Shearwater

Open Source Floating Sensor Platform for Measurement and Reporting of Marine Carbon Dioxide Removal

This project is intended to provide a template and instructions for reproducibly building and operating a floating sensor platform. The platform is designed for medium-term (1-2 years or more) deployments at coastal locations, and is designed to house and optionally provide real-time telemetry from sensors in the domains of ocean chemistry, oceanography, and meteorology.

We believe the design is flexible enough to have substantial variations, though note that we do not advise attempting to deploy this platform aside from coastal settings. Although it could potentially be towed or motored some short distances and operated wirelessly for short periods of time, the platform is intended to be lashed to a dock, pier, barge, or similar, and for it to receive low-voltage shore power.

One of the guiding principles for the project is that wherever possible we chose commercially available, off-the-shelf components (COTS) so that this project will remain affordable and can be reproduced by facilities or individuals who may not have access to (for instance) machine shops to mill custom enclosures or an electrical engineering department to design and send printed circuit boards (PCBs) out for custom fabrication. We leverage the mature industrial automation industry for components wherever possible; companies serving this field have had a good deal of time to make robust and relatively inexpensive components.

Where possible we choose affordable components, bearing in mind that coastal and ocean environments are among the harshest in the world and there will be areas where we choose more rugged or higher-quality components in hopes of those components better surviving harsh conditions.

Although there are a number of different aspect of this project - mechanical, electrical, software - we feel that it could be completed by a small group or even an individual who is ready to learn some new skills. We outline the major subsystems below – groups or individuals who wish to use some parts of the system can use just the one or more subsystems relevant to their specific project.

Physical Platform

Dock Blocks

The first prototype we have designed is based on the commercial Dock Blocks system. This is far from the only choice we could have made for this project, and there was significant debate on whether it was the best choice. Some other options are described below.

One aim of the project was to be able for a small group to be able to assemble the system without the use of heavy or specialized machinery, without the use of a welder or a crane. Although this platform would be difficult to construct on the water in rough conditions, in a calm and protected environment with people who are comfortable working on the water we contend it is possible. The unistrut and the all-thread connectors should be pre-cut or pre-assembled where possible in a shop setting.

Another goal of the platform is to be able to have enough space and buoyancy for one or more humans to be able to do some manual pumping of seawater for lab-based analysis. There is high likelihood that at some point in time some component will fail within the electrical enclosure, and removing the enclosure to troubleshoot and repair in the lab will not always be feasible. Therefore we intend the area around the enclosure to have enough room for such activities, weather permitting.

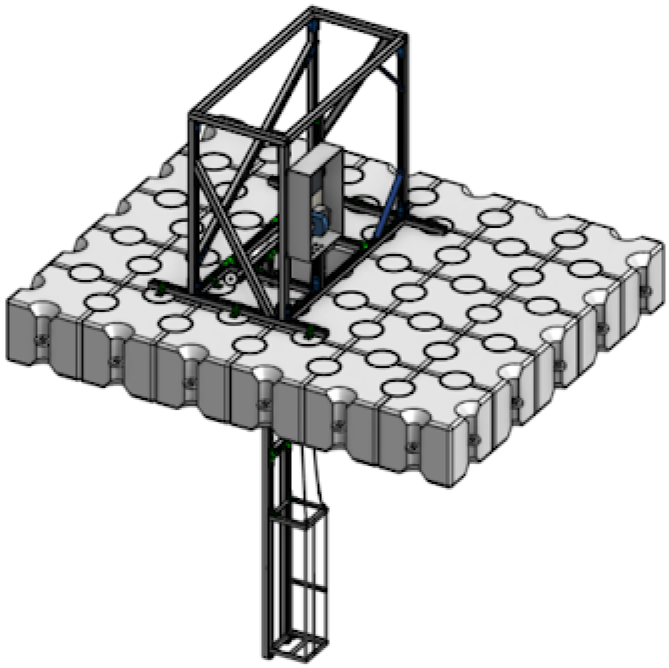
We also strive for being able to service our underwater sensors relatively easily - without requiring a diver. We expect that we will have significant biological growth that will need periodic de-fouling, and many ocean chemistry sensors in particular will require frequent calibration. There may be additional need or desire for mounting sensors on our cage that are not integrated with our live-streaming telemetry; we still want to be able to connect to these sensors for data download and reconfiguration/re-launch. The platform is designed in such a way to allow one or two operators to hoist up the sensor cage and service it while standing on the platform.

