Protei

Open Source Sailing Drone

Abstract

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Authors:

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ISBN:

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Introduction

Open_sailing is a growing international community, with the goal of developing open-source technologies to explore, study, and preserve oceans. This summer, a group converged in Rotterdam to develop Protei_006, the prototype for a potential fleet of low-cost, shape-shifting, DIY, semi-autonomous oil-collecting sailboats, that each sails upwind and collects oil sheens off the top of the water near the sites of spills. This robotic sailboat is intended to be self-righting, durable, inexpensive, and easily reproducible.

The goal this summer was to develop, test and document the making of a full-sized (3 meter) Protei vessel, as well as to emphasize that an articulated hulled boat sailing upwind can more effectively collect oil than the existing pollution-cleaning technologies. Current methods for cleaning oil pollution on water, such as those implemented in the BP oil spill in the Gulf of Mexico, only collect 3% of materials, expose workers to toxic chemicals, and are constrained by weather conditions (Kerr, 2010).

Protei, alternatively, is unmanned, uses accessible, inexpensive or recycled materials, and tolerates chemically hazardous and rough weather conditions. Because of its open hardware philosophy, and its ease and cost of reproduction, it can be constructed and deployed on a large scale. It can eventually be appropriated for other purposes, such as cleaning other chemical pollutants and material waste off of water, as well as ocean surveillance.

The design and implementation of Protei will be an ongoing evolution, as people all over the world continue to build and deploy it, and contribute to its efficiency and robustness.

Solving a man-made problem with the power of nature

General informations about the oil spill
Amount
Area
Type of oil
Worst environmental disaster in the history of USA
Twchnology used.

Our class of oil.

- large areas
- thin sheen of oil
- Oil going towards the sea (as opposed to go towards the land)

A marine oil spill is a type of pollution, caused by the release of crude oil from the depths of the ocean due to human activity.

ajouter
Surface currents
NOAA reports

diagram with order of cleaning

ORDER	LOCATION of the oil spread	ACTIONS for cleanup
1	the source of the leak	closing taps with ROVs (remotely operated underwater vehicles)
2	just after oil has escaped from the source of the leak	capture oil right at the source, using a «top kill hat» or bell technique (FOOTNOTE HERE)
3	perimeter of the surface of the water body	?
4	along the surface of the water, including thin oil sheens to heavy slacks and tarballs	Controlled burning, dispersant, skimmers (and unmanned surface vessels, such as Protei)
5	Oil spread over a large area	containment and absorbtion techniques, such as ......
6	On the beach	It is very difficult to target oil to remove from solid substrates, such as coastal sediments and rocks. Flushing with hot water is one method, but it is fatal to much coastal biomass
7	At the bottom of the ocean	ROV

Table _._. The seven orders of oil leaks and the appropriate clean-up techniques, according to Cesar Harada's[1] observations from his studies and experience at the oil spill in the Gulf of Mexico.

Protei will be most useful for cleaning oil spills of the fourth order, in which there is a thin sheen of oil that has spread throughout a large surface area of water, and that is travelling towards the sea (rather than towards the land). This is because Protei is a small vessel, that sails upwind and collects

1 http://www.cesarharada.com

Currently, oil spills of this nature and of this magnitude are often targeted by fishermen using re-purposed fishing vessels. Protei, alternatively, provides many benefits over these current methods, being that it is unmanned and robust.

greenpeace

AP

REPURPOSED MANNED FISHING VESSELS	PROTEI
Exposes crew to health risks and toxins	unmanned and autonomous
Cannot operate during a storm	can operate during extreme weather conditions
Cannot operate at night	can sail at night 9using alternate means of location sensing, such as SONAR)
Sensing of oil limited to human eye sight	alternate sensing technologies on board, based on oil prediction programs with wind and surface current trajectories
Not sustainable and environmentally destructive, requiring oil or diesel for driving power	renewable energy, using solar power for the actuation, and wind energy for locomotion (in sync with environmental conditions and influences)
Expenxive	inexpensive
Proprietary	Open-Source hardware in order to solve other problems with similar technology

Table _._ Benefits that Prote can provide over current methods of oil spill relief performed by fishermen and repurposed vessels.

Wind and surface currents

WInd ans surface currents is what moves the oil.
We wan tuse the same froces to clean up the oil.

3 digrams

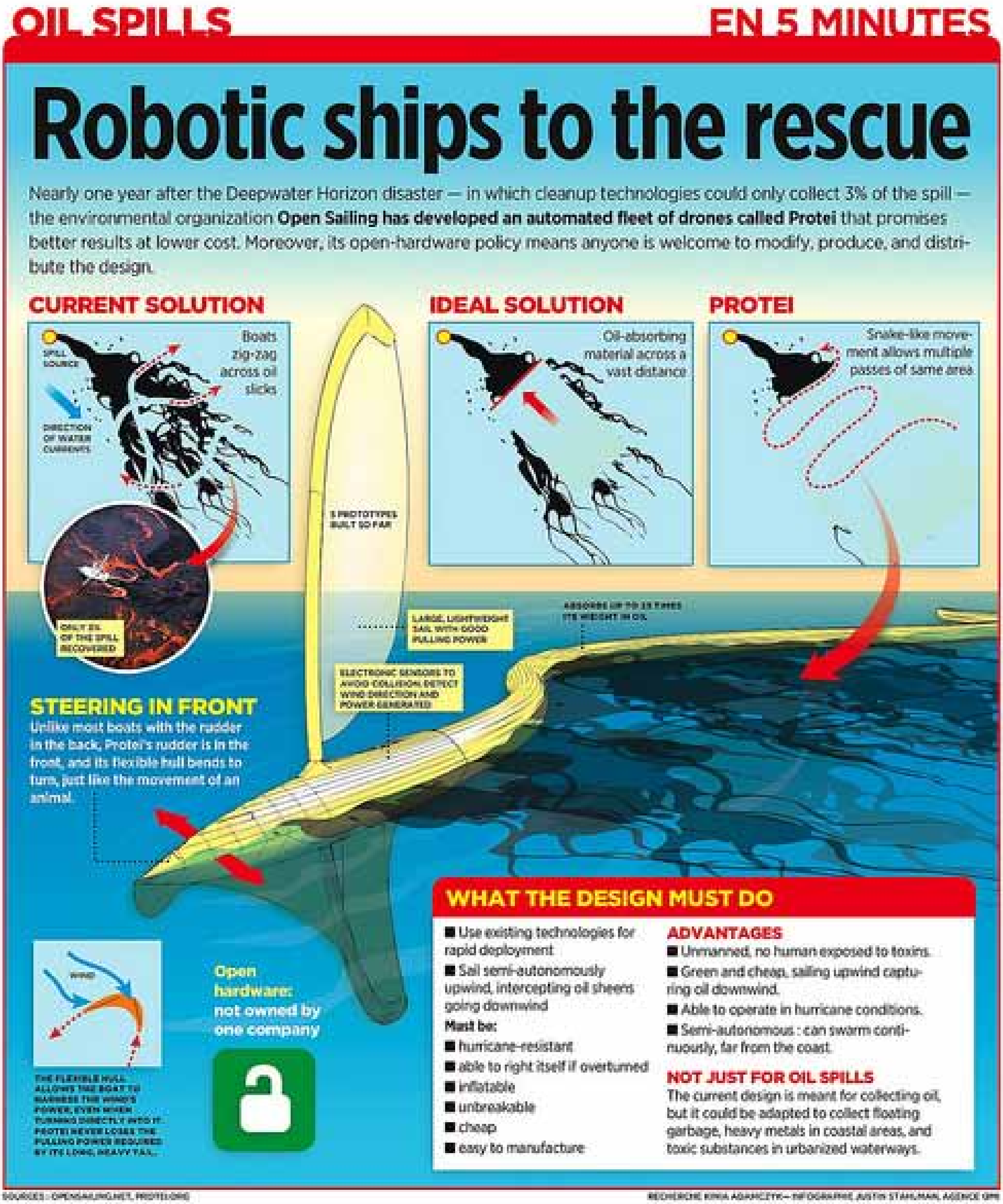
-skimmers cleaning celan path in a sea of oil
- one long piece going upwind
multiple long pieces going wind
protei taking upwind.

diagram with order of cleaning

diagram with order of cleaning

diagram with order of cleaning

diagram with order of cleaning


OIL SPILLS
EN 5 MINUTES
Robotic ships to the rescue
Nearly one year after the Deepwater Horizon disaster — in which cleanup technologies could only collect 3% of the spill — the environmental organization Open Sailing has developed an automated fleet of drones called Protei that promises better results at lower cost. Moreover, its open-hardware policy means anyone is welcome to modify, produce, and distribute the design.
CURRENT SOLUTION
SPILL SOURCE
DIRECTION OF WATER CURRENTS
Boats zig-zag across oil slicks
ONLY 3% OF THE SPILL RECOVERED
IDEAL SOLUTION
Oil-absorbing material across a vast distance
PROTEI
Snake-like movement allows multiple passes of same area
LARGE, LIGHTWEIGHT SAIL WITH GOOD PULLING POWER
ELECTRONIC SENSORS TO AVOID COLLISION, DETECT WIND DIRECTION AND POWER GENERATED
STEERING IN FRONT
Unlike most boats with the rudder in the back, Protei's rudder is in the front, and its flexible hull bends to turn, just like the movement of an animal.
WIND
THE FLEXIBLE HULL ALLOWS THE BOAT TO HARNESS THE WIND'S POWER, EVEN WHEN TURNING DIRECTLY INTO IT. PROTEI NEVER LOSES THE PULLING POWER REQUIRED BY ITS LONG, HEAVY TAIL.
Open hardware: not owned by one company
WHAT THE DESIGN MUST DO
■ Use existing technologies for rapid deployment
■ Sail semi-autonomously upwind, intercepting oil sheens going downwind
Must be:
■ hurricane-resistant
■ able to right itself if overturned
■ inflatable
■ unbreakable
■ cheap
■ easy to manufacture
ADVANTAGES
■ Unmanned, no human exposed to toxins.
■ Green and cheap, sailing upwind capturing oil downwind.
■ Able to operate in hurricane conditions.
■ Semi-autonomous : can swarm continuously, far from the coast.
NOT JUST FOR OIL SPILLS
The current design is meant for collecting oil, but it could be adapted to collect floating garbage, heavy metals in coastal areas, and toxic substances in urbanized waterways.
SOURCES : OPENSAILING.NET, PROTEI.ORG
RECHERCHE KINGA ADAMCZYK — INFOGRAPHIE JUSTIN STAHLMAN, AGENCE QMI

ideas to contribute to the applications of sailing to oil spill clean-up

Why a saili boat with an articulated hull?

- 1/ back rudder
- 2/ front rudder
- 3/ front and back rudder
- 4/ articulated hull

Some ideas to contribute to the science of sailing with an articlated hull

low speed implication

- Better directional control of long heavy loads
- Better power control of long heavy loads
- Upwind sailing (with articulated hull + 2 sails)

Better control of heading and resistance to lateral drift with more wet surface

- Less turbulences (no separate centerboard + Rudder)
- Less mechanical effort, less energy on actuation
- Less impact on waves (flexible body following waves)

High speed implication

- Lateral lift
  - Optimization of upwind sailing
  - Optimization of trajectory

Scope

This manual documents the building of Protei_006 by the Protei_team from June 1st, 2011 and September, 11th 2011 in Rotterdam. It is aimed at describing the design and construction of Protei. It is not a detailed construction manual, but it should provide sufficient information to motivation, versions and research goals behind the design of the successive Protei versions.

The architecture of this manual is highly modular so one can download and print on demand an isolated chapter and still have a self standing meaningful document. The content of this manual is expandable, anybody is welcome to expand a section or suggest new ones. Just as we build successive versions of Protei, successive version of this manual are edited.

The size format of the paper is industry standard A4, published on-demand for environmental concerns. The binding of the manual is preferably a ring binder so each reader can easily add notes and expand this documentation.

How to use this manual

As well as providing background information about the project, the instructional portion of this manual is divided into the mechanical construction and the electrical design, as the Protei team was divided into these sections in building this prototype. The mechanical and the electrical elements should be developed in parallel, as they are closely linked.

Each section is divided into subsections corresponding to specific structural elements, for example, the sail, the winch, the cable system, and the GPS. For each element, there is overview information, specific information on its construction, and troubleshooting tips.

DISCLAIMER

Protei is not the result of academic or scientific research. Protei is a direct response to environmental crises, including the financial and technological inaccessibility of solutions to the general public. It is an exploration of the concept of a flexible-hulled sailing boat, and the consequences of this bio-inspired design. We understand that this design may not be the most efficient and that nothing that we have done is completely new. Our vision is an artistic, collaborative, and open exploration of ultra-low cost, do-it-yourself sailing, and its application to oil-spill relief.

