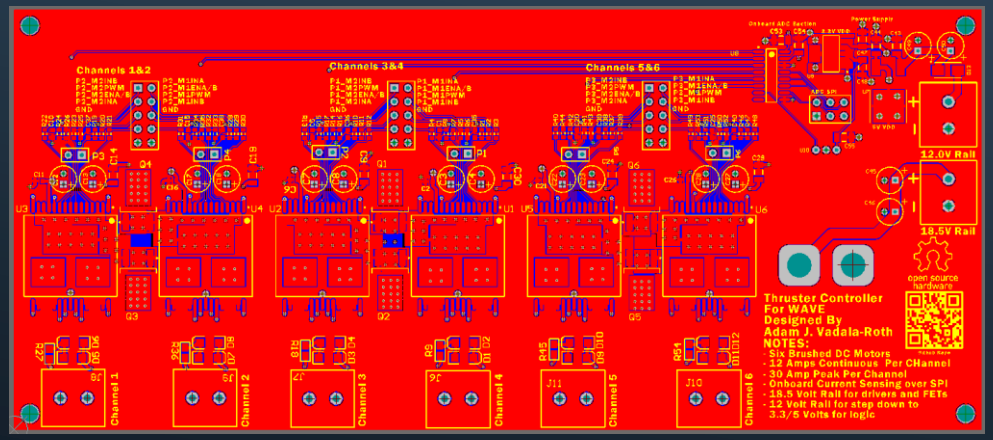
WAVE

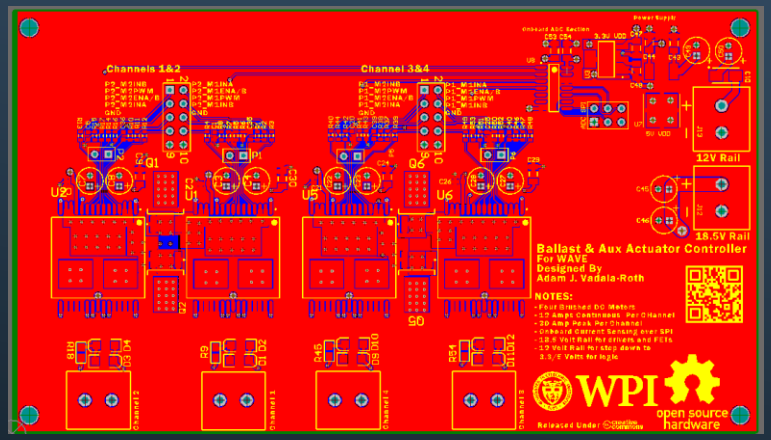
Conversion Board



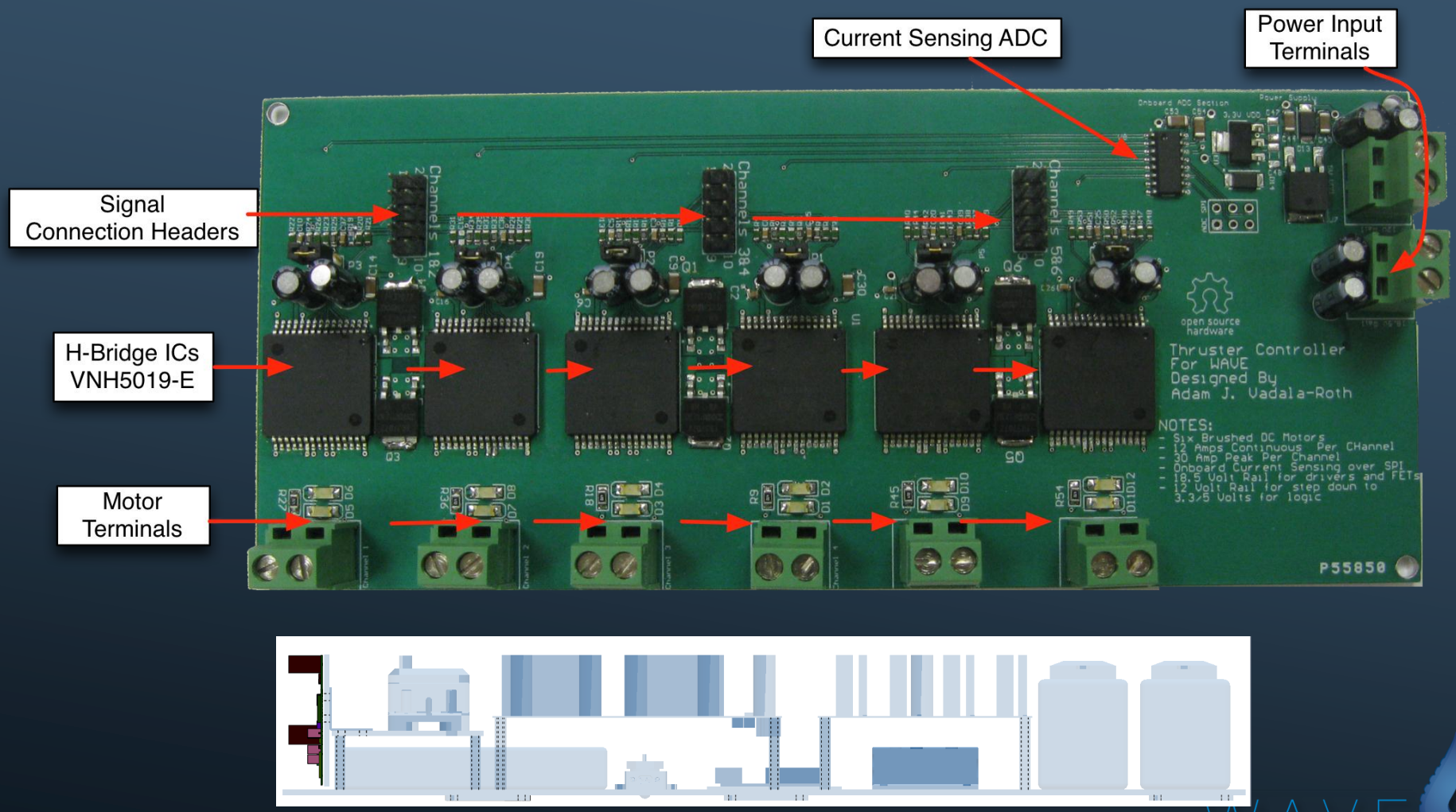
Thruster and Ballast Controllers

Driver IC	ST Microelectronics VNH5019-E
Motor Type	Brushed DC Motors
Current Draw Per Channel	12 Amps Continuous
Current Peak Per Channel	30 Amps
Features	Current sensing on each channel over SPI
	5v and 3.3v logic level compatible