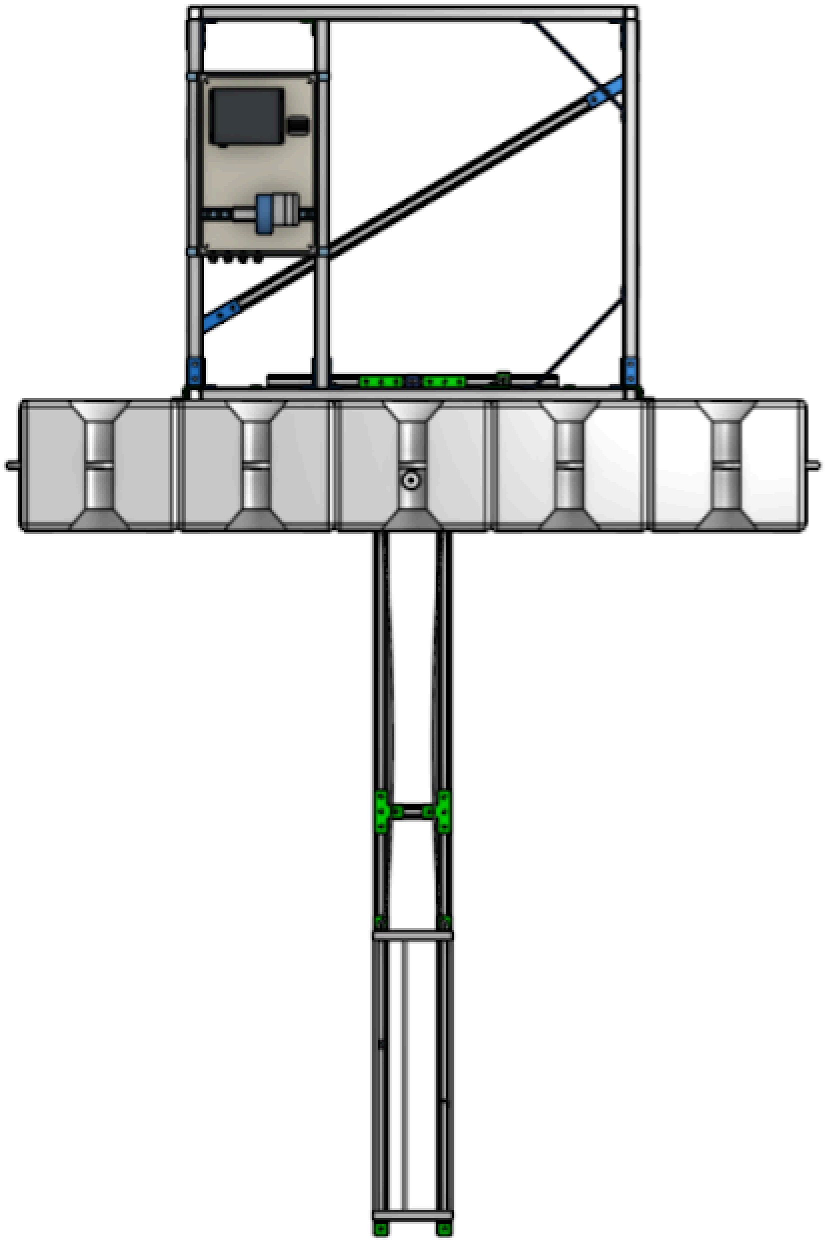
Note that care should be taken to prevent pinnipeds from taking perch on the platform. Dock-blocks has a new railing system in development, if this component is available we think it could be effective at preventing pinniped ingress:

