Open Wave-Energy Control System Development Platform

FOA/Topic

Marine Energy Foundational Research and Testing Infrastructure (DE-FOA-0002234)
Topic Area 1 (Foundational Research and Development)

Team Member Organizations

Monterey Bay Aquarium Research Institute
Open Robotics

Technical Points of Contact

Andrew Hamilton, Ph.D.
Monterey Bay Aquarium Research Institute

Tully Foote, Community & Business Development Manager
Open Robotics

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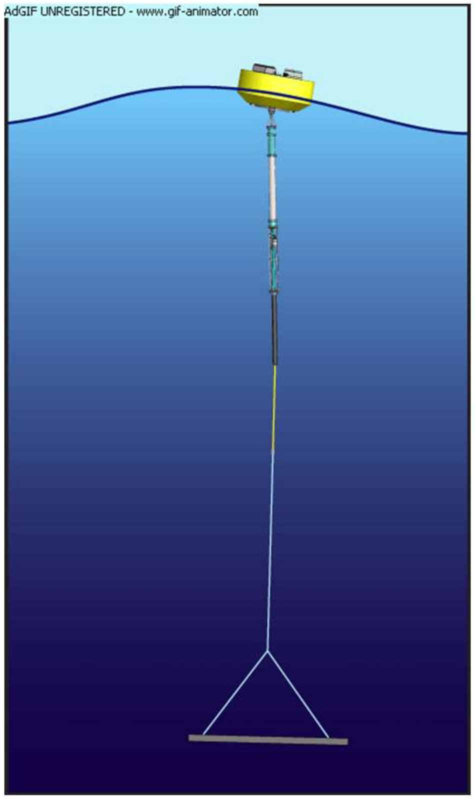