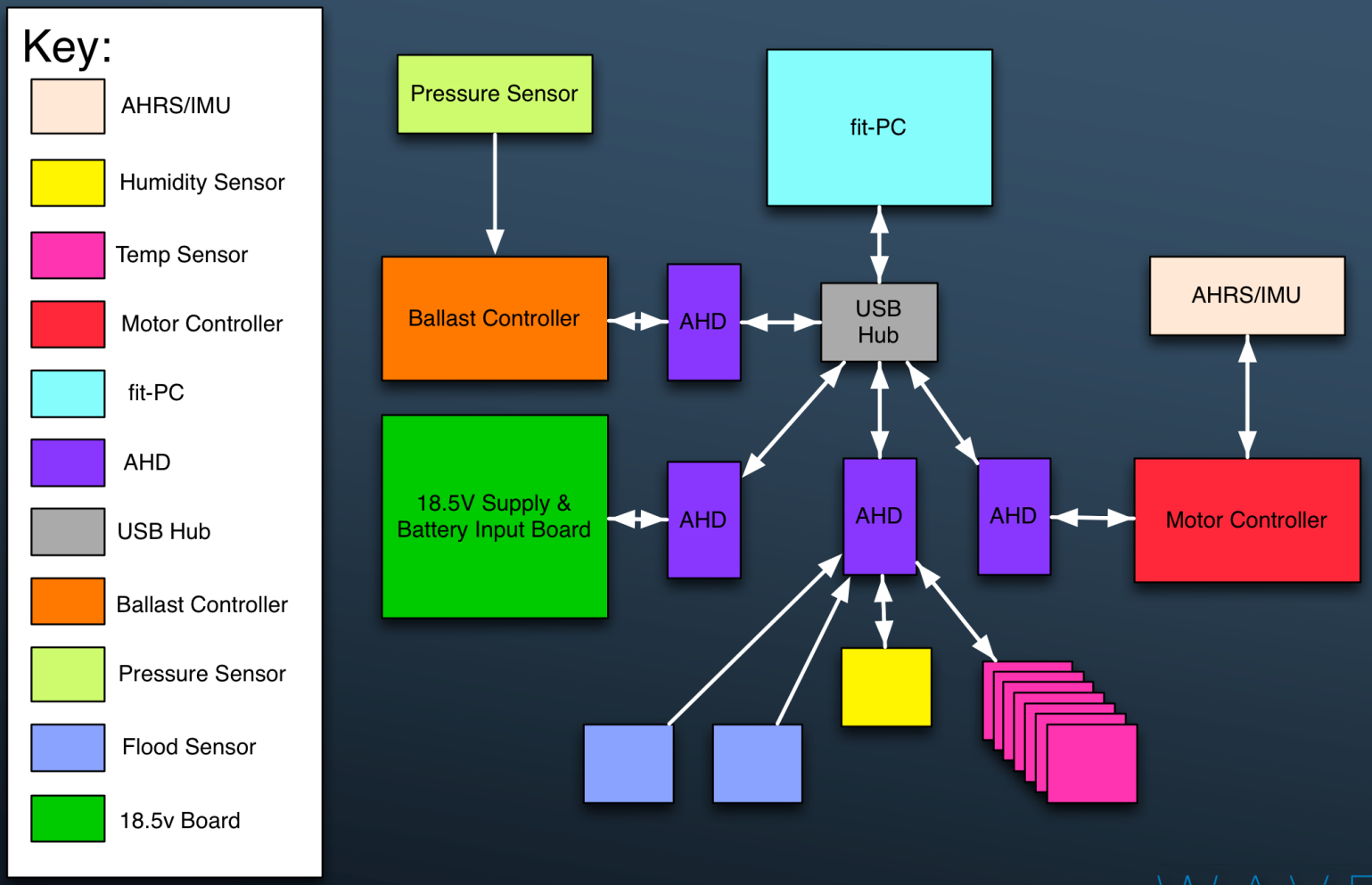
Closer Look at Thruster Board



Modular Electrical Infrastructure

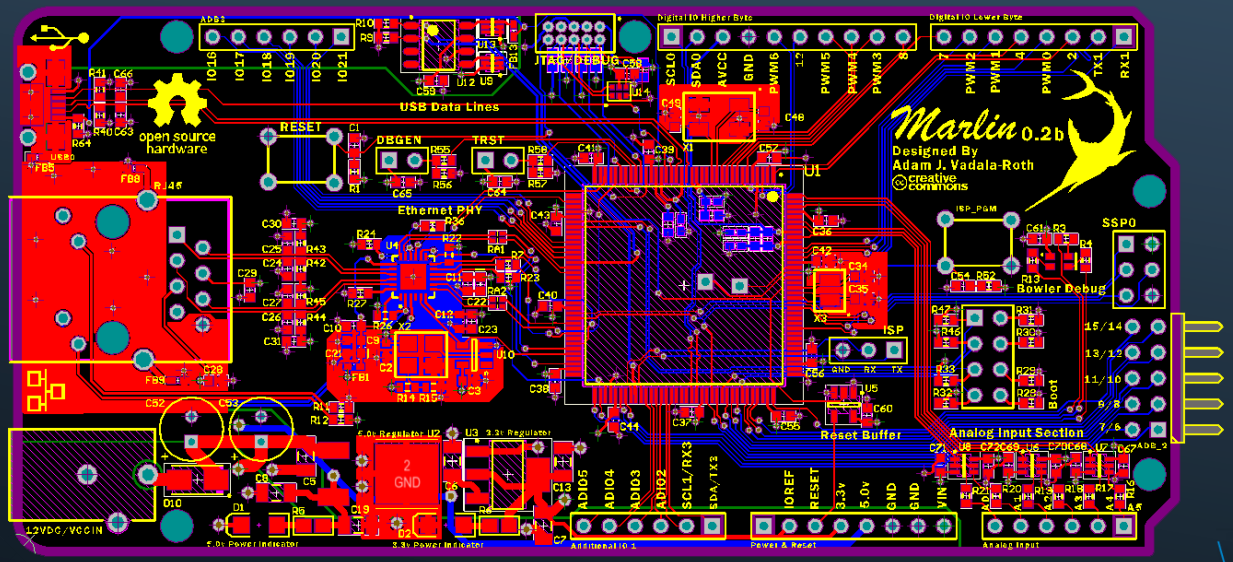
- Electrical Infrastructure is the core of WAVE's modularity.
- Based around individual abstract modules - Abstract Hardware Devices (AHDs).
- Parallel distributive computing platform
  - Highly scalable
  - Easy to use platform for module development and implementation.