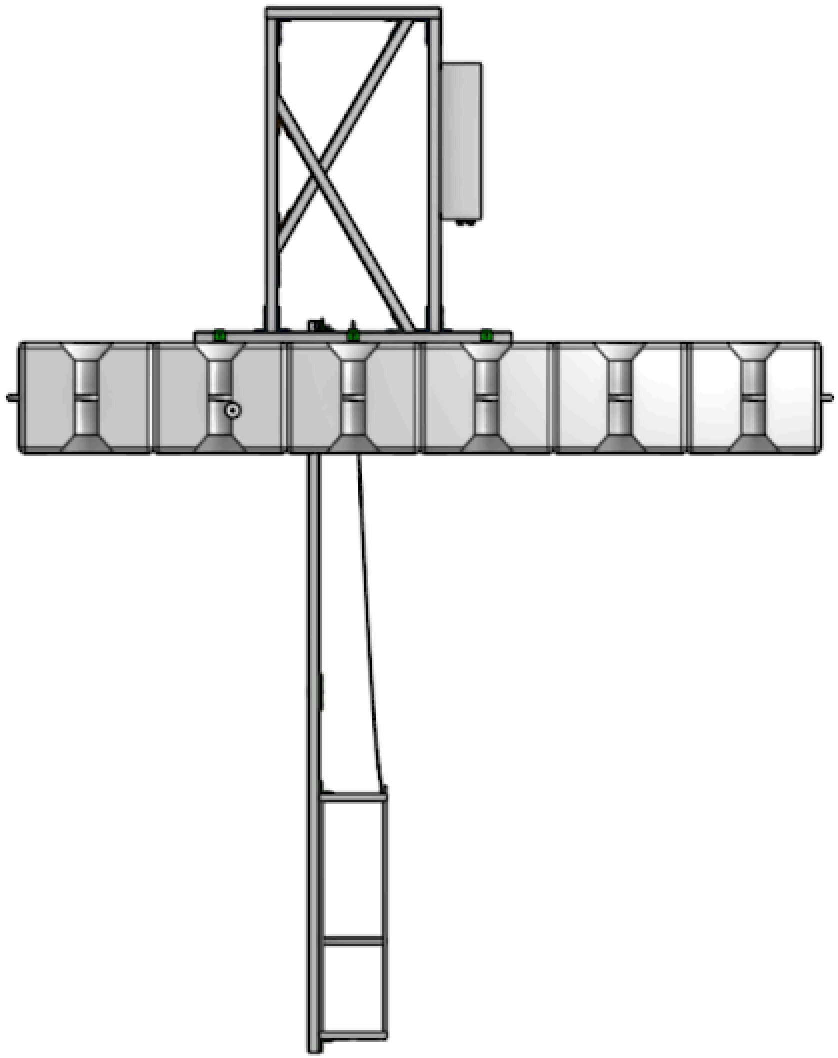
Until this is available, we propose using the traditional dock-blocks handrails (pictured below) with rope netting along any areas of the platform that might be accessible by pinnipeds. Other approaches may work as well or better, but we encourage implementers to not forget this operational consideration.

Platform Design

We use OnShape as our CAD platform, we will eventually provide public links to these models; in the meantime below are some screenshots. For our use case and the time being we are assuming the sensor cage itself is a welded stainless steel cage (we had one already) that we attach to the unistrut super structure. Future iterations or different applications by others may look different. Although we initially planned on having the central “moon pool” 2 blocks wide (each block is ~.5m square) we have since contracted to one block; your usage may vary.







Scaffolding

We chose stainless steel unistrut as our scaffolding infrastructure. Unistrut is commonly available in many places worldwide, and there are many fittings available. Stainless steel is one of the more expensive unistrut options available, but especially for initial builds we determined this was the option most likely to have a successful outcome. If you are using stainless unistrut, make sure you use stainless fittings to avoid galvanic corrosion.

We also considered fiber-reinforced plastic (FRP) struts. This may be a significantly cheaper option that will resist corrosion, although there have been reports of it not performing well in constant sunlight and forming dangerous hairs that easily embed in the skin. If you choose this path for your scaffolding, take great care when cutting, use of power tools to cut this material can generate a great deal of fibers that can get into the skin or lungs and be very difficult to clean up – advise use of hand tools to cut (a hacksaw has been reported to work well here).

Connections

The dock-blocks system has a single polyethylene “pin” that connects any two blocks together. This pin rotates to lock in place.

Although not officially supported by dock-blocks, many of their customers have connected hardware to these pins to mount things like our unistrut scaffolding to the platform without having to get underneath the platform to make the attachments. ½” all-thread with two jam nuts is one hardware option we believe will work well here.

Unistrut could be directly mounted to the bolt or all-thread, but another option our team discussed in order to separate the platform/pins from the scaffolding is to use a piece of custom stainless hardware (yellow in the marked-up image below) to lock into the (green) unistrut with standard unistrut fittings (red) regardless of orientation:

Alternate Platforms

There are other similar modular dock systems out there that could work for a platform like this, we have not exhaustively vetted everything else. For significantly more capital expenditure there are companies which will build and deploy a platform for you – see for instance https://www.marinefloats.com/.

We also discussed modifying a small pontoon boat or catamaran to serve as the floating physical platform – this could certainly work as well. See below for more details.

Another alternative we discussed was using (& modifying) a COTS boat, something like:

Primary Sensor Selection

We specified several sensors for our primary use case, marine Carbon Dioxide Removal, other uses may have other requirements; our design here should accommodate different/additional sensors. The sensors we've designed for include:

- Seabird HydroCAT-EP V2 (including pH)
- Sunburst SAMI-CO2
- Sunburst iSAMI-pH
- Gill Maximet Marine GMX560

We believe this set of sensors to be a good choice for baselining and field operations for marine-based Carbon Dioxide Removal.