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Intellectual Property
Open_Hardware

The typical business model for a company pursuing technological innovation generally operates in the following order of priorities: Profit, technology, environment, people. Protei, on the other hand, reverses that business model, making the highest priority the environment, followed by the contentment of the workers, followed by the technological developments, followed by profit. This business model lends itself to the open-source nature of the project.

talk about challenges - how to make profit / succeed with this business model longer term... efficiency in the work environment; legal issues

The concept of Protei functions primarily as an open-source project. The design will be an ongoing evolution, as people throughout the world continue to build and implement it, and contribute to its efficiency and robustness. Its implementation depends on people willingly participating, collaborating, and sharing unique skillsets. It depends on accessible information and affordable components, and the sharing of ideas based on a multitude of areas of expertise.

Protei is made of open-source hardwares and softwares for the control, power and communication (between the vessel and an operator on land), including Arduino, Xbee, and a variety of sensors. Many of the mechanical components and materials are extracted from common and industrial products, such as power drills, plumbing equipment, and intact wooden scraps.

The entire nature of the construction of Protei is based on an open-source approach. Rather than a hierarchical chain of command, people share their own ideas for each aspect of the project, including hardware, software, fabrication, design, and testing.

In order to successfully grow into a fleet of DIY drones that can have impact on the oceans, the team needs to document, distribute and share the information of the mechanical build and electronic components. This feeds back into Protei's success, which depends on ongoing contributions to its design and functionality.

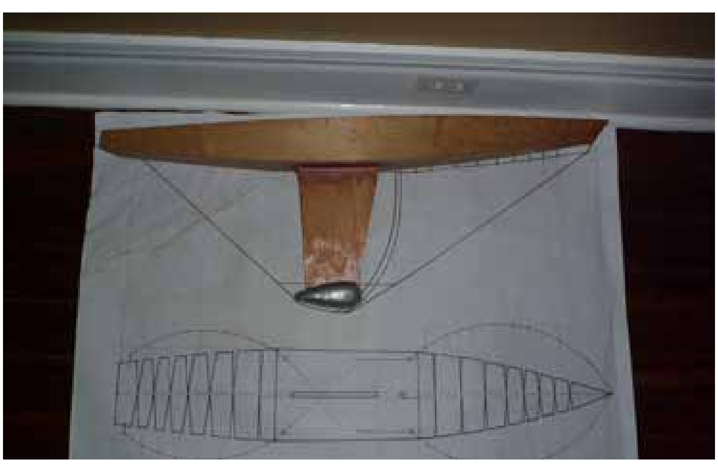
The Protei team encourages the use of these materials, and of all materials that we have documented online and elsewhere, for the purposes of furthering the development of Protei as a concept and a technology. We hope that users will document and share any and all progress made using our material.

Open_Hardware Object mechanical design	Documentation, textes, photos, videos, communication materials	Sourcecode	Name, trademark

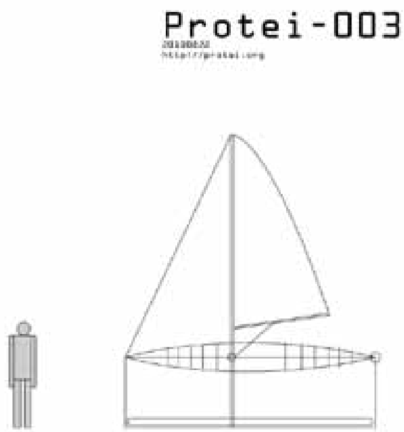
Protei_001

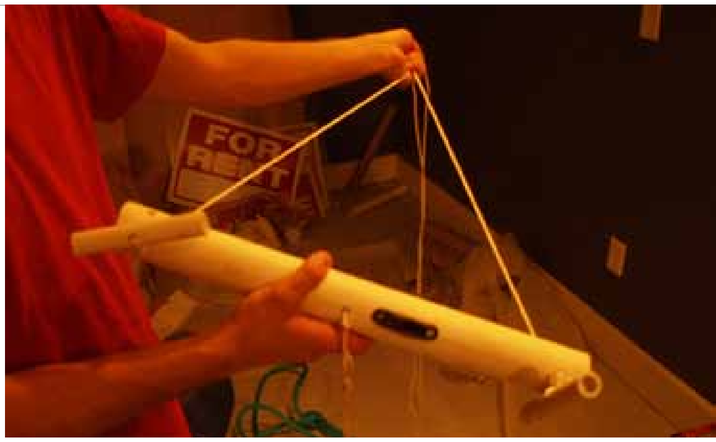

LOUISIANA
BUCKET
BRIGADE

Protei_002

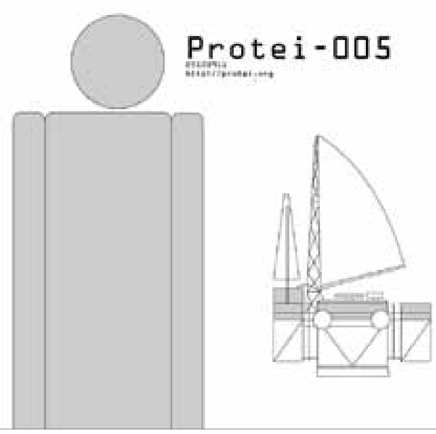


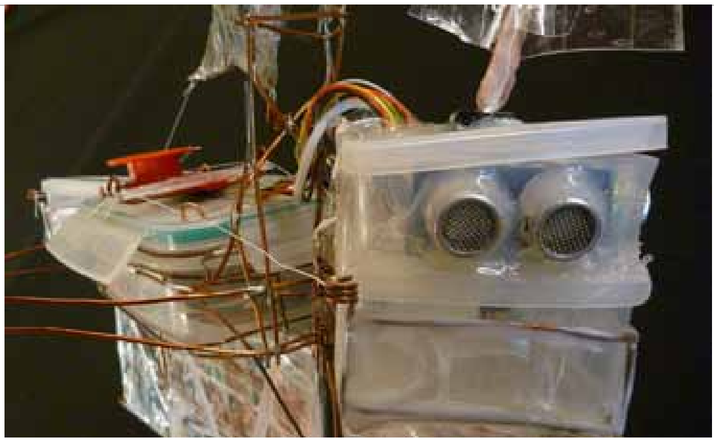
Protei_003

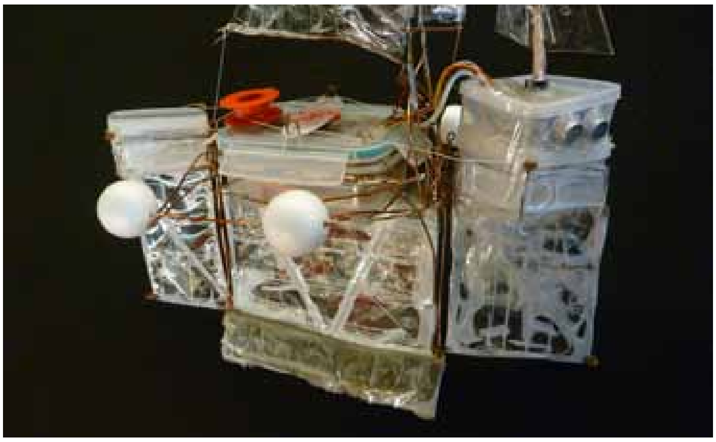


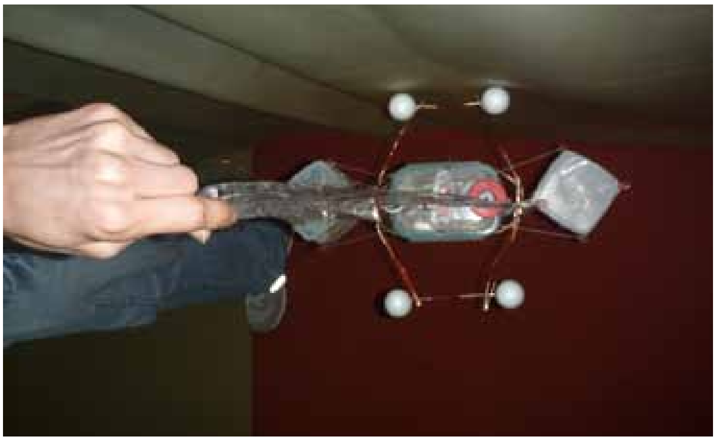


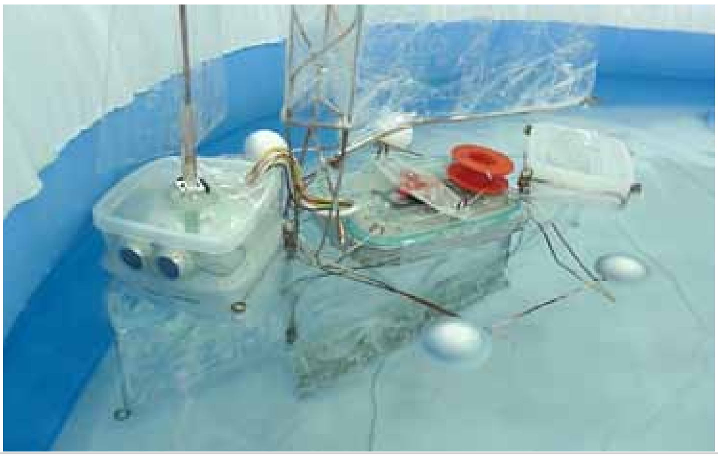
Protei_005



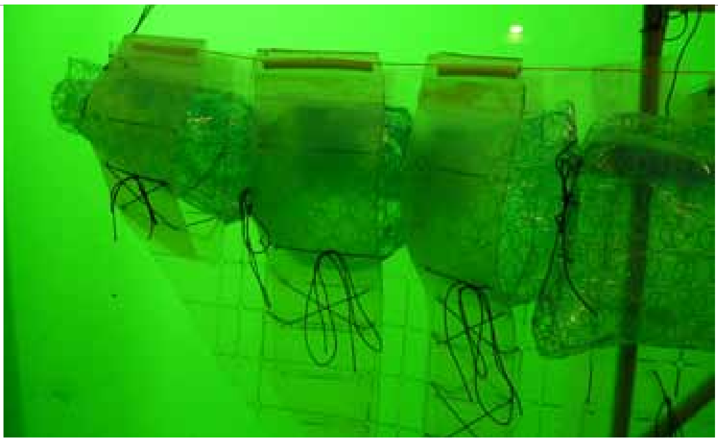


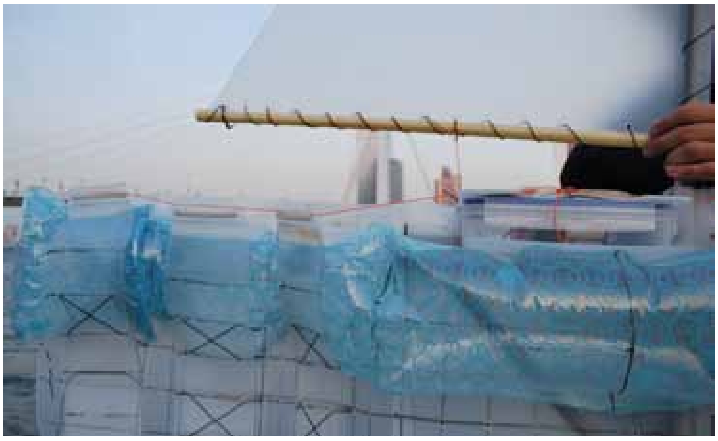






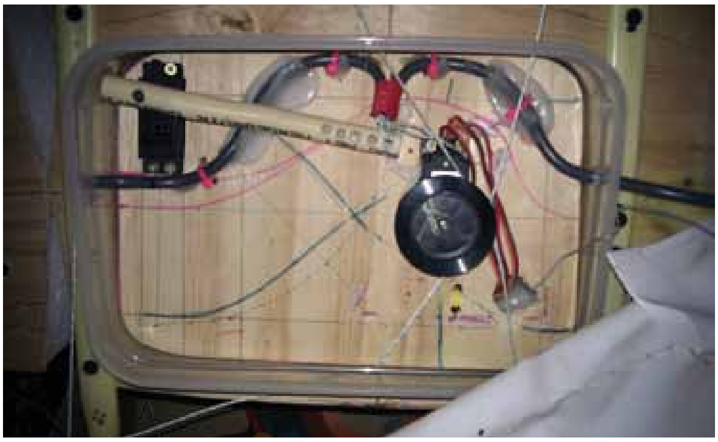
Protei_005.1





Protei_005.3

Protei 005.3 is an enhanced version of Protei. The hull is mostly made of foam, sandwiching one layer of wood. It is 108 cm long, 108 cm high, and 12 cm wide, divided into 3 equal sections of 38 cm each. The bow and stern section are fully segmented, and the middle section houses the electronics. This version has two motors, one which is a servo with an extended arm to trim the sail, and the other which reels a winch attached to two lines that control the articulation of the bow and the stern simultaneously. Because of the high torque required to reel the winch to articulate the hull, there are outriggers on either side to decrease the angle and reduce the torque. Protei_005.3 uses a Futaba 40 MHz remote control from a local hobby shop.