Communication Diagram

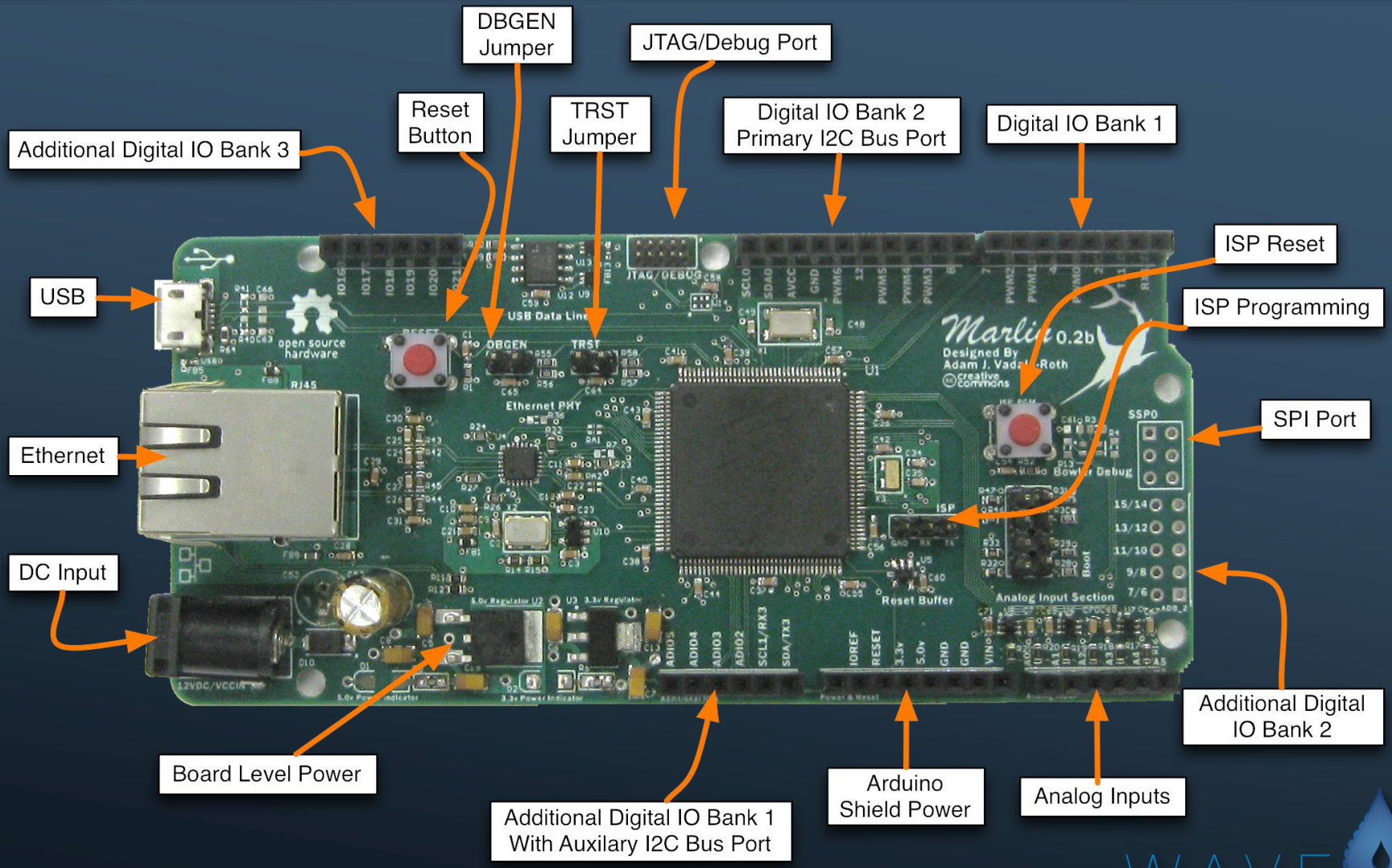


Abstract Hardware Device

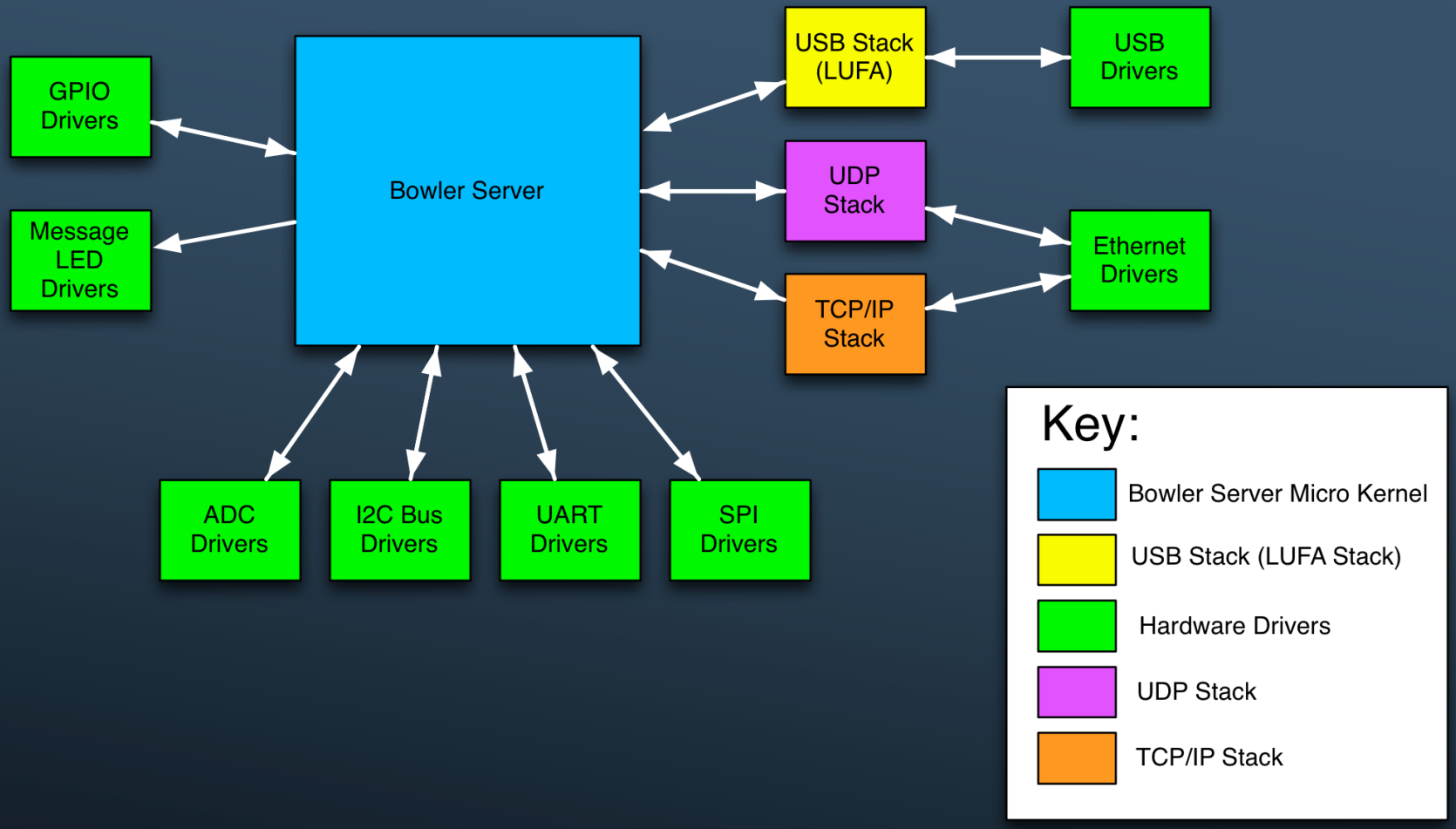
Processor	ARM Cortex M4 (Dual Core)
Connectivity	USB & Ethernet
Communication Protocol	Bowler (Neuron Robotics)
High Level Controller	Java (NR-SDK) on separate Linux PC
Features	Multi Channel PID
	Arduino Shield Compatible