Electronics enclosure

Sub-sections below detail different groupings within the enclosure. A table of possible components along with possible sourcing is listed below.

Enclosure

For the enclosure itself, we use a larger model from Polycase (we used WQ-81-02). Others may well be suitable. Polycarbonate reinforced with fiberglass, with stainless steel fittings and a continuous gasket is a good choice. In an ideal world we would hope to assemble the enclosure contents in the lab, install, and never have to open it up on the water. In the real world, this is likely to be a relatively common occurrence for troubleshooting and maintenance. The enclosure should include DIN rails - we use these where appropriate for mounting components. The DIN rails get mounted to the interior panel which you should also purchase with your enclosure. We used the ABS plastic version here: WQ-81P-01. Use self-tapping sheet metal screws with a drill to mount the DIN rails or other non-DIN rail mounted components.

Incoming Power

In line with many of the industrial automation components we're using throughout the system, our primary power bus is 24v. Note that since this is < 50v this is considered low voltage and hence generally safe to work with, though we still advise taking care when operating with electrical equipment.

We advise a small Uninterruptible Power Supply (UPS) that can be DIN-rail mounted to provide continuous power when unexpected events occur. Our 19.2 Wh Phoenix Contact UPS can provide on the order of tens of minutes of operation, and can be wired such that software can react and gracefully shut down when main power is interrupted. The UPS also functions as a power conditioner, outputting a steady voltage despite possibly noisy input. Because the floating sensor platform might be a long physical distance from the power supply that is supplying DC power, and DC will suffers from voltage drop dependant on resistance, distance and other factors, we recommend setting upstream DC output to be well above 24V and relying on the UPS as a power-conditioning capacitor. Calculators are widely available to help with determining output voltage based on length, wire material, and wire size (gauge, often AWG in the USA). Particular care should be taken with the upstream transformer – AC connections at 120V, 208V, or 480V are considered high voltage and are all life-threatening, especially in wet environments.

Power distribution

External power is supplied to the UPS; everything else in the enclosure should be powered via (downstream of) the UPS. Care needs to be taken here, however: because our oceanographic sensors expect 12V power instead of the 24V standard in industrial automation, we have a step-down transformer to convert from 24V to 12V, and expect that all of the sensors are connected to the 12V rail. We specify that 12V rail is the bottom-most DIN rail. Outputs to sensors need to be fused so that any possible sensor malfunction does not have the opportunity to short out the rest of the system.

It is important that we have programmable control of sensor power; we want to be able to power off sensors to conserve power, and there will be times where we will want to power cycle sensors for troubleshooting. We do this by means of an industrial relay controller or smart relay. Optimal choice here is the Revolution Pi Relay Module, but we have also demonstrated that the Arduino Opta will function here. These modules will have their default connection to ‘Normally Open’; power will be off by default and need to be enabled by software control.

Panel penetrations

There will be a few penetrations in the enclosure. Try to avoid ‘compression fittings’ or gland fittings. Though these may be IP68-rated, this is the most likely source of salt-water ingress. MacArtney SubConn is the most dependable solution here. For our case, our chosen oceanographic/biogeochemical sensors already have these connections and hence avoids having to design any adapters. Note that this may mean you need to have appropriate cables made by MacArtney.

Power and Ethernet

Depending on usage, you will likely need to have at least “battery power” bulkhead input, 2- or 3-pin. The MacArtney pair you will need here is BHB2F/BHB2M. (If possible, aim to connect the ground pin to a real ground from the shore side.) In general with these male/female pairings you should plan to have the ‘hot’ connector be the female side to minimize possible shocks or short circuits. Where the hot end is coming from will depend on your situation, more on this below.

If your platform is intended to be connected to hard-line ethernet, you should plan on a separate 8-pin ethernet bulkhead - SubConn DBHRA8F/DBHRA8M.

For typical installations, both power and ethernet are fed to the platform via shore lines, likely fed from whatever barge or pier the platform is lashed to. A number of factors can inform how these cables are routed. If you intend for your installation to be stationary for a long time and permitting allows it, the most stable way to connect will be to run the ethernet and low-voltage power cables through an appropriately-rated, waterproof conduit underwater to the platform. But other options exist, including running the cable above water, possibly routing along whatever lines are lashing the platform to the barge or pier. Much care should be taken here, as these cables will be less durable in response to chafing than standard marine lines. Because the power lines are carrying low-voltage DC current we can be confident that even if insulation gets worn away we will not endanger life, but this situation should still be avoided to ensure equipment is not damaged and continues working as designed.