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Introduction

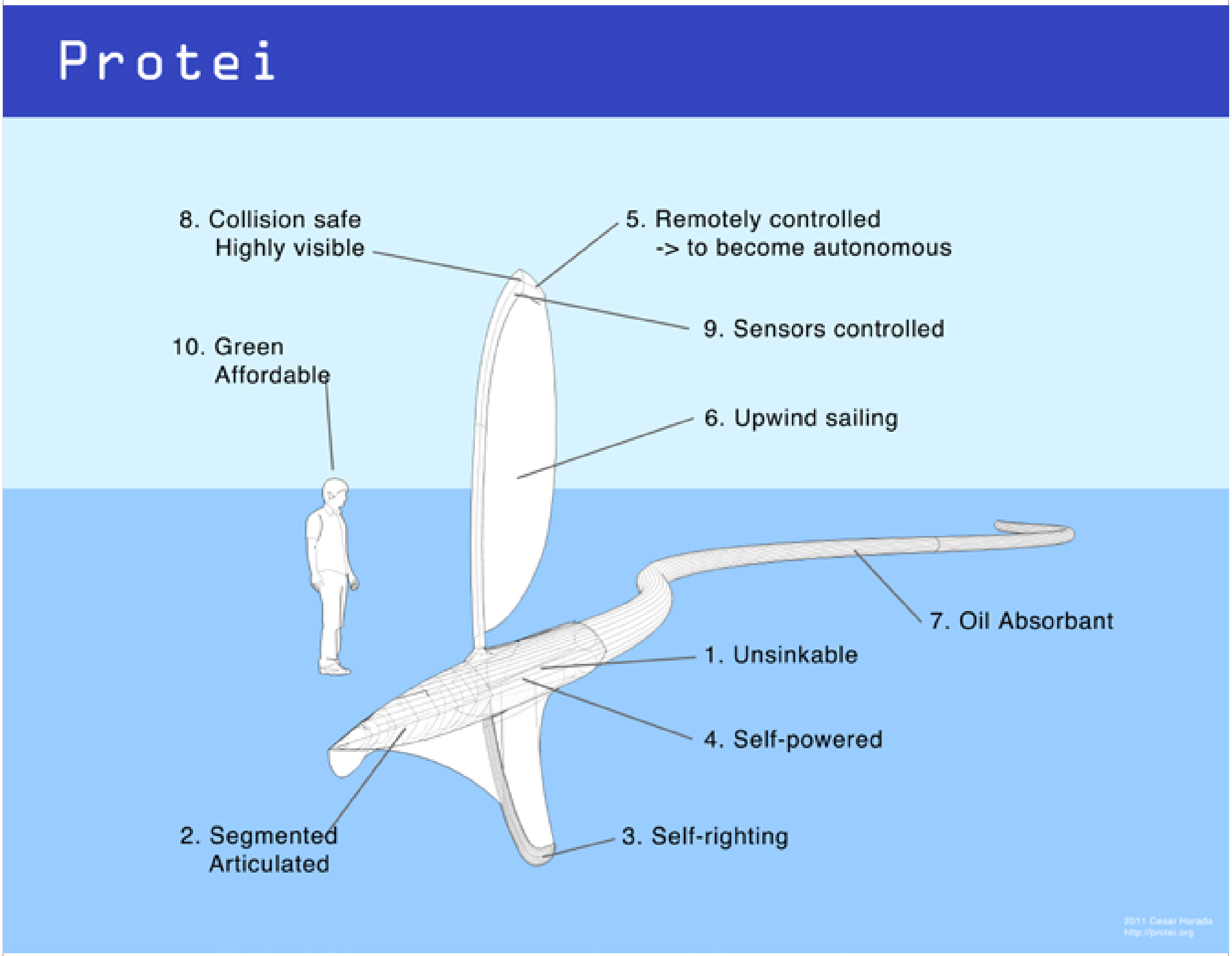


Figure x.x and x.x+1. Protei and its criteria: Unsinkable, segmented / articulated, self-righting, self-powered, remotely controlled and developing energetic autonomy, upwind sailing, highly visible / collision safe, green & affordable.

Goals

In order to make suitable technical choices for the materials and methods using in the construction of Protei, we have listed the global properties (see “Property” column in table x.x) we want to achieve. We have solutions for each property (see “Criteria” column in table x.x). The criteria are meant as refinements to achieve for each global property, which can be associated with a testing protocol, used to validate the technical solution.

For example, the criteria that Protei_006 be self-righting is tested by manually heeling the boat in the water to 90° and evaluating if it returns its original position. If it does so, we can state that the combination of the Ballasted Keel and the Light Superstructure meets the self-righting criteria.

Propery	Criteria	Solution
Maneuverable	Steerable while towing	Shape-shifting through a flexible hull
	Optimised to sail upwind	Control of the sail
Stable	Self righting	Ballasted Keel
		Light Superstructure
	unsinkable	Puncture Proof Buoyancy Material
		Enough Buoyancy
	Robust	Neoprene Skin and use of robust materials
Safe	Collision-safe	COLREGS Compliant lighting system
Towing Capable	Can tow sorbent	Enough Pulling force Boom hooking point
Unmanned and automated	RC (for steering and sail trim) up to 1000m)	Xbee module
	Determines position data	GPS Module
	Store GPS data	SD card shield
	Power	Battery

General properties

General Specifications

Length overall: 3.0 m
Beam: 1.42 m
Mast height: 3.78 m
Max draft: 1.47 m
Voltage: 14.4 V
Max current draw: 45 A
Displacement: 120 kg
Desired steady state speed: 2 knots

Picture of the real thing

System Overview

Protei_006 is a 3 meter remote-controlled boat, controlled over radio by a user within 500m and line of sight. It has a segmented, shape-shifting hull, constructed of flexible spines that run lengthwise (through cross sectional bulkheads) and bend under stress. A flexible EPDM-Foam skin encases the skeleton. There is one 4 meter tall sail, and a large keel that extends downwards 1.2 meters from the hull. The majority of the boat's ballast is housed at the lowest point of the keel, which provides most of the stability. This also enables Protei_006 to be somewhat self-righting.

Protei_006's body is nearly cylindrical and very unstable. Most righting momentum comes from our ballast to right the vessel. In case of a violent gust of wind, the sail lies flat on the water, safeguarding it from destruction.

For steering and control, Protei_006 has three motors - one spins a winch to control the trim of the sail. The other two are attached to linear actuators that each control the articulation of the bow and the stern, which curve independently. The actuators pull and release cables that run throughout the longitudinal spines of the hull.

The battery and linear actuators, which provide most of the weight of the boat, are at the bottom of the keel, along with 25kg lead ballast. The main electronics, the winch, and the GPS are housed in the waterproof, shockproof pelican cases[1] compartments of the hull (which make up the separate segments). Protei_006 stores GPS data from its trips.

1 http://www.pelican.com

Fiona’s stuff on the new ID doc. xfer to here

Mechanics
System overview

Protei_006 is the first “large scale” Protei prototype. She is meant to be an articulated sailboat that can carry hardware to perform oil collection and remote sensing at sea . The design is a bio-inspired design, with almost elliptical hull profiles. The construction of Protei is meant to be replicable by amateur builders and enthusiats. This section describes the process of building and assembling the mechanical components of Protei. In addition to this document, CAD files and drawings are provided on the website so that laser cutting and CNC machining are possible.

Hull

The hull of Protei is based on a skeletal structure composed of cross sectional bulkheads and longitudinal spines. The hull is divided into segments that are delimited by bulkheads (sometimes referred to as “ribs”) which define the shape of Prote_006. The bulkheads are connected via PVC tubes that are referred to as “spines”. There are twelve outer spines that define the shape of the hull and one central spine that holds the bulkheads together around which everything bends. The spines are comprised of tubes of different diameters so that they slide into each other and allow the hull to bend. The outer spines are attached to each bulkhead by rivets, which allows each segment to be dismantled while still connected to its spines.

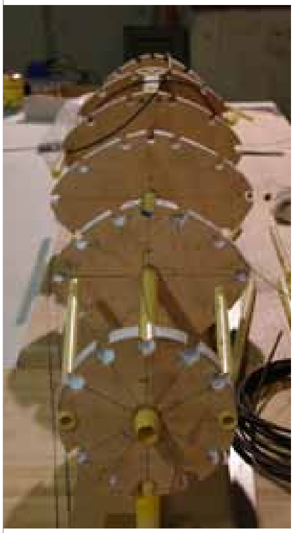


Fig. _._ Hull construction and assembly of the bulkheads

Hull Construction and Assembly

The hull construction and assembly process can be divided as follows:

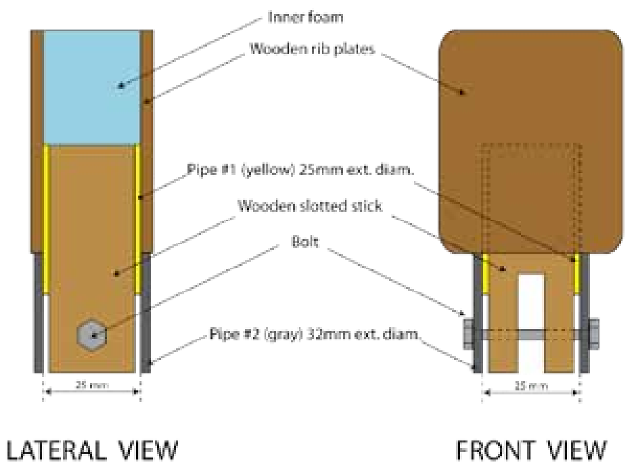
A) Bulkhead Fabrication
B) Pipe Cutting and Assembly
C) Riveting the Hull
D) Adding Flotation

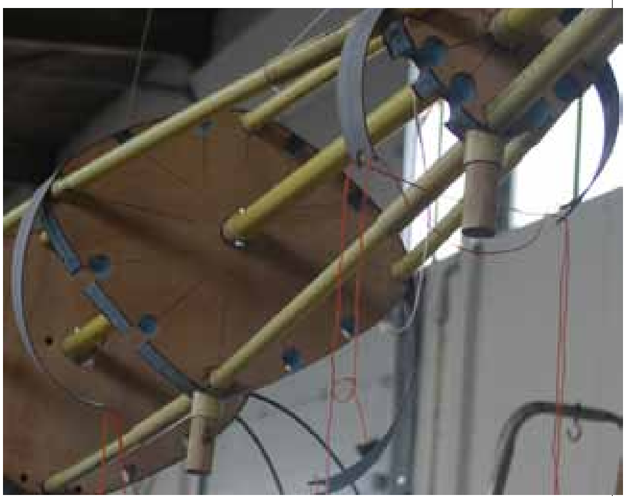
Fig _._ numbering of the bulkheads

A) Bulkhead Fabrication

Bulkheads are cut from 3.5mm plywood (DXFs are available in appendix) and glued to foam with epoxy. Holes are drilled through the plywood-foam composite for the spines to fit through. Finally, the keel attachment is placed at the bottom of every bulkhead (refer to diagram below).


Fig. Cutting the bulkheads





Next, the connection between bulkhead 3 and 4 is built (technical drawing available in appendix) to construct the 3-4 connection pieces from a wood and foam sandwich. In addition to the main sandwich piece, there are 4 aluminum pins and 4 wooden supports that maintain the connection attached to bulkheads 3 and 4.
After the parts are fabricated, the wooden supports are screwed into the bulkheads 3 and 4, and the sandwich is connected to these supports using four pins (these pins can be PVC but preferably should be aluminum).

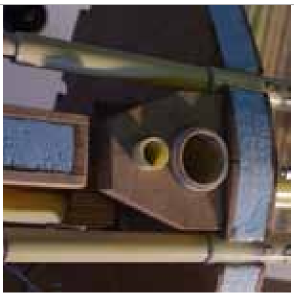
  

Fig _._

B) Pipe Cutting and Assembly of Spines

The central spine is made up of a 3m long, 22mm extension diameter PVC tube that runs through the body. To constrain ribs laterally, 50mm pieces of PVC (26mm ext diameter) pipe are glued to the bulkheads (see detail below). The spine is passed through the bulkheads and a screw and nut are used to connect the long spine to the 50mm pieces.

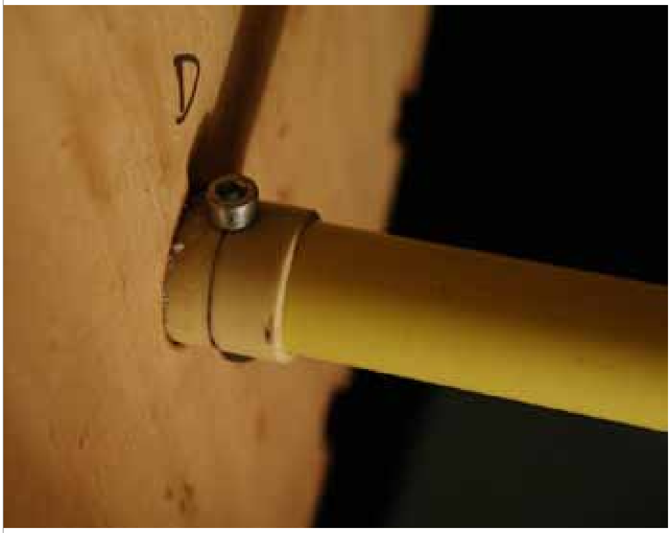


Fig _._

The next step is to cut the PVC tubes for the lateral spines. From now on, this section refers to two different types of tubes: the tubes referred to as "active" *do* have Bowden cables inside (there are 4 of them - one for the top,bottom starboard and port); whereas "passive" spines refer to those that do not have Bowden cables (there are 8 of these).