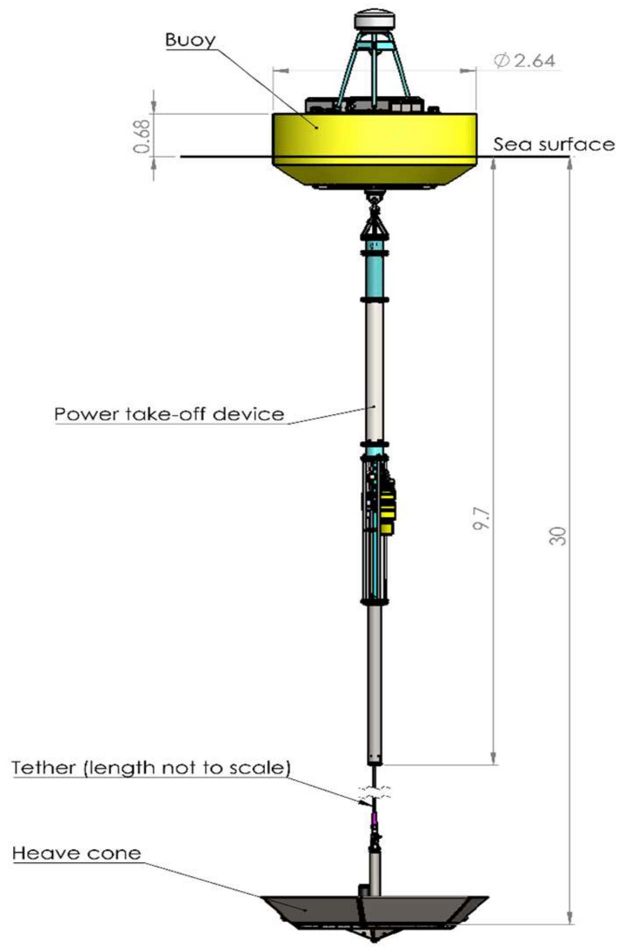

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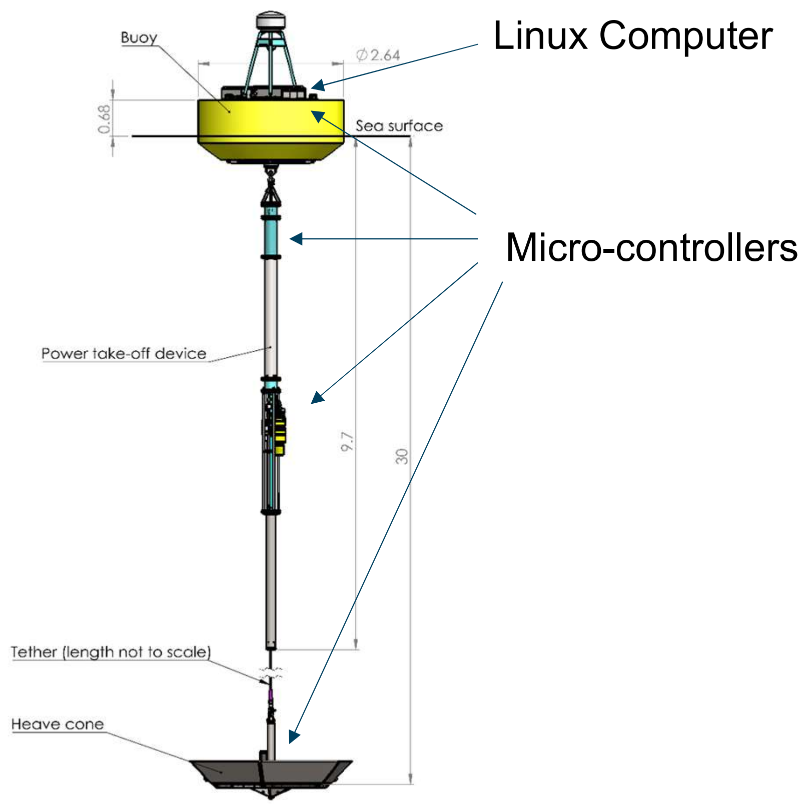
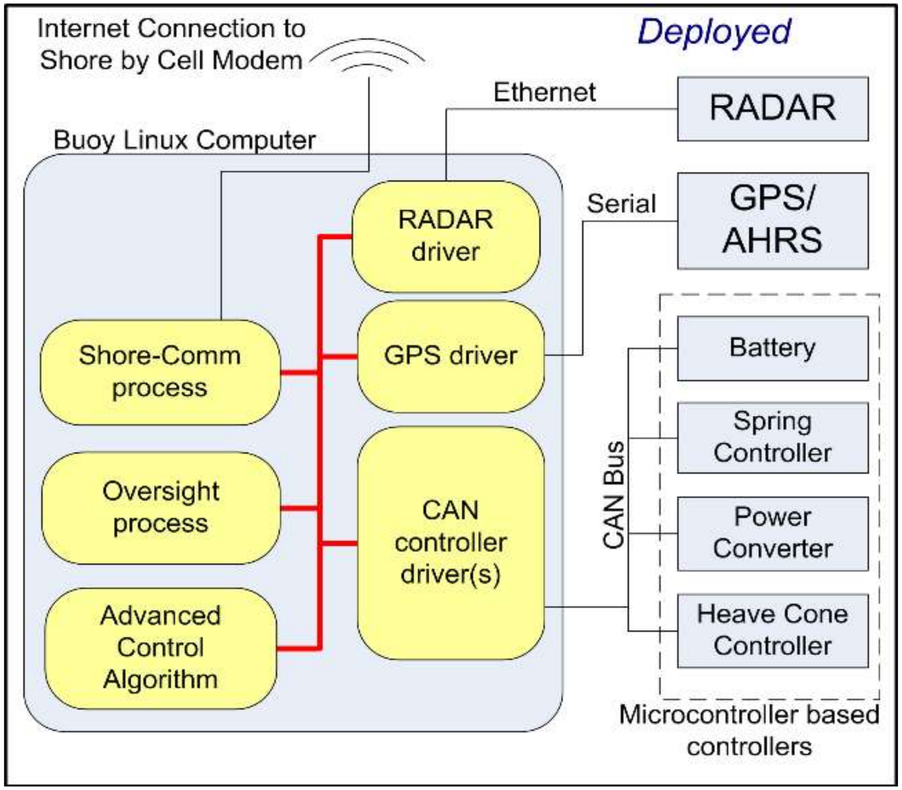
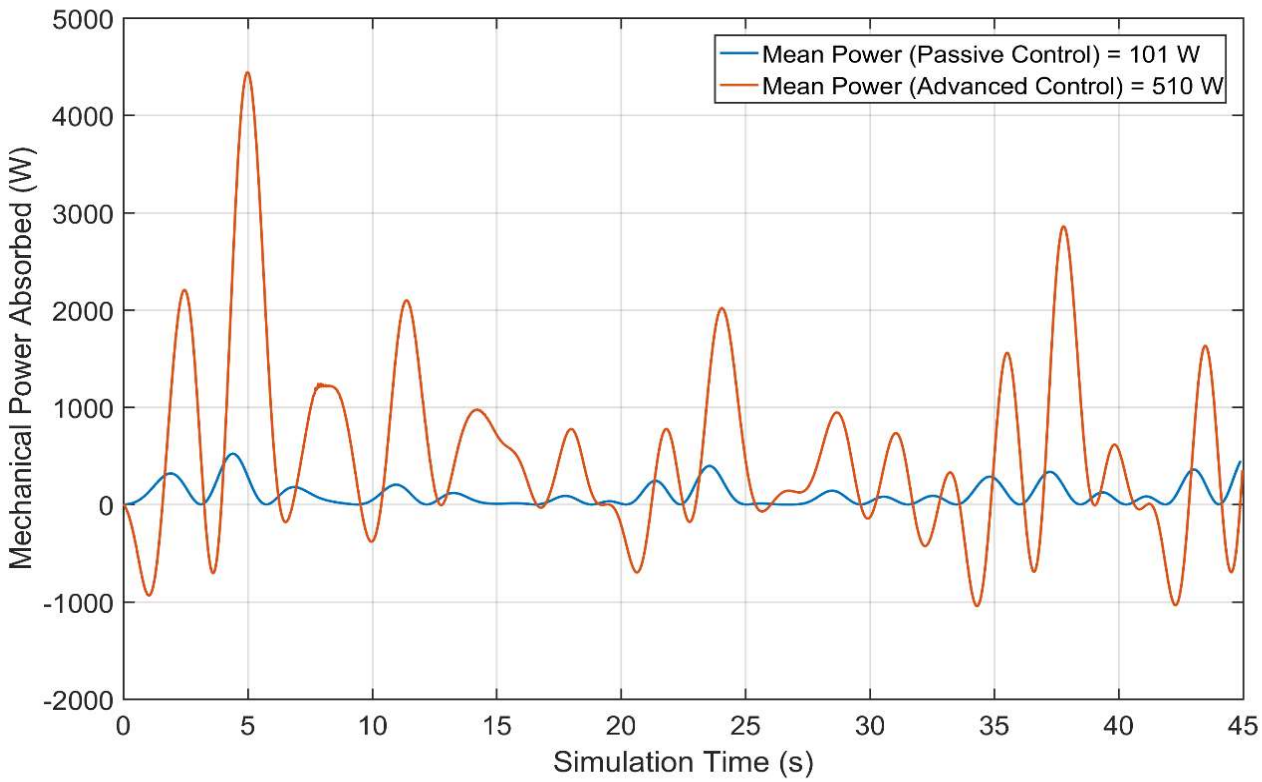
Integrate ROS2 into our existing Wave-Energy Buoy