Because unexpected things happen, forklifts or vessels can catch a stray cable, storms can wrench our platform away from whatever it is lashed to, we design for the power and ethernet connectors from shore to be able to break away without damaging equipment.

Sensor Connections

Unless you are simply using the platform to house sensors that are battery-powered and self-logging, you will also likely need to have one or more power/communication cables that connects to the sensors. Many oceanographic sensors rely on 6-pin power + serial (typically rs232, sometimes rs422) connectors. Use MacArtney SubConn bulkheads connectors, one of MCBH6M/F for each (oceanographic) sensor you are connecting and powering from the system - different sensors may have different gender connectors. Some oceanographic sensors will ship with pre-made SubConn cables, but may be special cables that have DB9 or USB-B connections forked out to connect to a laptop. These forked connectors will not be waterproof and should be avoided. If you are comfortable with potting compound you may be able to cut and re-seal the cables; safer operation will be to have MacArtney manufacture the proper-length cables with appropriate 6-pin ends.

Plan to get color-coded sleeves so that operators can quickly see what connectors go to what sensors. All of the 6-pin power + serial connectors are likely to have the same connector, but quite possible to have different pinouts, and connecting power to pins that are not expecting it may damage sensitive equipment. We unfortunately do not have any great solutions for this problem other than careful education and standards around which connectors go to which sensors. There are other cable manufacturers which provide keyed connectors for this purpose. MacArtney does not provide such keys as of this writing, perhaps some day they will add this to their catalog. It might also be possible to build your own custom keys on top of our enclosure and the cables. If you successfully figure this out please share with the community!

We advise putting penetrations on the bottom of the enclosure, where possible. Gravity means that waves or condensation on cables will drip down away from the enclosure, rather than towards it.

Compute

RevPi

Maple Systems

We've also successfully used the POC-400 from Indsutrial PC, as well as the older POC-300. These are much more fully-featured units than the ARM-based Revolution Pi's.

Serial communications

Most of the sensors used in this space will have serial communication as an option, on many this will be the only option. As this is how we communicating with the sensors, and the sensors are the primary purpose of this entire platform, we advise investing in quality equipment here.

We have explored some usb-to-serial options; this does offer some efficiencies of space and will be the lowest-power option. Something like this adapter from StarTech. But despite the ubiquity of USB for personal computing, using it in an embedded system should be avoided if at all possible, USB tends to be an unreliable protocol especially where there might be electrical noise present.

Moxa makes the highest quality equipment in this space. If you can get by with 4 ports, the NPort 5000ai is a reasonable choice, but note that it will consume 5W of steady power. If you need 8 or more ports, the NPort 5610-8-DT-T might be a good option, tho note that this will bump you up to over 7W and $940 as of this writing. If you are only ever planning on operating from shore power then power consumption should not be a concern here.

Moxa makes single port options, and you can find these from other vendors too (though be warned that you will tend to get what you pay for in this space) – but multi-port options are ideal as we'd rather support fewer ethernet ports.

Enclosure sensing

It will be important to have environmental sensing within the enclosure - in particular we want to measure temperature, humidity, and pressure. We may be able to get some additional information about some of our internal devices (eg CPU temperature).

For humidity and temperature, colleagues at NOAA have successfully used this chip (purchase link) with high accuracy and fast response time – but this will require a PCB and I2C integration, so we will likely steer clear of this. Sensirion also makes quality temp/humidity sensors but again are bare components that will need PCB integration.

Others have successfully used the Bosch bme280 - which measures temperature, humidity, and pressure at levels that should be sufficient for us, but again would require PCB and I2C (or SPI) integration.

A reasonable option might be the iMet-XF UAV Sensor - this is a bare PCB that will require some care with mounting and connecting (and possibly conformal coating?) but would give us temperature, humidity, and pressure with a RS232 interface (possibly connecting to our serial-to-ethernet hub above?). There is also a optional uBlox CAM M-8 GPS module that integrates here which might be a good backup option.

Networking

For the networking we're doing in this enclosure, there should generally be no need for anything higher than simple, unmanaged switches with 10/100Mbps connections. If you're planning on doing security (or underwater) camera connections within the system you should consider a gigabit switch (1000Mbps) and possibly managed.

We've mainly been using simple unmanaged DIN-rail mounted switches such as the one listed below from ATOP.

Another consideration would be something like https://www.brainboxes.com/ or https://botblox.io/

Compute infrastructure

We are leveraging

Communications

Let upstream concerns worry about it. Or you can integrate a cell modem. Our electronics enclosure assumes there is a DHCP server somewhere within.