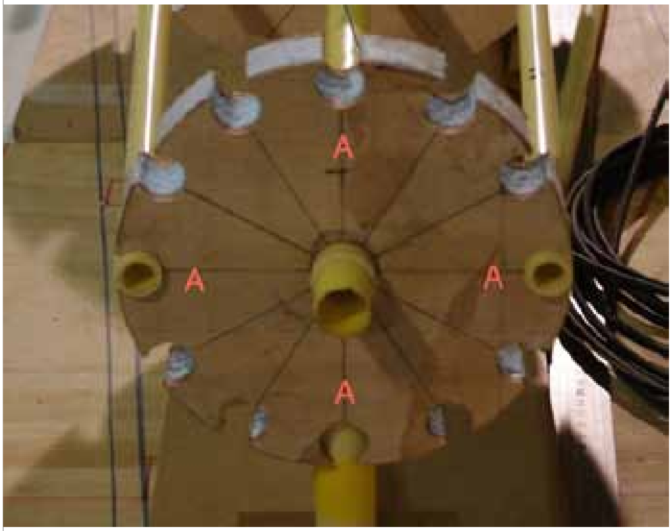


fig. _._ Bulkhead 7 with the slots for the active spines labeled (the unlabeled ones are passive)

Assembling the Active Spines

Assembling the 4 active spines is a rather complicated task.

The active spines are comprised of two different diameters of PVC tubing: 16mm tubes that slide into a 19mm PVC tube that is glued to the bulkheads using epoxy. See the picture below for detail:

Fig _._. Gluing actuation tubes to bulkheads.

After the spines are in place, the Bowden cables can be routed. The starboard and port Bowden cables are routed first. These cables are routed from the bow and stern to the midships compartment (between bulkhead 3 and 4). The cables are constrained at the bow using another piece of PVC glued into the inside of the spine and a Bowden cable screw. A detail of how the cables are constrained at the bow is shown below.

Fig _._. Constraining of the Bowden cables at the bow. Note the Bowden cable screws and brown PVC insert. The stern cable attachments are done the same way.

The lateral Bowden cables travel through the spines until the midships compartment where they are routed to the starboard side so they can be then pulled on by the linear actuators. Detail is shown below.

fig. Detail of the midships starboard compartment showing lateral Bowden cable connections

Next, the top and bottom Bowden cables are routed, these cables are not meant for actuation but for changing the amount of vertical curvature and to provide some flexibility of the hull in waves. These cables are attached to springs close to the midships compartment.

fig. Detail of the top Bowden cable attachment to the midships section.

Assembling the Passive Spines

The 8 passive spines are assembled in a similar, but more straightforward, way than the active spines. Pieces of 12mm PVC tube run between each bulkhead and are glued to a 14mm outer PVC tube that then gets riveted to the bulkhead.

fig. Hull alongside the glued passive spines ready to be inserted

C) Riveting the hull

fig. Rubber and Textile belts around bulkheads with orange tension lines (left) and rivets (right)

D) Adding Flotation to the hull

There were two ways of adding flotation that were explored. First, airbags were placed inside the body and pressurised so that they fit snugly inside each compartment.

fig. Airbags inside hull

However, the airbags were abandoned because it added too much stiffness to the bending, and the seals on the bags were not reliable as they constantly leaked. As an alternative, Styrofoam slices were used to provide flotation. Circular slices were cut for each section and then adjusted to allow space for boxes, connectors, spines etc. inside the hull.

fig. Adding flotation to the hull

The Styrofoam slices had the advantage that they provided a fixed amount of buoyancy and did not oppose the bending of the hull.

Keel

Fig. Inner structure of the keel

Fig. Finished keel with linear actuators, batteriesand ballast mounted

The keel is comprised of vertical layers of wood sandwiched together by two outer plates on either side. It extends downwards from the body of the boat 1.2 meters, and houses most of the boat's ballast at its lowest point, which keeps the boat upright. Three horizontal slots are cut in the very bottom of the keel, one for the battery tube and ballast, and two for the linear actuators. In the inner vertical plates of the keel, there are two narrow slots running vertically from the horizontal slots, to the compartment in the body of the boat that houses the electronics and the winch. Through these slots runs tubing which holds the wiring from the batteries and the linear actuators in the keel to the control box.

The two outer plates are screwed in at multiple points, yet removable. The three horizontal slots at the bottom of the keel enable easy removal of the linear actuators and the batteries.

Keel Construction and Assembly

The keel is composed of four inner wooden plates, two for each side, cut to the following dimensions (Fig. x.x). These four sections are sandwiched around the skin with two outer plates that are and bolted in (see the "x" marks in Fig. x.x). The grooves allow for the tubing for the cables and the wiring to run vertically from the keel to the body.

fig x.x - the four inner plates bolted together

fig x.x. The multiple layers of the keel

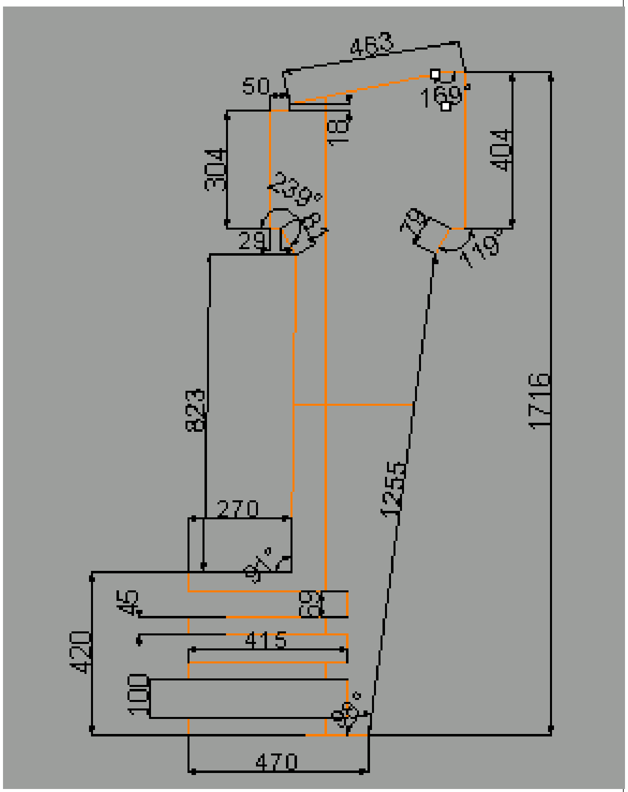


Fig _._. Keel shape and 2D drawing with dimensions (in mm)

Skin

Rivet the skin

The skin is constructed from neoprene segments, organized in an 'armadillo armor plate' fashion. Each segment will slide over the other, allowing the articulated hull to curve. At the front sides of each segment, the skin is riveted onto the frame of the hull. At the backsides, each segment is hold in position by slightly pre-tensioned rubber straps. The rubber straps make sure that the entire skin will return in the straight position after the hull is being bent. The neoprene is reinforced on all the edges with rubber, to prevent ripping. The skin is not waterproofing the hull, as that is not the aim. It's major task is to streamline the hull and to add to the buoyancy of the vessel.t

Reinforce the edges

The skin consists of seven segments, draped over the hull and attached to the keel and the frame.
[Insert overview photo of the skin]
The pattern of the skin: [Insert Illustrator file with patterns]
Each segment is secured by a flexible rubber connection. The pattern of the connection patches: [insert pattern of the wooden stencil]
At the bottom, the skin is attached to the rubber keel with bolts, nuts and washers. This is the schematic pattern for the reinforcement at the bottom:
[insert pattern]

Glue rubber and Neoprene

xxx glue and xxxx binder are used to glue the rubber to the neoprene. A few drops of the binder is stirred into the glue, until they are well-mixed and a homogeneous color. The rubber is sanded thoroughly and cleaned with acetone. A layer of the glue on is applied to both surfaces. After drying for a few minutes, the rubber and the neoprene are pressed firmly together, at every contact point. Applying force is more important than the duration of the pressure. To prevent buckling of the rubber, it is stretched slightly when attached to the neoprene.

Add flexible connections

Flexible rubber straps are glued to the sides of each skin-segment. Inner tubes are also appropriate here. A slit is cut at one end (of what?the strap or the tube or the segment...), and the edges are rounded off. The cut inner tube can be slid over the side (of what?) and glued to the neoprene. Make sure to use the most flexible ones (what?) you can find! The straps hold the skin in position, therefore they must apply a certain tension to the skin. High elasticity is key because if the tension of the skin is too high, the motors will be strained when curving the hull. For extra reinforcement, rubber sheet connection patches (seen in figure...?) can be glued on top of the straps. Stencil (figure x.x) refers to the shape that the strap should be cut. Once cut to shape, a slit is cut in the middle (of what?) so that the ropes can be pulled through and tied to the rubber strap of each segment in front.
[insert photo of white rope + knot]

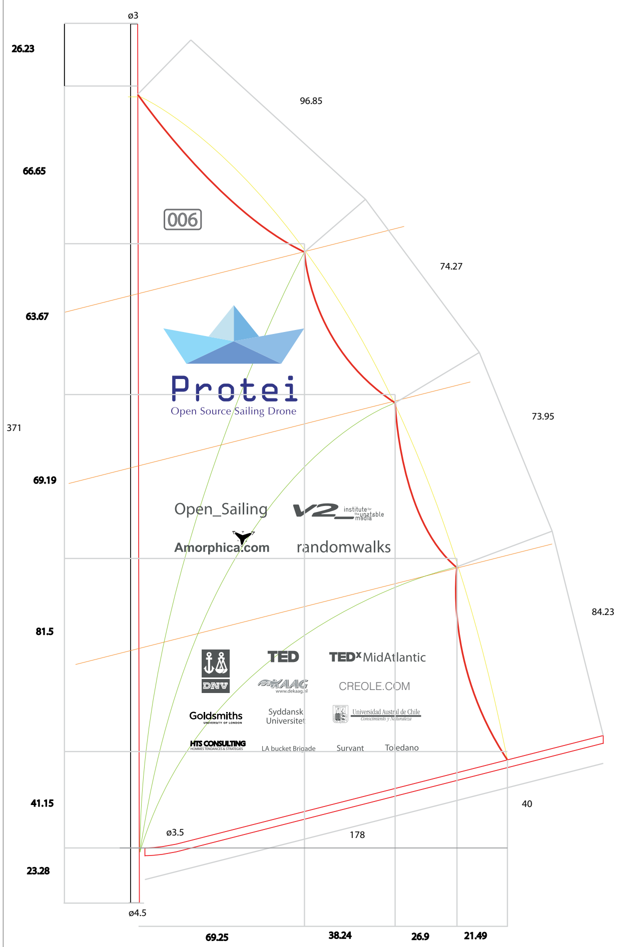
How to build (pictures, tips & howto's) Rivet the skin

Cut out the pattern pieces of the skin segments and drape them over the hull. Cut six straps from rip-stop material, lengths according to the circumference of each hull slice. We used left-overs from the sail to create the straps. Position the strap in the centre of a hull slice and drill a hole that fits your rivet. Start at the bottom of one side. Fasten the first rivet. If it is hard to push it in, gently hammer it. Pull the strap tight and work your way around the segment. Repeat this procedure for each part of the skin. Please note that each skin segment should only be attached on the front sides. The backsides stay loose in order to be able to reach the electronics inside the hull.
[insert photo of rivets and white strap]
The first segment, the 'nose', is an exception. This one is not riveted. Sew a few inches to close the nose and slide it over the frame.
Reinforce the edges
The skin needs to be reinforced with rubber on every part where force is applied. More specifically, at the bottom where it connects to the keel and around every cut-out on top. Inner tubes from bicycle wheels are very suitable to do the trick. Most of them will have a fold, which you can use to slip it around the edges easily.
For the bottom parts: cut the tubes open as shown in the picture, to benefit from he fold and to maximize the area where the bolts and washers will be attached later on.
[insert sketch of cutting the inner tube]
Glue rubber and Neoprene
To glue the rubber on the neoprene, we used glue and a binder. Add only a few drops of binder. Stir the two components until they are mixed well and you reach a homogeneous color. Sand the rubber thoroughly and clean it with acetone. Apply a layer of the glue on both surfaces. Let it dry for a few minutes, then press both parts together. Note that it is contact glue, so you really need to press every single inch. Applying force is more important than the duration of the pressure. To prevent buckling of the rubber, stretch it a little bit when attaching it to the neoprene.
Add flexible connections Flexible rubber straps are glued to the sides of each skin-segment. Again, inner tubes can be used. Cut a slit at one end. Round-off the edges. Slide it over the side and glue it to the neoprene. Make sure to use the most flexible ones you can find! The straps are meant to hold the skin in position, therefor they must apply a certain tension to the skin. However, all these forces add up and will give the motors a hard time when

curving the hull. High elasticity is key. For extra reinforcement (and better looks), we glued rubber sheet connection patches on top of the straps. See stencil for the shape. Cut a slit in the middle. Pull the ropes through. Tie the rope to the rubber strap of the segment in front of it.
[insert photo of white rope + knot]
Connection to the keel
Finally, the skin is closed around the hull by connecting it to the keel. Make holes through the upper part of the keel and both sides of each skin segment. Put a bolt through, with washers on both sides. We used these special ones, for a nice finishing:
xxx
[insert picture]
Trouble shooting, conclusions etc
For the prototype of Protei 006, we used neoprene to construct the skin and the keel. Advantages are the flexibility and the buoyancy properties. However, we did not research the chemical aspects yet: how will it be affected when in contact with crude oil? Furthermore, neoprene rips or tears easily when there is a small scratch. One might want to research similar materials that are stronger.
Same chemical consideration goes for the PVC tubes!