Advanced Controls



Components of our Proposed Project

- Integrate ROS2 into our existing Wave-Energy Buoy

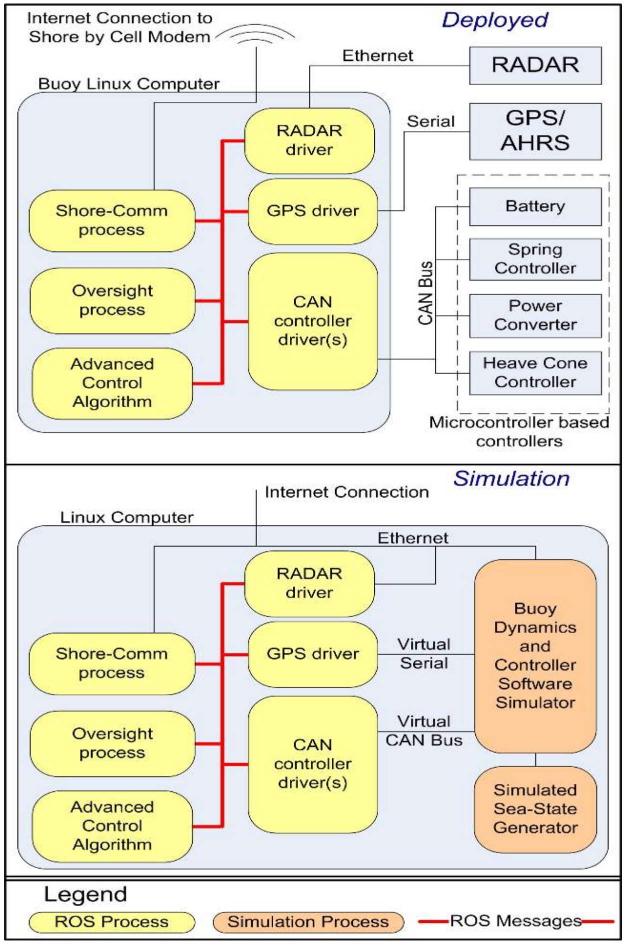
- Create a simulation environment

- Entrain external researchers. Simulation and then at-sea testing.

Entrain external researchers

- Perhaps the most challenging part of this project.
- We have a few initial candidates: Sandia National Labs, Ted Brekken at Oregon State, JHU/APL.   And other candidates…
- Simulation First, then on-buoy operations.
- These researchers may be ROS2 beginners, so we need to make the system approachable. Simplest solutions possible.
- Good tutorials and examples
- Easy access. Docker, Cloud based, etc.
- Active and responsive forum.

Create a simulation environment



Options:

- *Matlab/Simulink/WecSim*
- ***Ignition Gazebo***
- *Other Options*

Decisions:

- *Tools*
- ***Architectural choices***

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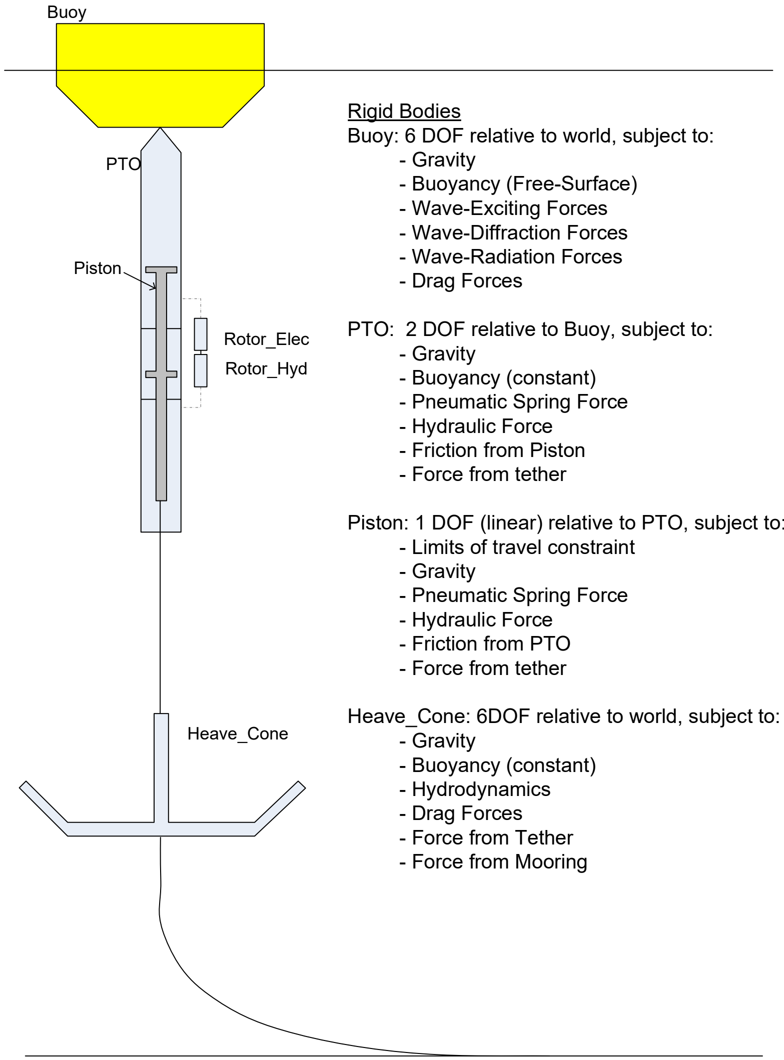