Closer Look at AHD



AHD Software Structure

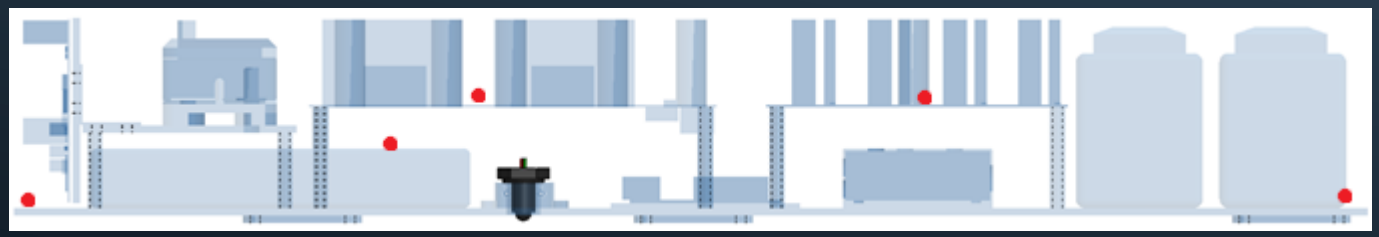


Embedded Software

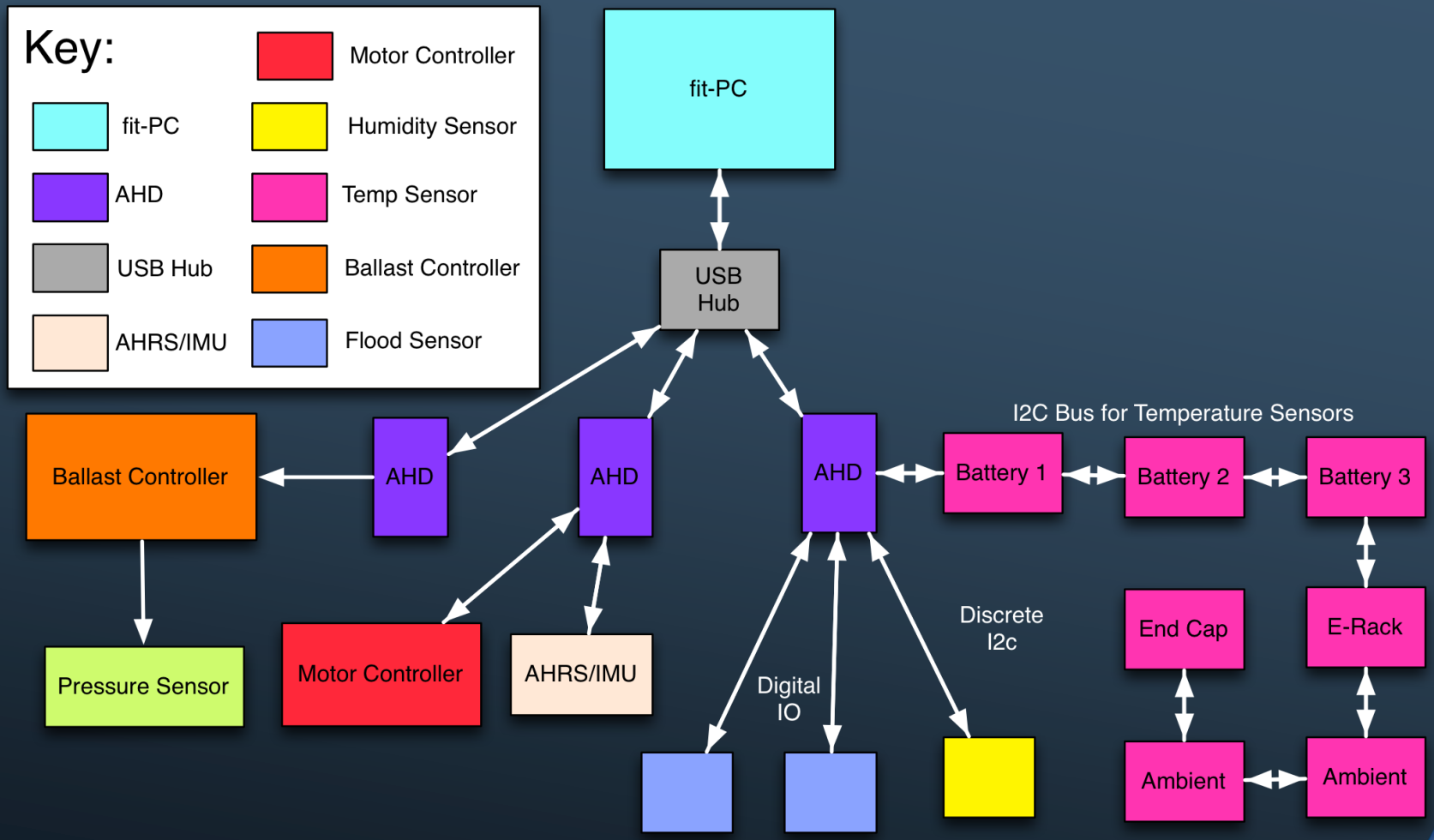
- C Language
- ARM CMSIS Library from NXP
- Bowler Communication System
- JTAG Program/Debug
- NXPUSBLib
- Communication
  - USB
  - Ethernet
  - TCP/IP Stack