Sail

Inspiration



Pic-
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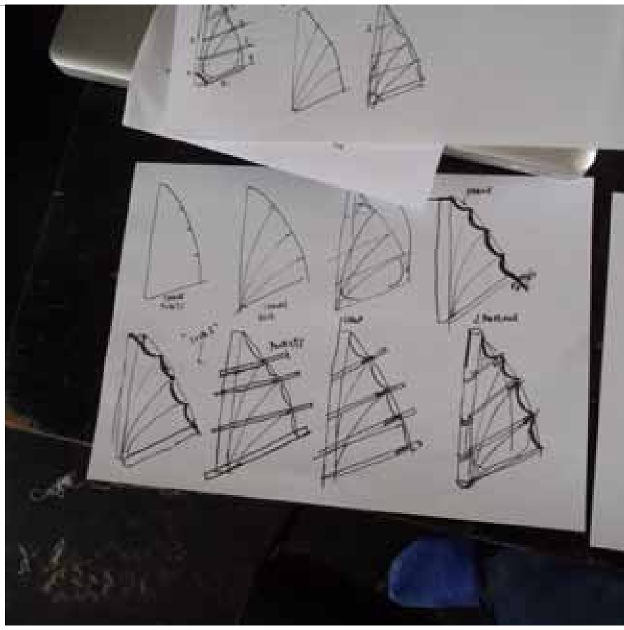



Protei


CREOLE.COM
Goldsmiths

Picture of the real thing

Picture of the real thing

Ropes

Sail Winch

Fig x.x. Overview of the system

Sail winch overview

The sail winch provides the control of the main sail of the the boat, by reeling in or out the main sheet. It consists of a drum shaft-coupled to a DC motor, a lid for waterproofing, and three blocks for wiring.

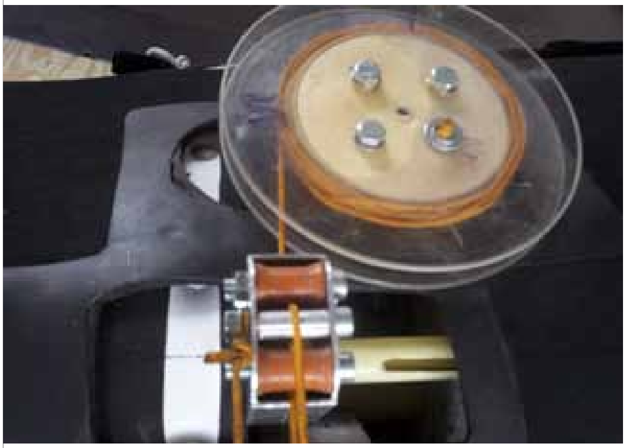


Fig. Drum and main block wired

The main block is fixed to the hull and consists of three rolls that distribute the main sheet to the second block, comprising a traditional double pulley system. The last block is a simple shackle connected to the boom by a wooden clamp.

Between the double pulley and the shackle, there is only one sheet that is doubled by a shorter rubber band, in order to keep tension at any time.

Fig. 3D view of the winch

Sail winch assembly

The assembly for the winch is divided into the following steps :

1. Assembling and fixing the winch motor box
2. Assembling and fixing the main block
3. Assembling the boom clamp
4. Wiring the drum, the main block and the double pulley
5. Wiring the shackle

Fig. 12V windscreen wiper

Fig. Motor, shaft, coupling, lid and wooden support.

Fig. Motor,lid and wooden support assembled

Fig. Aluminum shaft

Assembling and fixing the winch motor box

The winch motor box is composed of :

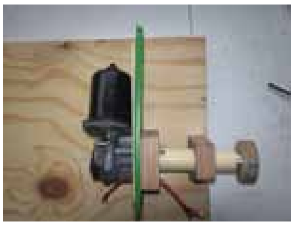
- a 12V DC geared motor. We used a car windshield wiper motor (see picture)
- a lid and the associated box for waterproofing.
- a wooden support, that will be screwed to one of the boat's ribs. This support has a hole for the shaft, three holes for the vertical screws, and a hole for the power cables
- a small piece of PVC tube glued inside the hole for power cables to let the power cables go through the lid.
- an aluminum coupling that fits inside the hollow shaft and around the motor shaft.
- an aluminum hollow shaft with a coupling for the motor (Ø28mm, length : 125mm)
- a wooden drum support (Ø58mm, 2cm long) with a centered hole of Ø28mm
- a drum : two round slices of Plexiglass (Ø14cm) and an inner drum of Ø8cm.

We used three vertical screws to hold the motor, the lid and the wooden support together. In order to provide efficient coupling with the motor, we drilled a Ø4mm hole trough the motor output shaft and we threaded it (M4 standard metric — ISO 965). We used two M4 screws to hold the motor shaft, the coupling and the aluminum shaft.

The wooden drum support is first screwed horizontally to the top of the aluminum shaft, then screwed vertically to the support. In order to avoid tearing the skin or jamming in the drum, the screw heads are counter-sinked.

Motor, lid, support and aluminum shaft

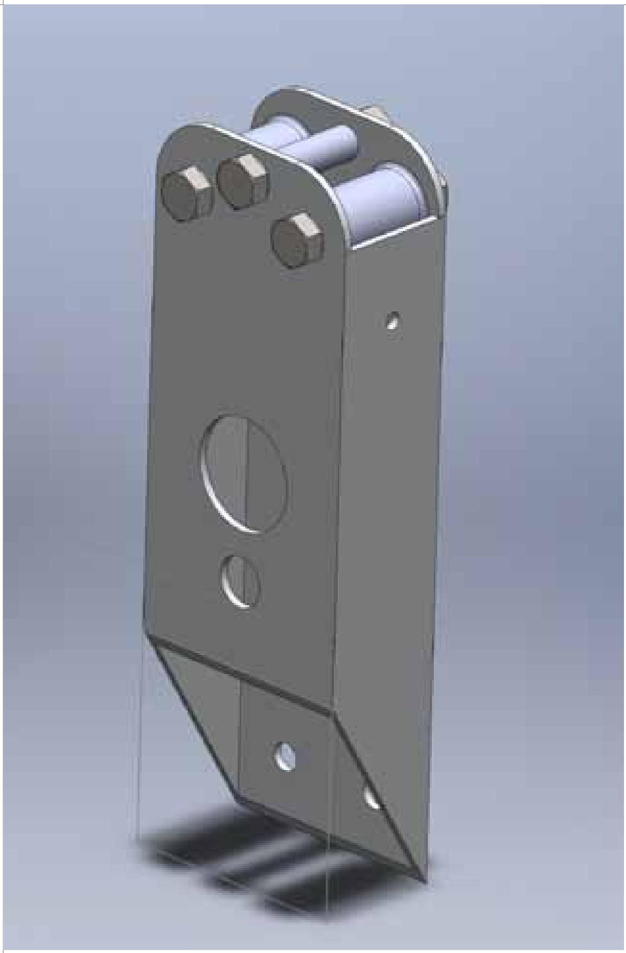
PVC Guide added



Drum support added

Drum added

Fig. _._ - _ A flexible rubber tube running to the control box can then be clamped to the output of the PVC tube, to provide efficient waterproofing.



3D isometric view of the main block

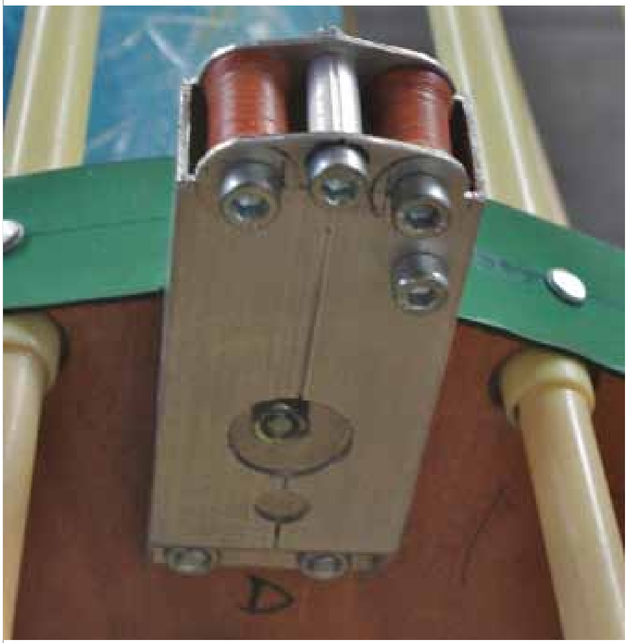


Fig the main block, before wiring

Assembling and fixing the main block

To the left is a 3D view of the main block:

- the central hole (Ø20mm) is designed to let one of the skeleton spine go through.
- the secondary hole (Ø9mm) is designed to access one of the bolt that holds the main block to the rib.
- the back holes (Ø5mm) are also designed to hold the main block to the rib.
- The lateral hole (Ø3mm) is the entry point for the sheet coming from the drum.

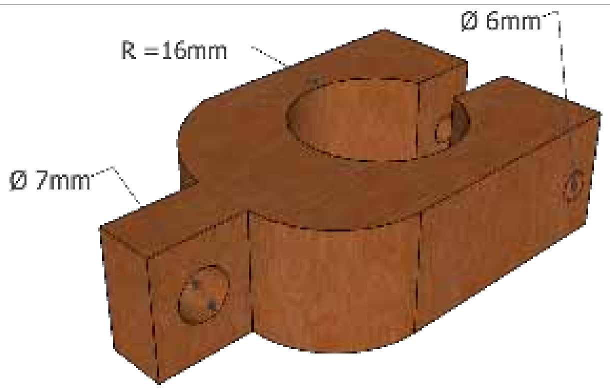


Fig the boom clamp

Assembling the boom clamp

Here is a 3D view of the boom clamp :
The shackle is attached to the 7mm hole.
A bolt is going through the 6mm hole to clamp the boom, which goes through the 32mm main hole.

Wiring the drum, the main block and the double pulley

Attach the sheet around the drum and follow these steps :

1. insert sheet into the lateral hole from the main block
2. go around one of the main rollers
3. go around one of the double pulley rollers
4. go around the second main roller of the main block
5. go around the other double pulley roller
6. attach the end of the sheet to the central roller of the main block.

Wiring the shackle

1. Fix the shackle to the Ø7mm hole of the boom clamp.
2. Wire the shackle to the double pulley with a 10cm long sheet.
3. Cut a 7cm piece of rubber band and attach it between the shackle and the double puley. Make sure it is shorter than the sheet, but long enough not to break when tension is applied (the sheet should then support the tension)

Linear actuator

As mentioned in the previous chapter, Protei is a boat with a shape shifting hull. Thus external power (force) is required to control the shape of the hull. The linear actuators are built to fulfill this functionality. The maneuverability control of Protei is through its shape changing, like the behavior of fish, not by the conventional rudder. Hence, a powerful and reliable linear actuator is a crucial factor to the survival of Protei in the open ocean. Two identical linear actuators are constructed for Protei 6: one for the bow and the other is for the stern. So by appropriate control algorithm, we can control the bow and the stern separately. And besides the banana shape of Protei, we can also make an s-shape of protei.
Overview

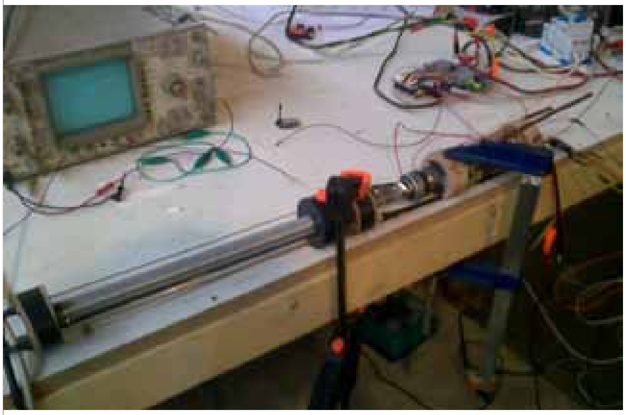


Fig. Mounting the linear actuator to the keel
After testing, the linear actuator are encapsulated into the yellow PVC tubes and fixed by screws. The yellow PVC tubes are used as both the frame and the water proof shield. When mounted to the keel, these actuators are located at the bottom.