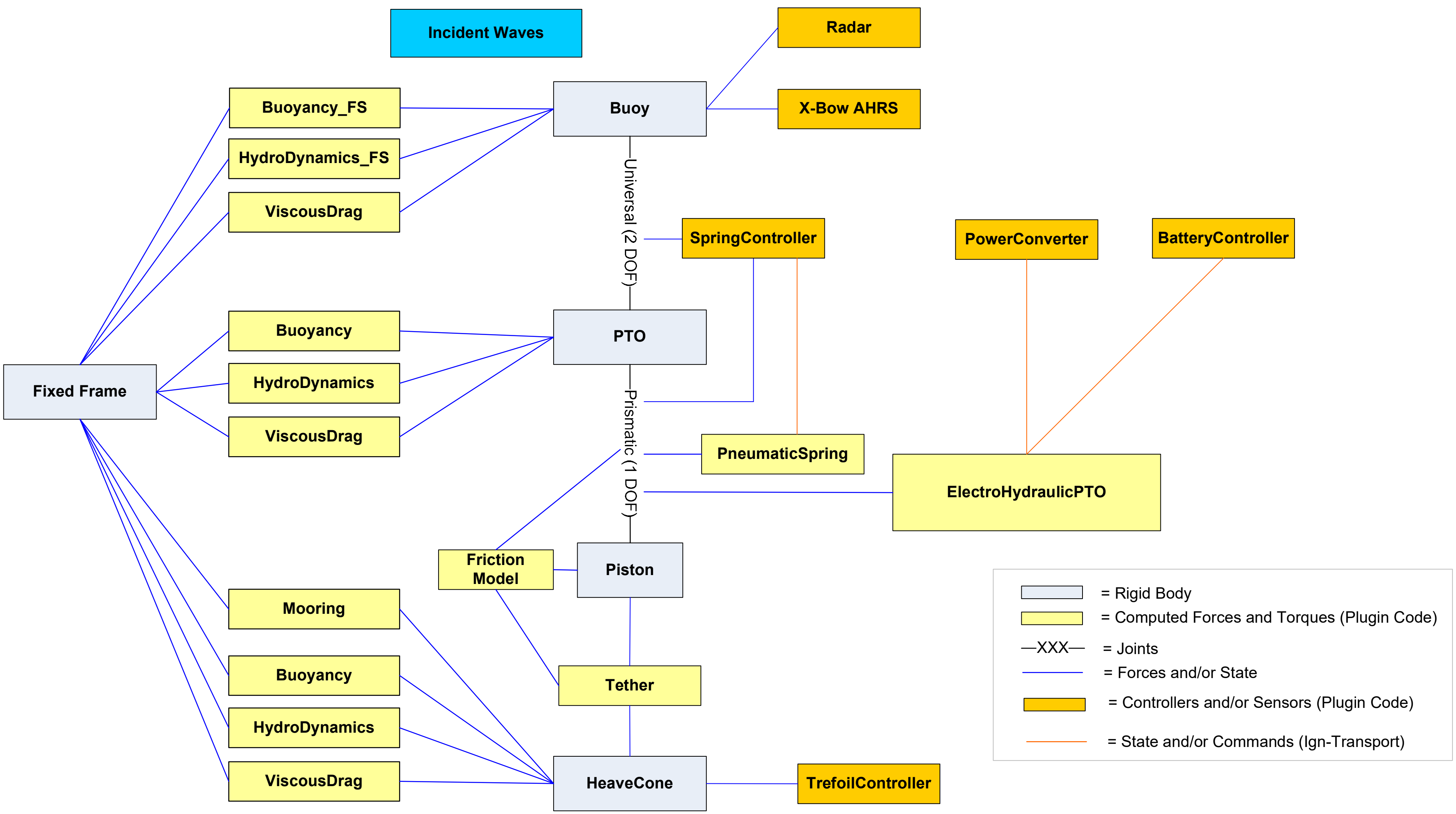
Rigid Bodies

Buoy: 6 DOF relative to world, subject to:
- Gravity
- Buoyancy (Free-Surface)
- Wave-Exciting Forces
- Wave-Diffraction Forces
- Wave-Radiation Forces
- Drag Forces

PTO: 2 DOF relative to Buoy, subject to:
- Gravity
- Buoyancy (constant)
- Pneumatic Spring Force
- Hydraulic Force
- Friction from Piston
- Force from tether

Piston: 1 DOF (linear) relative to PTO, subject to:
- Limits of travel constraint
- Gravity
- Pneumatic Spring Force
- Hydraulic Force
- Friction from PTO
- Force from tether

Heave_Cone: 6DOF relative to world, subject to:
- Gravity
- Buoyancy (constant)
- Hydrodynamics
- Drag Forces
- Force from Tether
- Force from Mooring



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ProtoPneumaticSpring

Invite | Set up build | Clone | ...