Sensor Capabilities

- AHRS/IMU
- Temperature
- Ambient Humidity
- Depth
- Water Leakage



Sensor System Hierarchy



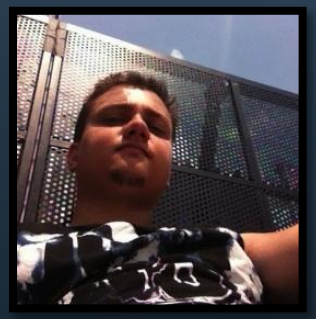
Questions

WPI

SOFTWARE Challenges

Daniel Miller, Eddie Osowski, Angel Trifonov





WAVE

Problem Statement

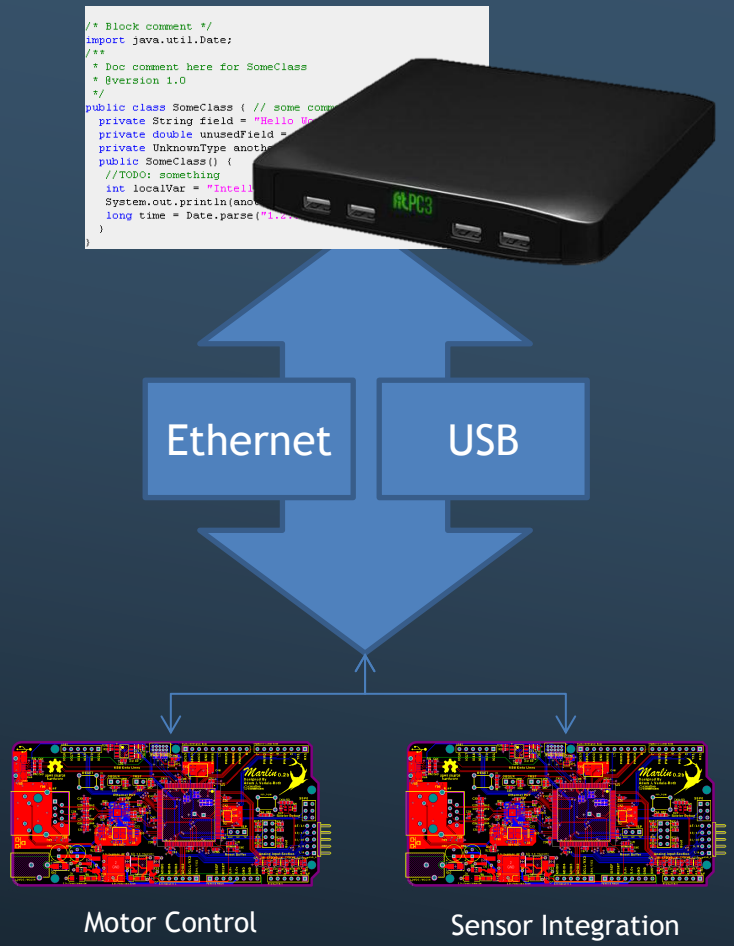
The WAVE requires a modular software system to complement its modular hardware, including a communications framework, simply configurable tasks and behavior, and a poolside robot monitor.

Computational Requirements

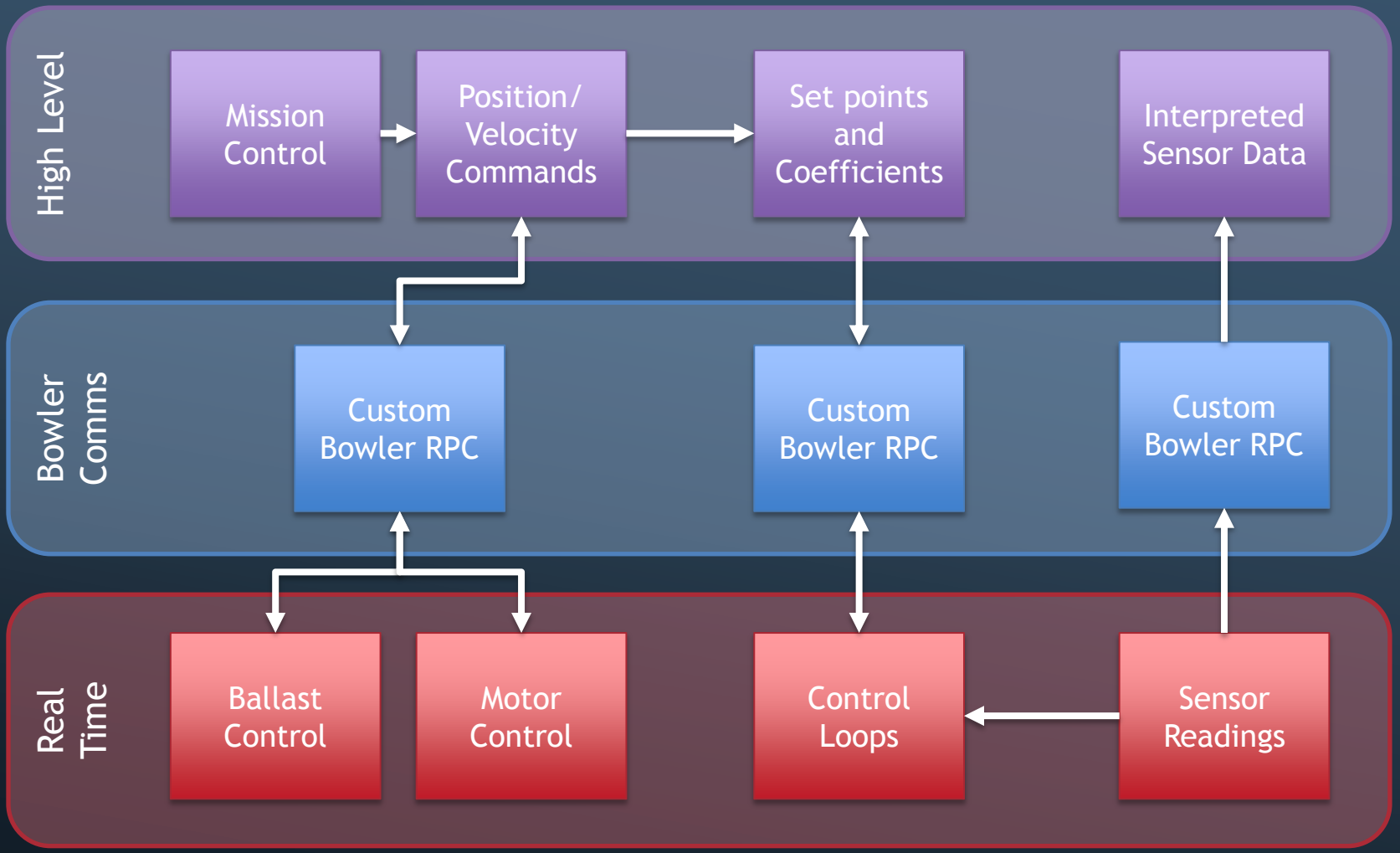
- Distributed Processing
  - Communication with AHDs
  - Custom Remote Procedure Calls (RPCs)
- Fully autonomous operation
  - Customizable Mission Planning
  - Centralized Log system
- Multi-Client Poolside User Interface
  - Monitor robot status
  - Sensor data visualization
  - Safety Controls