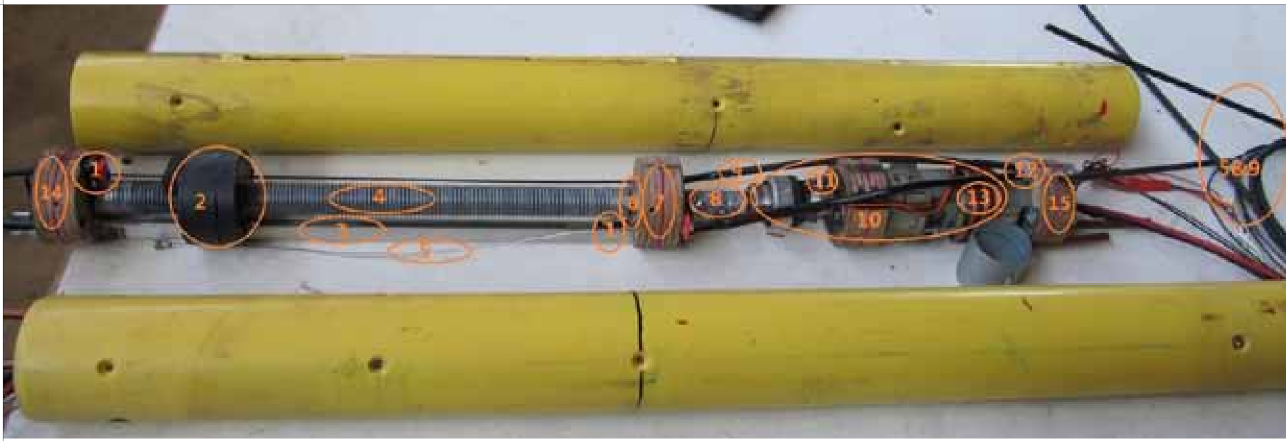


Fig. structure of the linear actuator
Component list:
Limit switch
Pulling part (with a nut inside)
U-shape aluminum guide
thread shaft
bowden cable
bearing
Wooden support part B
soft coupling tube and holes-clamp
bowden cable housing
DC motor with gear box and clamp (from electric hand drill)
magnet sensor
Bowden cable guiding nut
water circulation tube
Wooden support part A
Wooden support part C

How does it works

As shown in the above picture, there is bowden cable fixed on the pulling part. when the DC motor rotates, the pulling part moving back and forth, thus the bowden cable is pulled or released. When one side of the bowden cable is being pulled, the bowden cable on the other side is releasd, resulting in the boat curving to one side. The limit switches are used to detect the extreme position of the pulling part. When one of the limit switch is being trigged, the motor has to stop rotating immediately and reverses the direction. The magnet, together with a hall-effect sensor, is used to count the number of rotation. From the number of rotation, we get an indication about the moving distance of the pulling part.

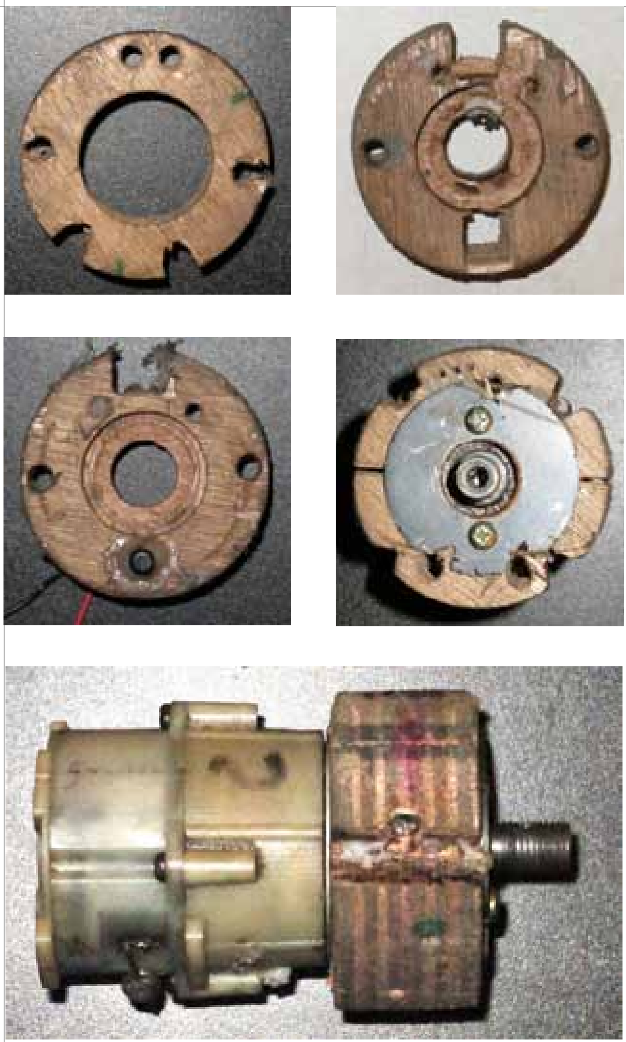


Fig. wooden support for the gear box of the DC motor

All the wooden supports has the same outer diameter, so that they can be mounted into the same tube and keep the shaft concentric. One of the disadvantages of these wooden parts is that although they are very easy to manufacture, they are not strong enough to endure strong force. We have already switched to aluminum materials for these supports.

The idea of water circulation tube is to cool the DC motor while its own cooling fan doesn't work. When Protei is moving, it creates water pressure which force the water comes in through one of the tube and goes out through another tube. To make this circulation possible, at the inlet of the tube we put a trumpet shape connector to collect water pressure. This connectors are composed of several tubes in different diameters mounting together.

Fig. Trumpet shape connector for water circulation tubes

Electrical Overview

Protei's electrical system is designed to accomplish two tasks: communicate reliably with an onshore transmitter, and precisely control the on board actuators.

Communication is accomplished using Xbee modems, which allow for medium range (maximum 500–1000m) bidirectional wireless communication.

Two of the actuators control linear movements, these are located in the keel. Through the use of limit switches and a rotational sensor, these can be position-controlled in closed loop feedback. The third actuator, the sail winch, can only be open-loop-controlled at the moment, though connections have been built into the microcontroller to allow for future closed-loop-control using a rotational sensor.

The diagram below shows a schematic representation of the data and power connections between components on Protei_006. It also provides a not-to-scale representation of the physical location of these items. Each item is described in further detail on the following pages. Larger schematic images can be found in Appendix B, and source code can be found on Protei's git repository, at: https://github.com/Protei/Protei-005-6.

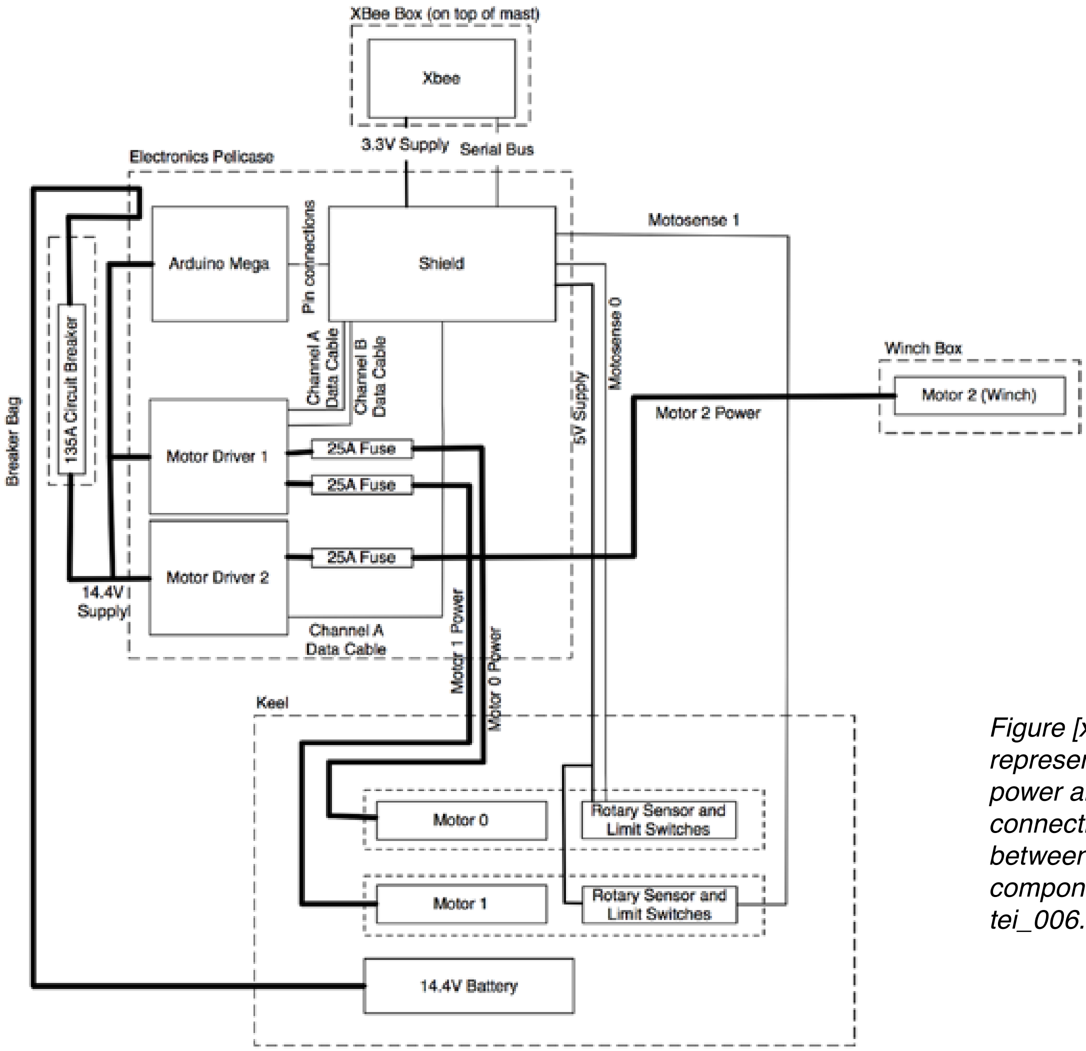


Figure [x]: A schematic representation of the power and data connections between electrical components on Protei_006.

Cable Routing

Routing cables between the different dry compartments on Protei_006 is actually quite complicated. Each box has one or more short pieces of PVC pipe inserted into it, and glued and waterproofed. A flexible hose is clamped around the rigid pipe, and electrical wires are forced through the flexible hose. In this way, we can create waterproof connections without the expense of pricy waterproof connectors. The diagram below shows a schematic of these wires and the hoses the connect the dry compartments.

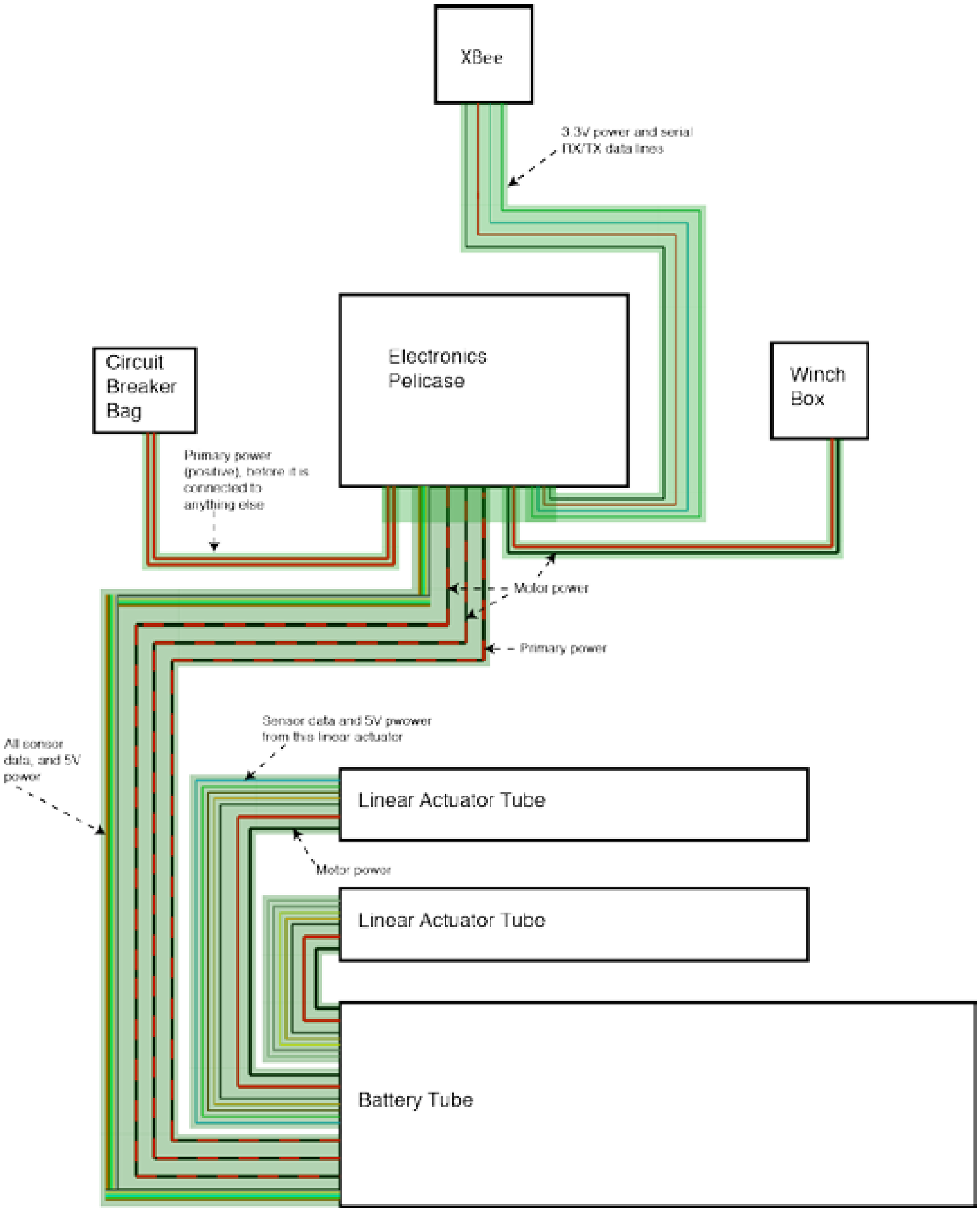


Figure [x]: A schematic of the cable routing on Protei_006. Thick red and black lines show power connections, thin colored lines are data connections.