Here's where you'll find this repository's source files. To give your users an idea of what they'll find here, add a description to your repository.

master | Files | Filter files

/

Name	Size	Last commit	Message
data		19 hours ago	update images for model
docs		2022-02-12	Initial add and commit
examples		21 hours ago	minor updates; adding mbari_wec.sdf; testing eqn in readme
src		19 hours ago	add test data and plots; add prescribed velocity for debug
.gitignore	624 B	2022-02-12	Initial commit
CMakeLists.txt	379 B	2022-02-12	Initial add and commit
README.md	6.84 KB	16 hours ago	README.md edited online with Bitbucket

README.md

Prototype Pneumatic Spring Plugin for Ignition Gazebo

This plugin implements the Pneumatic Spring as two Nitrogen-filled cylinders above and below the piston head. The cylinders are modeled to follow a Polytropic Process:

$$PV^n = C$$

where P is pressure (Pascal), V is volume (m^3), n is the Polytropic Index, and C is a constant. In the case n==λ (adiabatic index λ=1.4 for diatomic gases such as N_2; special case of polytropic without heat transfer with the environment), the gas cylinders follow an Adiabatic Process.

An initial P_0 and V_0 are chosen and the current V is computed from $V_{dead} + Ax$ where V_{dead} is the dead volume remaining at extent of piston in compression. A is the surface area of the piston head in square meters, and x is the piston position in meters. Given that all pairs of (P_i, V_i^n) are equal (constant C), the current Pressure can be computed from:

$$P = P_0\left(\frac{V_0}{V}\right)^n$$

Temperature is related using Ideal Gas Law:

$$PV = mR_{specific}T$$

where T is temperature (K), m is mass of the gas (kg), $R_{specific}$ is the mass-specific gas constant for N_2 ($J \cdot kg^{-1} \cdot K^{-1}$).

When heat transfer occurs (n!=λ), the rate of heat transfer, $\dot{Q}$ in watts (W), can be computed as:

$$\dot{Q} = \left(1 - \frac{n}{\lambda}\right)\frac{c_p}{R_{specific}}PA\dot{x}$$

where c_p is the specific heat capacity of N_2 under constant pressure, A is the area of the heat transmission surface, and $\dot{x}$ is the velocity of the piston.

Modeling

The value of n for the upper and lower cylinders was determined by fitting P vs V data taken from bench tests by linear regression of the form:

$$\log P = -n\log V + \log C$$

where n is the Polytropic Index. The bench data from the physical system show a hysteresis in both cylinders, so curves were fit to each direction of piston

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ProtoElectroHydraulicPTO

Invite | Set up build | Clone | ...

Here's where you'll find this repository's source files. To give your users an idea of what they'll find here, add a description to your repository.

master | Files | Filter files

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Name	Size	Last commit	Message
build		2 days ago	Edited README.md file and added .gitignore to build directory so this directory ...
docs		2 days ago	Initial commit
examples		2 days ago	Added mbari_wec.sdf to examples directoryw
src		2 days ago	Added ignition transport messages to report ElectroHydraulic PTO state at each ...
tests		2 days ago	Edited README.md file and added .gitignore to build directory so this directory ...
.gitignore	624 B	2 days ago	Initial commit
CMakeLists.txt	415 B	2 days ago	Initial commit
README.md	5.9 KB	2 days ago	Fixed typos in README.md

README.md

Prototype ElectroHydraulic Power TakeOff Plugin for Ignition Gazebo

This plugin implements a quasitatic model of the MBARI WEC electrohydraulic power takeoff device. The parts of this device modelled here includes the hydraulic piston, hydraulic motor, electrical motor/generator, electrical load dump and battery.

This plugin responds to two main inputs, the hydraulic piston velocity, and an electrical motor winding current specification. With these two inputs, the plugin computes the resulting hydraulic oil pressures which provide a force result that is applied to the hydraulic piston prismatic joint. To do this, the plugin also computes the hyraulic rotor RPM that will result frome the specified piston velocity and applied torque from the motor. This torque is computed from the specified electrical motor winding torque. As in the real system, by default this is a function of the rotor RPM, but can be over-ridden by a user specified value. This feature is mimic'd in the plugin, by sending an ignition transport message with a value between -35A and 35A, the plugin will apply that torque for up to two seconds before reverting to the default current versus RPM relationship. In all cases, the effects of the measured volumetric and mechanical efficiency of the hydraulic motor, and the measured electrical efficiency of the electric motor and battery system are included.