Distributed Processing

- Mission Control software
  - fit-PC 3
  - Java
  - Neuron Robotics SDK
- AHD Communications
  - USB (Standard)
  - Ethernet (High Bandwidth)
- Embedded Software
  - RPC Controlled



Communication with AHDs



Remote Procedure Calls

- Custom RPC List:
  - MOTV – Direct Motor Speed Control
  - ESTP – Emergency Stop
  - TWST – 6 DOF Velocity
  - BATT – Battery Voltage and Temperature

Robosub- RPC # 0001

3/27/2013

Battery RPC and Datagram definition — *Daniel Miller*

Packet Format:

Request sent to the AHD will be of the following format:

```
[2012/1/30 21:57:55:993]  Debug : TX>>
       Raw Packet:     03 74 f7 26 00 00 00 10 00 05 a9 62 61 74 74
       Revision:       3
       Device ID:      74:F7:26:xx:xx:xx
       Packet Type:    GET
       Direction:      (0) Synchronous
       Reserved:       0
       Data Size:      4
       Checksum:       169
       RPC:            batt
       Data:           62 61 74 74
```

The response generated by the AHD will be of the following format:

```
[2012/1/30 21:57:55:993]  Debug : TX>>
       Raw Packet:     03 74 f7 26 00 00 00 10 00 05 a9 62 61 74 74 XX XX. . .
       Revision:       3
       Device ID:      74:F7:26:xx:xx:xx
       Packet Type:    POST
       Direction:      (0) Synchronous
       Reserved:       0
       Data Size:      n
       Checksum:       169
       RPC:            batt
       Data:           62 61 74 74 XX XX XX XX XX . . .
```

Autonomous Operation

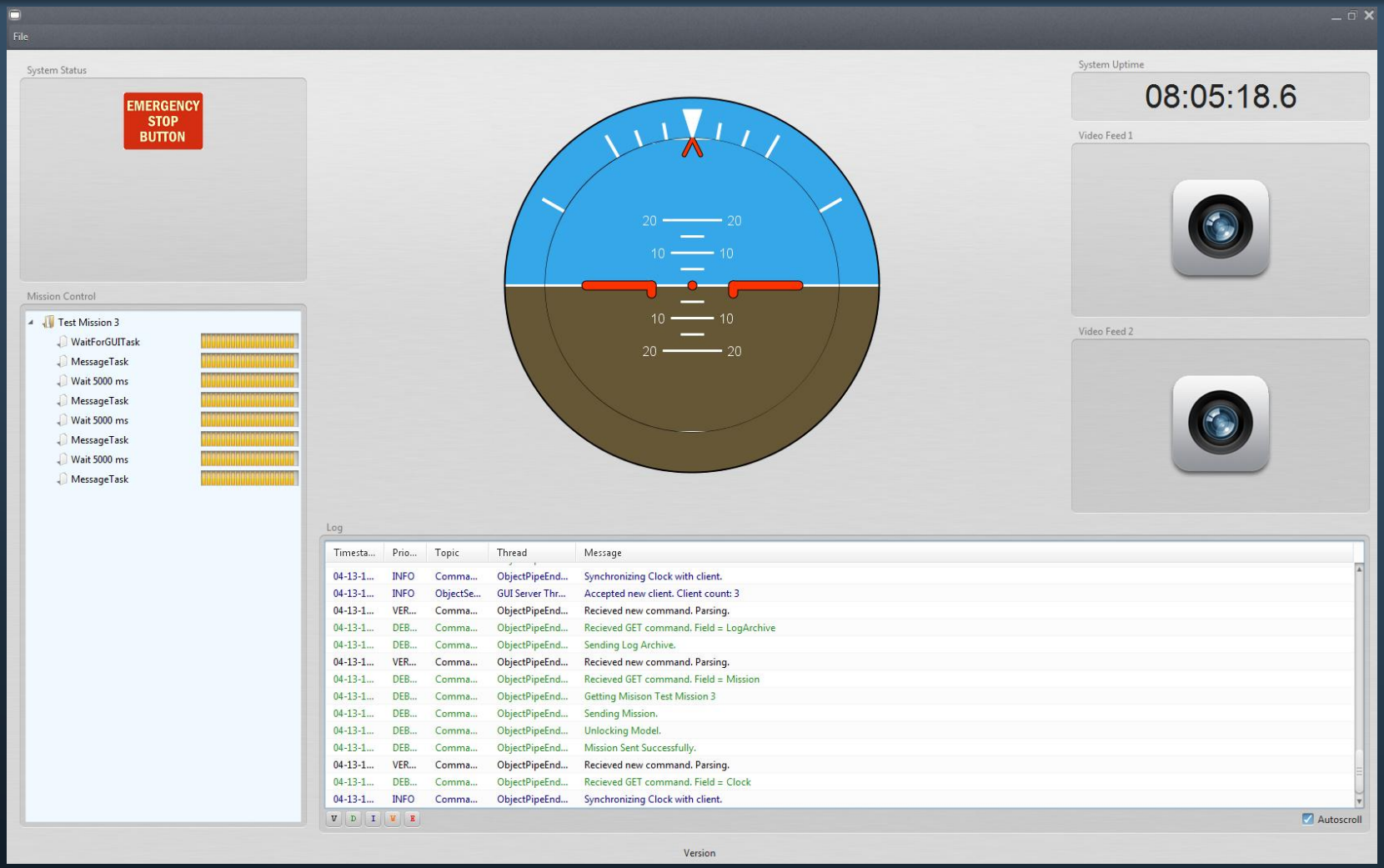
- WAVE does not require any user input after startup
- Gets all necessary info from provided txt and xml files
  - Properties File - Plaintext
  - Devices File - Plaintext
  - Mission File – XML
- Parses these to get mission parameters and device info