The largest cable hose, running from the Battery tube to the electronics box, runs inside the keel. The hose to the Xbee runs inside the mast, and other cables are simply routed around spines and bulkheads as convenient.

Figure 3.X: This cutaway view of the keel shows the channel that the hose runs through, inside the keel.

The wires indicated on this diagram are the actual wires that run inside Protei_006. Thick red and black lines indicate the AWG 14 power cables, and thinner colored lines are small AWG 22 signal wires. The color code is completely arbitrary, the only thing that is important is to be self-consistent. The signals in the sensor bundle are: 5V, ground, two limit switches and a rotational sensor for each actuator, for a total of eight signals. It also happens that the number of signal lines in standard Cat5 cable, so we used a Cat5 cable (not in twisted pair configuration) and an RJ45 connector for this connection.

An example of the waterproofing system for connections is shown below:

Figure 3.X: On the left, a PVC tube connector for an early prototype of the electronics box. On the right, the XBee tube, showing the hose connection there. Note that the portal is always a rigid tube, with a flexible tube then clamped (not shown)

Actuation System

Linear actuators

The linear actuators on Protei provide the pulling force necessary to bend the boat. The mechanical design has already been described above, This section focuses on the electrical design of the actuators. Electrically, there are two separate mechanisms — the driving mechanism, and the sensing mechanism.

Driving

The motor is driven through an H-Bridge motor driver, purchased from Elechouse[1]. The manufacturer claims that it will work with 12V motors at 50A continuous and 100A peak current. We have not thoroughly tested these claims.

Figure [x]: The motor driver board used for driving the actuators on Protei.

As shown above, each channel has six logic inputs — VCC, GND, EN (enable), RPWM ("right pulse width modulation" — this drives the right hand side of the H-Bridge), LPWM ("left pulse width modulation"), and DIS (disable). DIS is always left unconnected, as we do not need the functionality that it provides. VCC is connected to +5V, GND to the GND of the microcontroller, and RPWM and LPWM are connected to two PWM capable output pins from the microcontroller. EN is connected as described below in the sensing section. 12V straight from the main battery is connected to the POWER header on the opposite side. Each motor is connected to the controller in series with a 25A fuse to prevent the motor from damaging the motor driver.

1. http://www.elechouse.com/elechouse/index.php?main_page=product_info&products_id=667

Sensing

Sensing is accomplished through two mechanical limit switches, on either end of the actuator's linear range, and a Hall Effect sensor, which detects the rotation of a magnet attached to the motor's shaft. A schematic of the sensing mechanism is shown below. This is, of course, duplicated for each actuator. An Eagle Layout Editor file for this schematic, and all other referenced electrical drawings, is available on the Protei git repository: https://github.com/Protei/.

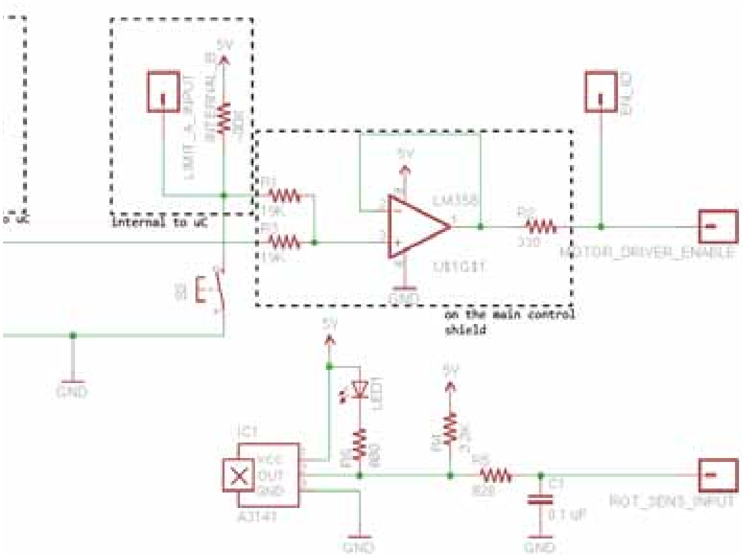


Figure [x]: The limit switches and rotational sensor.

The most complicated part of the above schematic is the limit switch function. The limit switches have two functions: the microcontroller can detect the state of each limit switch individually; and, if either switch is depressed, the motor driver will be disabled, until the microcontroller re-enables it. This is implemented through the use of the tri-state logic capability of the microcontroller digital I/O. When the EN_IO pin is set to high impedance (input) mode, the value of the motor driver enable pin is entirely set by the state of the switches. When one of the switches is toggled, the enable pin goes low, and can be reasserted high by changing EN_IO to output mode. In this way, the actuator is protected against software failure, and does not solely rely on the microcontroller for detecting switch presses. Obviously this only works if the default state of EN_IO is high impedance.

The rotary sensor uses an Allegro A3141 hall effect sensor to detect the presence of a magnet on the motor shaft. R4 serves as a pull-up resistor and R5/C1 is a lowpass filter. The output is briefly set low once per revolution, as the magnet passes the sensor. This can be read with a digital input on the microcontroller.

Communication system

The communication system uses two Xbee Pro 900 Series 1 devices for short range (~1000m) bidirectional radio communication. These communicate using the following simple protocol. The source code for the transmitter is in `ArduinoRC.pde`, and for the receiver, in `ArduinoControl/comm.h`, on the Protei git repository.

Every 100 ms, the joystick controller (transmitter) sends three pieces of information to Protei: the position of its left joystick, the position of its right joystick, and the status of its buttons (127 if no buttons or all buttons are pressed, 0 if just the left button, 255 if just the right button). These three bytes are split into two half bytes of 4 bits each, and each half byte is encoded with a Hamming7,4 code plus an overall parity bit to improve reliability of communication.

```
`S’
[halfByte1A]
[halfByte1B]
[halfByte2A]
[halfByte2B]
[halfByte3A]
[halfByte3B]
`E’
```

After Protei receives and processes the data from the transmitter, it responds by sending a message with a similar protocol, containing status information of the boat.

```
`S’
[statusHalfA]
[statusHalfB]
`E’
```

`statusHalf`, prior to being split into two half bytes and encoded with a Hamming7,4 code, is a bitmap with the following values:

MSB							LSB
N/A	N/A	Stern Actuator Rotation sensor (HIGH or LOW)	Stern limit switch B	Bow limit switch B	Bow rotation sensor	Bow limit switch B	Stern limit Switch A

Table 3.X: The bitmap of status information used to control status LEDs on the remote control.

This information is used by the joystick controller to display six status lights. A seventh status light blinks with each successful radio exchange, and an eighth simply indicates when the controller has power.

The remote controller is a modified hobby RC controller. The electronics have all been replaced with an Arduino and the XBee described above. Below is an image of the front side of the controller.

Figure [x]: An image of the remote controller used for Protei_006.

The functionality of the switches and indicators shown above are:

1. Sail winch wind up
2. Remote control power
3. Sail winch unwind
4. Bow articulation position
5. Stern articulation position
6. Remote control power light
7. Limit B switch status LED, bow actuator
8. Rotation sensor status LED, bow actuator
9. Limit A switch status LED, bow actuator
10. Limit B switch status LED, stern actuator
11. Rotation sensor status LED, stern actuator
12. Limit A switch status LED, stern actuator
13. Radio link status LED

Figure [x]: The XBee Pro 900 (Series 1),
used for sending and receiving data.

3.4 Microcontroller and connection shield

The primary microcontroller on Protei is the Arduino Mega 2560. We designed and built a custom connection shield for the Arduino.
The purpose of this shield is threefold: to contain the logic for controlling the motor driver enable pins, as described in the “Linear Actuators / Sensing” section above; to provide a regulated 3.3V supply with sufficient current for the XBee; and to make easy connections between the motor drivers and sensor inputs, and the pins on the Arduino Mega.
The voltage regulator used is an LM1117, with a 22 uF capacitor on the output (required by the LM1117 for stability), as shown below:

Figure [x]: The XBee power supply.
A list of the pin connections is shown below.
Pin choices were made by required functionality (PWM, a hardware serial port, etc), then by physical convenience (their location on the Arduino Mega).

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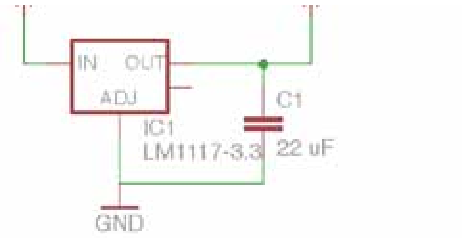


Figure [x]: The XBee power supply.

A list of the pin connections is shown below. Pin choices were made by required functionality (PWM, a hardware serial port, etc), then by physical convenience (their location on the Arduino Mega).

Motor Driver 1, Channel A, Enable	42 (Digital input/output)
1A, RPWM	5 (PWM)
1A, LPWM	6 (PWM)
1B, Enable	44 (Digital input/output)
1B, RPWM	4 (PWM)
1B, LPWM	7 (PWM)
2A, Enable	36 (Digital input/output)
2A, RPWM	8 (PWM)
2A, LPWM	9 (PWM)
Bow Actuator, Rotation Sensor	2 (Interrupt 0)
Bow Actuator, Limit A (lower)	38 (Digital input)
Bow Actuator, Limit B (upper)	40 (Digital input)
Stern Actuator, Rotation Sensor	3 (Interrupt 1)
Stern Actuator, Limit A (lower)	46 (Digital input)
Stern Actuator, Limit B (upper)	48 (Digital input)
Winch, Rotation Sensor (currently unused)	21 (Interrupt 2)
Winch, Limit (currently unused)	50 (Digital input)
Xbee, DIN	18 (Serial1)
Xbee, DOUT	19 (Serial1)

Table 3.X: Pin connections between the Arduino and peripherals.

A schematic of the layout for this shield is shown below. Red indicates connections directly along the surface of the protoboard, and other colors indicate connections made using wires attached to the protoboard. Note the LM358 in the center left, and the voltage regulator in the upper left.

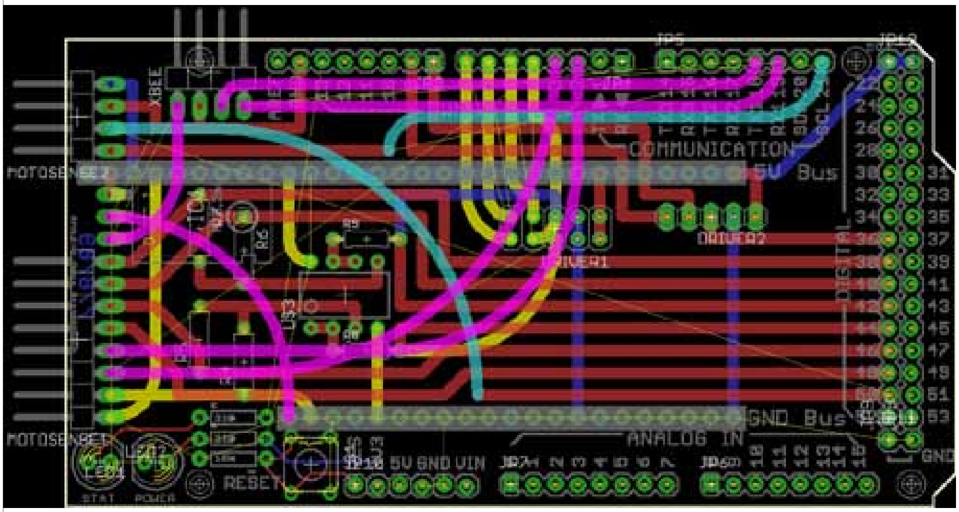


Figure [x]: The physical layout of the Arduino Mega shield.