Building

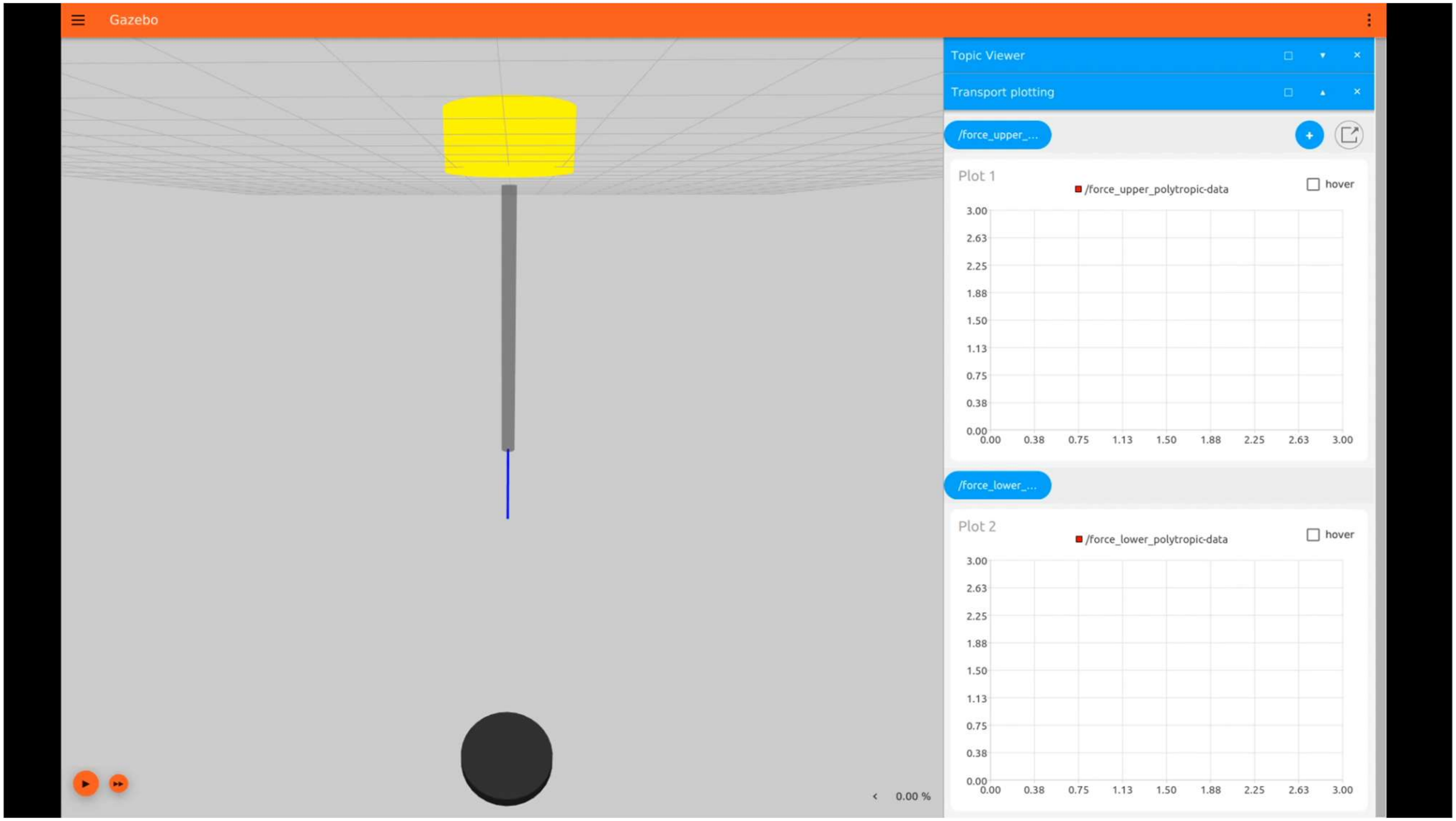
Instructions for building this are below, the "make install" step copies the plugin .so file to ~/.ignition/gazebo/plugins where it can be found by ign gazebo when listed as a plugin in a .sdf file.

From the top level directory, do the following to build the software and install:

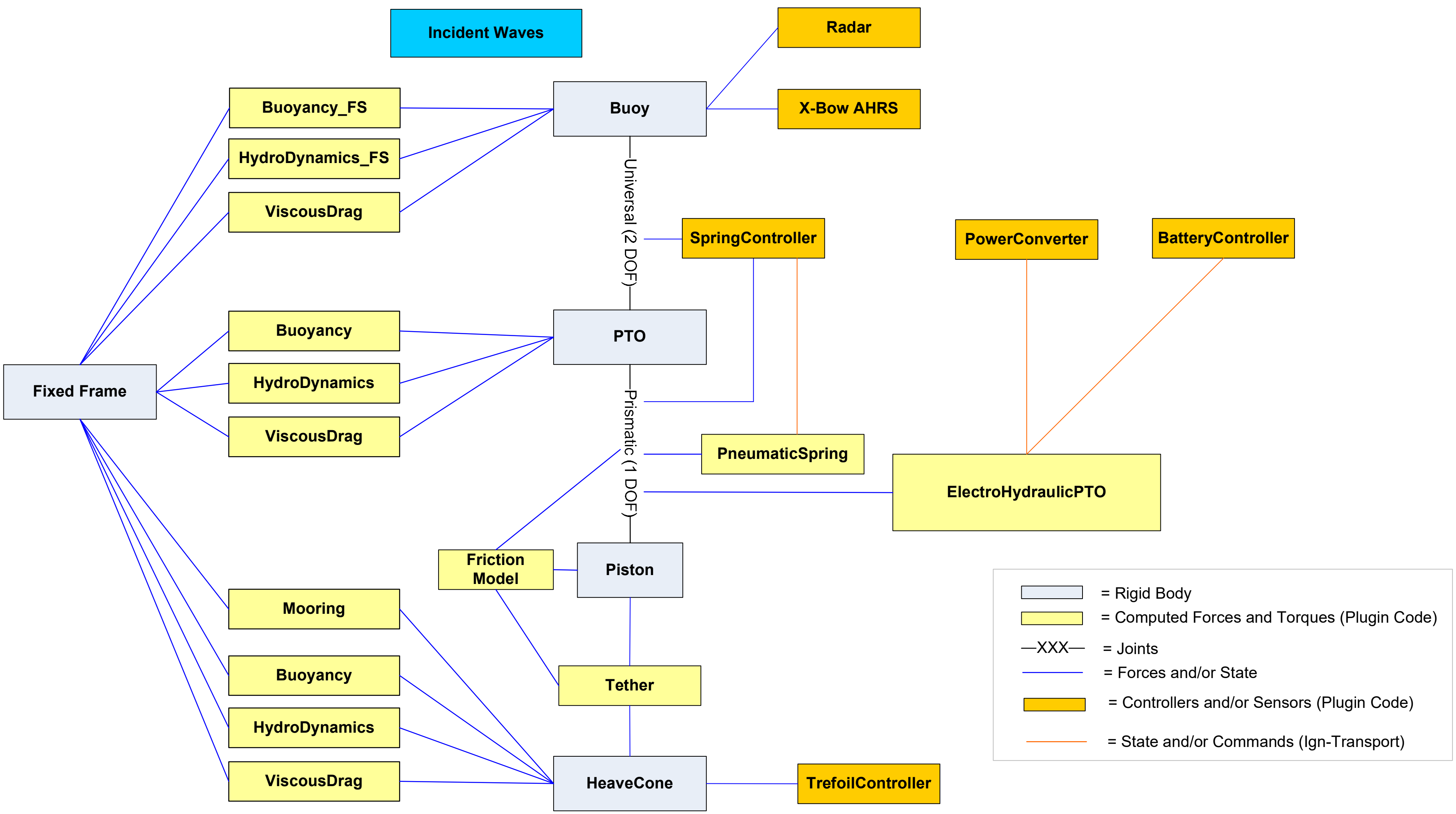
```
$ mkdir build
$ cd build
$ cmake ..
$ make
$ make install
```

Run Example

From the top level directory, do the following to run a simple example that uses this plugin



Gazebo
Topic Viewer
Transport plotting
/force_upper_...
Plot 1
/force_upper_polytropic-data
hover
3.00
2.63
2.25
1.88
1.50
1.13
0.75
0.38
0.00
0.00 0.38 0.75 1.13 1.50 1.88 2.25 2.63 3.00
/force_lower_...
Plot 2
/force_lower_polytropic-data
hover
3.00
2.63
2.25
1.88
1.50
1.13
0.75
0.38
0.00
0.00 0.38 0.75 1.13 1.50 1.88 2.25 2.63 3.00
0.00 %



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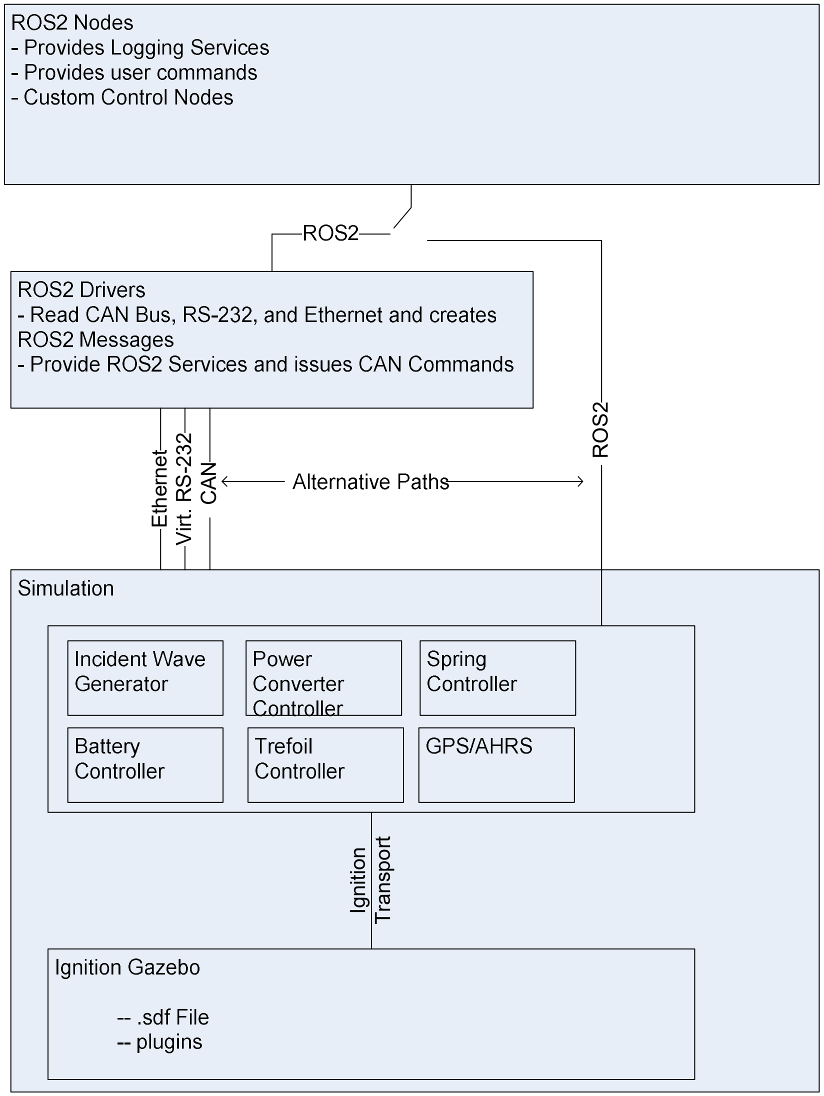