Mission Execution

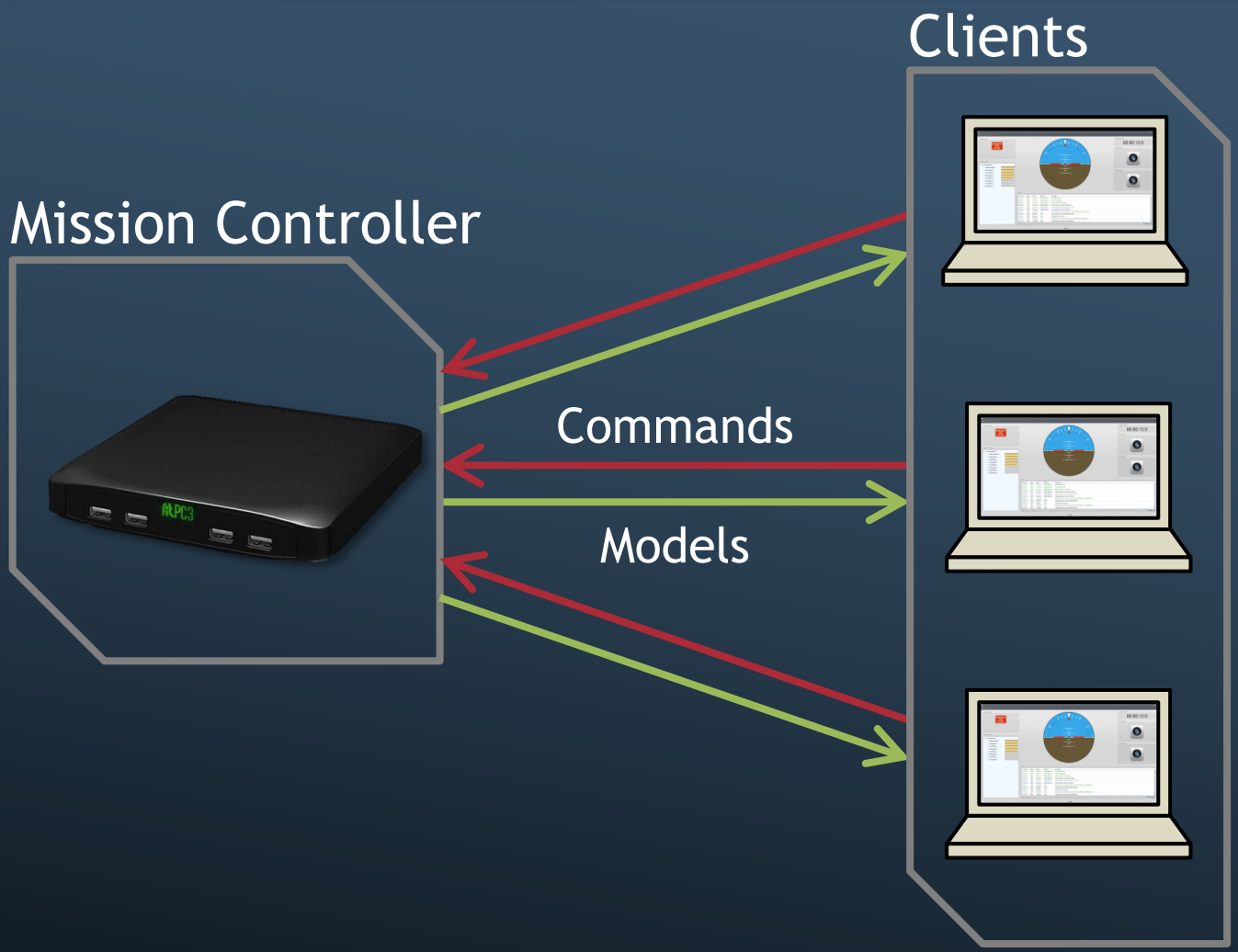
- Customizable XML files
- Used to create list of tasks
  - Synchronous
  - Asynchronous
- Tasks include:
  - Asynchronous sensor polling
  - Navigation and attitude set-points
  - Emergency situation response

```
<?xml version="1.0" encoding="UTF-8"?>
<Mission name="DriveTest">

     <Task type="Echo"
          message="Waiting for
monitor."/>

     <Task type="WaitForGUI"/>

     <Task type="PollAHRS">
          <Period>50</Period>
     </Task>

     <Task type="DriveToRelativePos">
          <X>0.0</X>
          <Y>150.0</Y>
          <Z>0.0</Z>
          <Speed>140</Speed>
     </Task>
</Mission>
```