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Ignition Gazebo Details

- Added Mass Handling
- ODE Solution. DART (Euler Method O(dt))
- State augmentation.

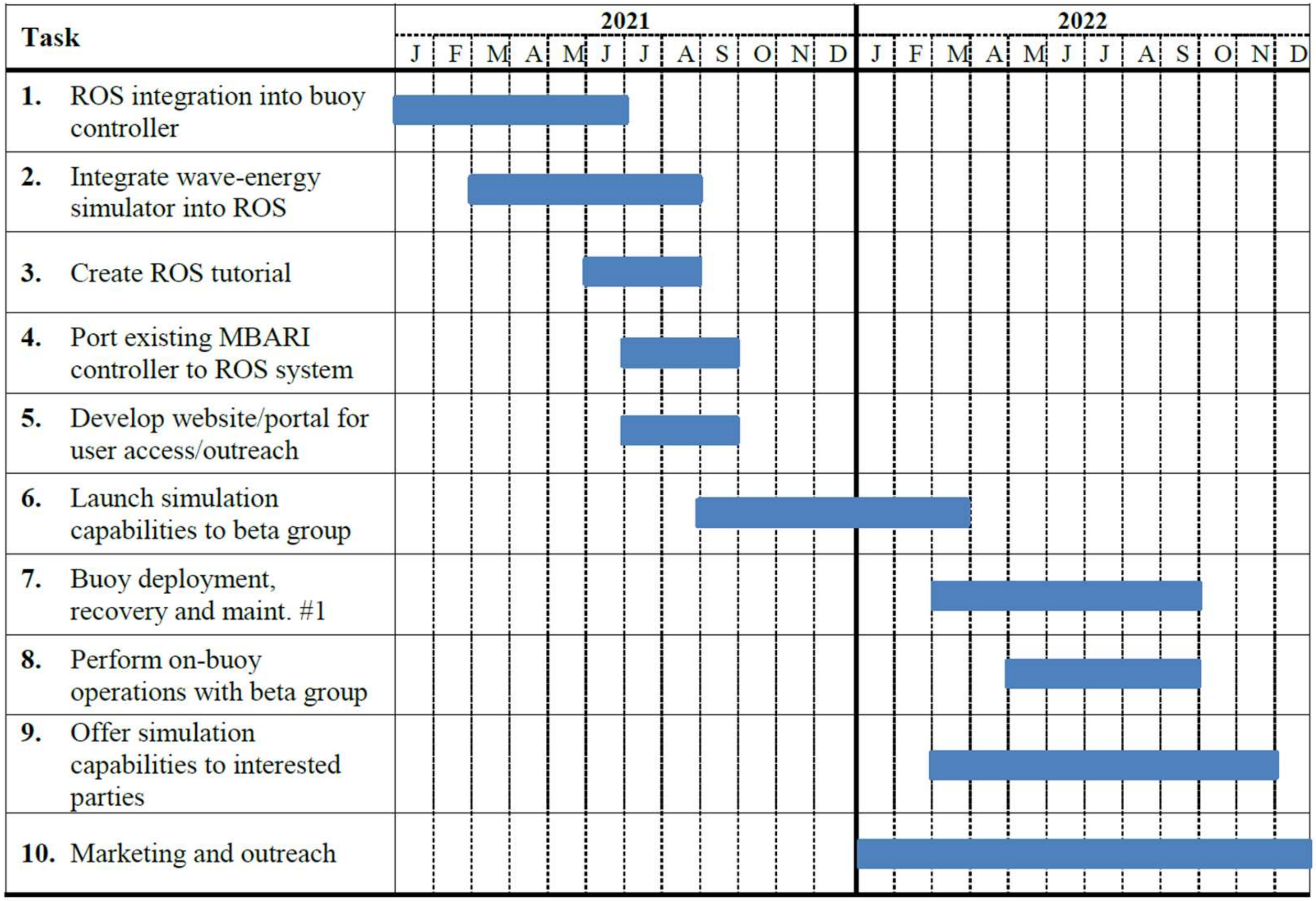
Development Process

- Testing and CI

Deployment Options

- User access…

Budget Period 1



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Simulation Challenge and Existing Tools

- *Not just rigid-body dynamics. Pneumatic spring and electro-hydraulic system.*
- *Wave-body interaction problem, specialized hydrodynamics.*
    - *Input: Wave-field*
    - *Output: Wave-energy converter behavior (motions, forces, electrics)*
- *Existing Simulink tools, are sophisticated, but Simulink…*
- *Ignition tools. What existing capabilities are present, and what capabilities that we add would be most useful for that ecosystem of tools.*
- *Architectural decisions…*