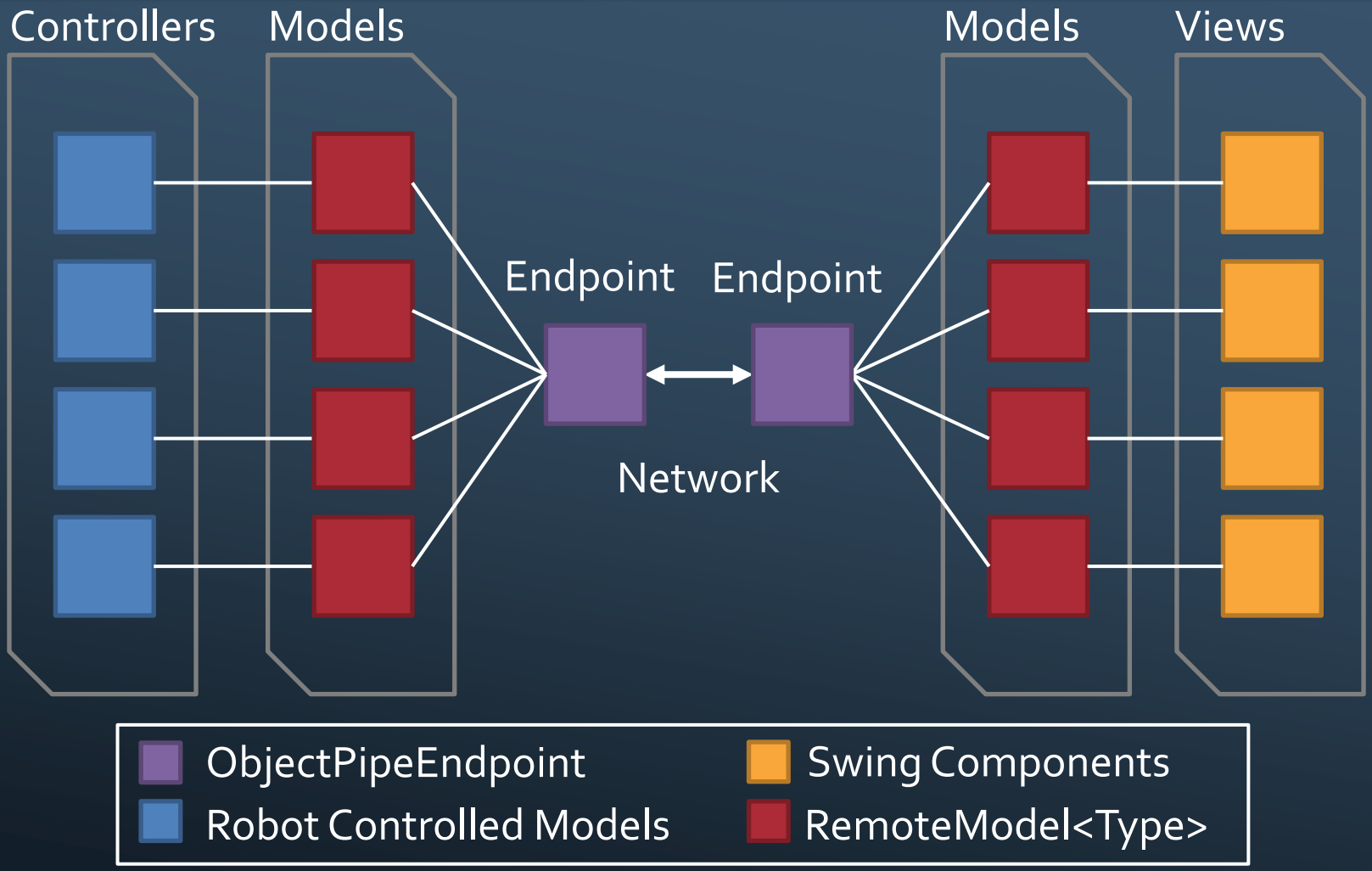
Poolside UI


File
System Status
EMERGENCY STOP BUTTON
Mission Control
Test Mission 3
WaitForGUITask
MessageTask
Wait 5000 ms
MessageTask
Wait 5000 ms
MessageTask
Wait 5000 ms
MessageTask
20 20
10 10
10 10
20 20
System Uptime
08:05:18.6
Video Feed 1
Video Feed 2
Log
Timesta... Prio... Topic Thread Message
04-13-1... INFO Comma... ObjectPipeEnd... Synchronizing Clock with client.
04-13-1... INFO ObjectSe... GUI Server Thr... Accepted new client. Client count: 3
04-13-1... VER... Comma... ObjectPipeEnd... Recieved new command. Parsing.
04-13-1... DEB... Comma... ObjectPipeEnd... Recieved GET command. Field = LogArchive
04-13-1... DEB... Comma... ObjectPipeEnd... Sending Log Archive.
04-13-1... VER... Comma... ObjectPipeEnd... Recieved new command. Parsing.
04-13-1... DEB... Comma... ObjectPipeEnd... Recieved GET command. Field = Mission
04-13-1... DEB... Comma... ObjectPipeEnd... Getting Misison Test Mission 3
04-13-1... DEB... Comma... ObjectPipeEnd... Sending Mission.
04-13-1... DEB... Comma... ObjectPipeEnd... Unlocking Model.
04-13-1... DEB... Comma... ObjectPipeEnd... Mission Sent Successfully.
04-13-1... VER... Comma... ObjectPipeEnd... Recieved new command. Parsing.
04-13-1... DEB... Comma... ObjectPipeEnd... Recieved GET command. Field = Clock
04-13-1... INFO Comma... ObjectPipeEnd... Synchronizing Clock with client.
V D I W E
Autoscroll
Version

Handling Multiple Clients



Communicating with the WAVE



Questions

Summary

MECHANICAL

Hydrodynamics

Thrusters

Electronics Housing

ELECTRICAL

Power Distribution

AHDs

Sensors

SOFTWARE

Distributed Processing

Autonomous Missions

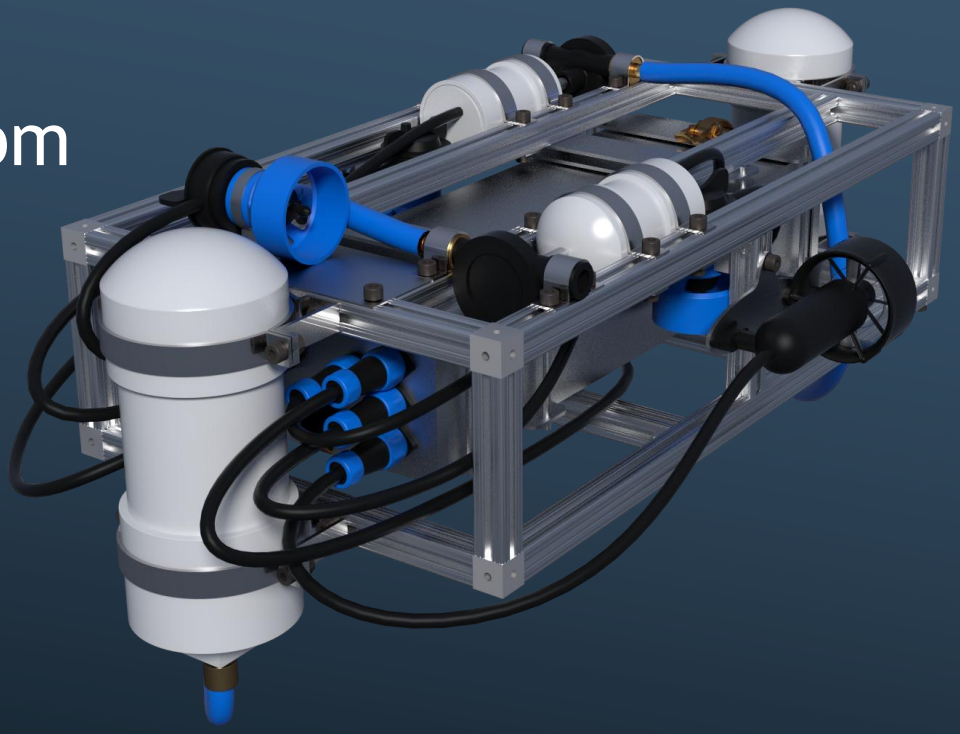
Poolside UI

Future Expansion

- Opens new project possibilities for WPI
  - AUV competitions
  - Biomimetic propulsion and ballast systems
  - Control surface design and analysis
  - Underwater
    - Communications
    - Localization and mapping
    - Manipulators

Conclusion

- Extensible AUV Platform
  - 6 Degrees of Freedom
  - Extendable Electronics
  - Easily configurable behavior
  - Remote monitoring



Acknowledgements

Thank you to:

- Kevin Harrington
- Alex Camilo
- Greg Overton
- David Ephraim
- Ennio Claretti
- Erik Scott
- NEST
- Neuron Robotics
- osPID
- Rascal Micro
- Our Advisors

Sponsors


Pololu
Robotics & Electronics


AMD


IDS


Allegro
MicroSystems, LLC
High-Performance Semiconductors


Gens ace


ADVANCED
CIRCUITS
Leading the PCB Industry in Quality & Innovation


ARM


NXP


VICOR
The Power Behind Performance


WAVE

Final Questions

And Video

WPI

Thank you!

WAVE