The connector labeled “MOTOSENSE1” has the following connections, from bottom to top: 5V, ground, rotational sensor for actuator 2, rotational sensor for actuator 1, limit switch B for actuator 2, limit A for actuator 2, limit B for actuator 1, limit A for actuator 1. MOTOSENSE2 is not connected in Protei_006, but the connections have been installed for future use. From bottom to top: winch rotational sensor, winch limit switch, ground, 5V. The XBee connector from left to right is: 3.3V, ground, XBee DIN, XBee, DOUT. The motor driver connections are, from left to right, LPWM, RPWM, Enable, ground, 5V.

Two images of each side of the completed Arduino shield are shown below. In the future, it would make sense to have a real printed circuit board professionally fabricated, for the rapid pace of development of Protei_006, it did not.

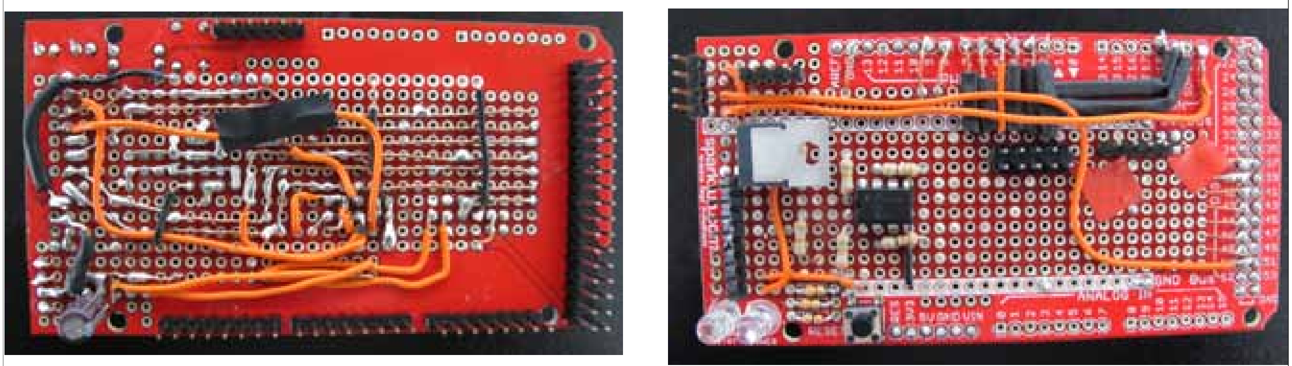


Figure [x]: The assembled Arduino Mega shield.

The Arduino Mega 2560, with its input shield, is mounted with the motor drivers and protection fuses inside a waterproof Pelicase.

Figure [x]: The mounting of the Arduino Mega (with shield), and the two motor drivers (stacked on top of each other) inside the waterproof Pelicase. The colorful cables on the right connect the shield to the motor drivers, and the thick wires on the left provide connections for the motor cables (which enter though a tube on the back of the Pelicase).

Power

Picture of the batteries

Power for Protei is supplied by a 14.4V, 9.9Ah nickel metal hydride (NiMH) battery in the keel (see section: Keel Construction, above). Power distribution for this Protei revision is extremely simple — battery power goes through a high current 135A circuit breaker, and from there is distributed to the motor drivers and to the Arduino Mega. Each motor driver output is further protected by a 25A fuse, to protect both the motor driver and the motor in the event of a stall or short circuit. The Arduino provides a 5V power bus, and a 3.3V voltage regulator (described above), provides 3.3V power for the Xbee.

Control firmware

The control process will be summarized below, but for full details, one should examine the source code and its comments directly. The most current firmware version is always available on Protei's git repository.[1]

The control firmware is based around a 20 Hz (period of 50 ms) control loop. Each loop cycle, the following tasks are performed:

1. Read and process any data the Xbee has received.
2. Send status information back to the transmitter.
3. Each MotorController object runs their main loop:
    a. Calculate the power output necessary for the closed loop actuators.
    b. Send the correct power levels to the two motor driver channels.
4. Send the winch motor power level.
5. Every 4 loops, print any debug information.

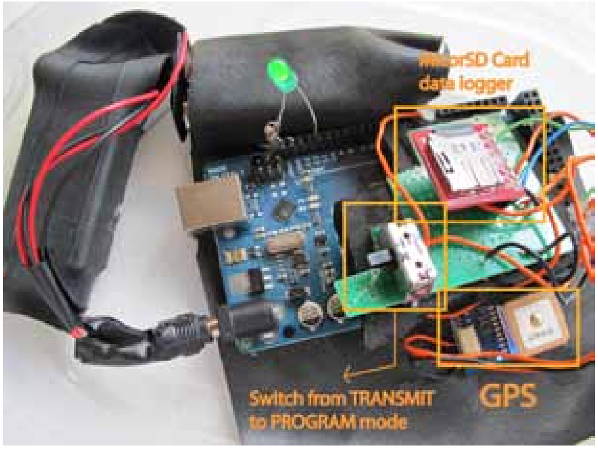
There are two important C++ classes used in the control software. The Motor class[2] has references to the 3 pins necessary for motor control, as described above, and to the three necessary input pins (Limit A, Limit B,and the rotation sensor). Through an interrupt (which must, due to the limitations of the Arduino environment, be set up outside of the class), a Motor object can keep track of the number of rotations that it has turned. The move function has some extra logic besides sending the correct PWM values — it also makes sure that the motor comes to a stop before reversing direction (to avoid miscounting rotations), prevents the motor from stopping while the rotation sensor is active (can cause rotation miscounts), prevents very small values from being sent to the motor (to save power), prevents the motor from moving against the limit sensor, and can reassert the Motor driver enable pins after a limit sensor is depressed.

A MotorController class[3] takes a target number of rotations, and a reference to a Motor object, and calculates the power level that should be sent to the motor. If the error (target rotations - current rotations) is less than 2, the motor is told to brake. Otherwise, the motor is told to move at K*error, where K is the gain of the object.

Figure [x]: A diagram of the structure of the control firmware
and relationships of the classes.

1 https://github.com/Protei/Protei-005-6
2 https://github.com/Protei/Protei-005-6/blob/master/ArduinoControl/motor.cpp
3 https://github.com/Protei/Protei-005-6/blob/master/ArduinoControl/motor_controller.cpp

Positional Sensing and GPS



The positional control system is performed using the MediaTek MT3329 GPS. It is an isolated system run off of two 9V batteries, enclosed in a box that fits above the winch box. The GPS transmits incoming NMEA (National Marine Electronics Association) sentences at 10Hz to the Arduino Mega. The NMEA sentences are stored as a text file on a microSD card, using the microSD card reader, from Sparkfun.com, sku#DEV-09802.
Example of GPS strings:
$GPGGA,215341.000,5155.9653,N,00428.0063,E,1,5,4.22,28.1,M,47.,,4
$GPGGA,215342.000,5155.9671,N,00428.0060,E,1,5,4.22,28.0,M,47.1,M,,*6.01
$GPGGA,215343.000,5155.9674,N,00428.0061,E,1,5,4.41,28.2,M,47.1,0E,
$GPGGA,215344.000,5155.9672,N,00428.0059,E,1,5,4.42,29.1,M,47.1,M,,*6A
$GPGGA,215345.000,5155.9683,N,00428.0054,E,1,5,4.22,29.9,M,47.1,M,,*62303R6A
NMEA sentences are specified electronically transmitted strings of data, containing global positioning information. For Protei_006, the useful information might include latitude, longitude, course, bearing, speed, time, date, satellite ID's, checksum, and altitude. For more information about NMEA sentences and standards, see http://www.nmea.org/ or http://wiki.openstreetmap.org/wiki/NMEA
With the GPS data, Protei_006's trip can be visualized on a map simply by uploading the entire text file (or pasting its contents) into GPS Visualizer (http://gpsvisualizer.com).

The trip is visualized on a map simply by uploading the entire text file (or pasting its contents) into GPS

Oil Absorbtion

Protei_007

Future Developments <g,,,>
Chart of ethics

Known Issues and Proposed Improvements

The current model of Protei is well balanced, maneuverable (by adjusting the trim of the sail and the curvature of the hull), responds to R/C control, and heels in the wind while staying upright. Because of its round, serpent-shaped hull, its heavy ballast, and its low center of gravity, in high winds and unstable conditions Protei lies flat on the water until conditions improve and it can right itself. (is this true? footnote saying we have to do more extensive testing?).
However, There are improvements for the build of Protei_007, to optimize its behavior, robustness, and maneuverability. Some improvements include the following:
Protei must be able to successfully tack back and forth across the wind - this will be achieved by better control over the hull articulation (the current motors have been replaced with more powerful ones). More tests must be performed towing the oil boom as it gets saturated with oil, as well as in rough oceanic and meteorological conditions. Eventually, Protei will need to be able to obey R/C commands from longer distances than the XBee's can provide.
The biggest improvement for Protei_007 will be one waterproofed unit in which all the electromechanical equipment live (rather than multiple separate units for each component). With one centralized compartment, it will be easier to find the source of a leak, as well as developing an automated system to rid water during the leak with the use of a water sensor and a bilge pump.
We must implement a better system for launching and retrieving the vessel, such as with a small crane or pulley mechanism. For the first test of Protei_006, the boat was lowered vertically 2 meters into the water. When retrieving it, the neoprene skin tore (about 2 cm) as it rubbed along the wall.

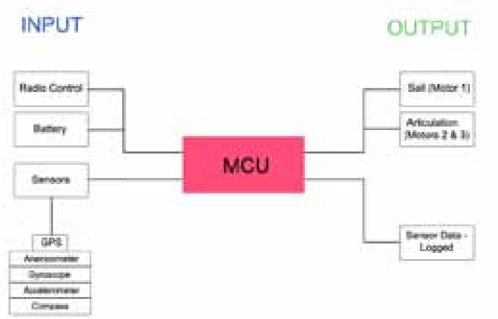
Trouble shooting, conclusions etc

This paragraph will move to 'the future' section.
For the prototype of Protei 006, we used neoprene to construct the skin and the keel. Advantages of this system are increased flexibility and the buoyancy. However, we did not research the chemical aspects of neoprete yet, including how it will be affected when in contact with crude oil. A downside to neoprene is that it rips or tears somewhat easily when in contact with a sharp object.
Same chemical consideration goes for the PVC tubes!

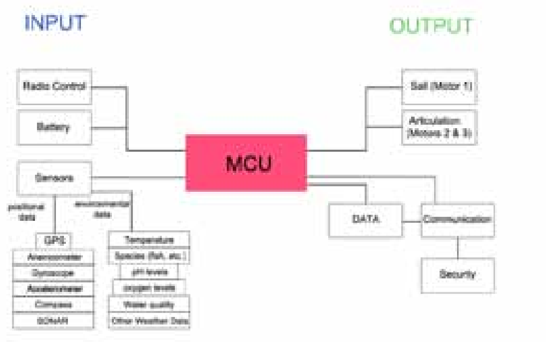
Evolution

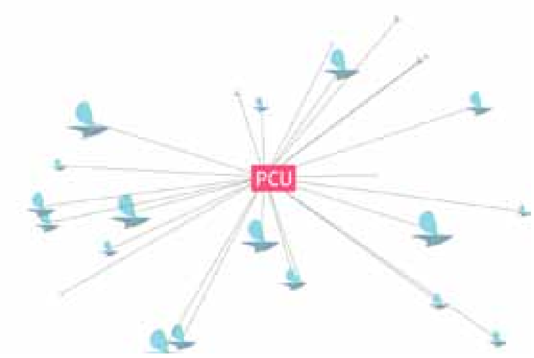
As the design of the individual Protei vessel improves, further versions will develop towards the behavior of multiple vessels, making up a swarm of sailing drones. As we progress, the vessel will move towards energetic autonomy, possessing sensing and decision-making skills, and eventually, will evolve from centralised swarm control to a decentralised system of systems.
The evolution of Protei is divided into six levels of networked systems, each building towards a more autonomous agent (the individual boat) with the capability of complex interactions (amongst the individual agents, and between multiple networks of agents). Eventually, Protei will be a self-organizing, multi-platformed network, with web-interface capabilities, to enable over-riding a unit (or units) of the swarm, whilst not disturbing the network as a whole. This current Protei model is between level 1 and 2: It is a radio controlled vessel, needing a human controller nearby (within RF range) to steer and control it. It is beginning to log environmental and positional data about itself and its journey (by storing GPS information).
The multiple Platforms of Protei
INDIVIDUAL VESSELS (1, 2, and 3):
1. Radio controlled with 1 user: The first platform for Protei is one single boat, with remote control, requiring 1 user to control it remotely. Control includes steering by directing the articulation of the hull, as well as determining the trim of the sail.t

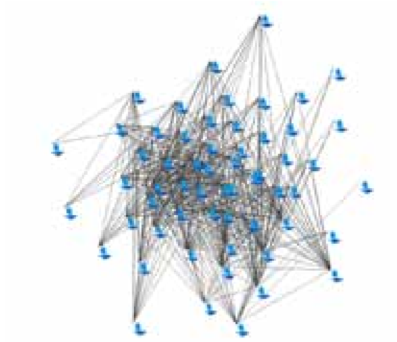
1. Radio controlled with 1 user: The first platform for Protei is one single boat, with remote control, requiring 1 user to control it remotely. Control includes steering by directing the articulation of the hull, as well as determining the trim of the sail.
(This category includes Protei_001 - 005). I think put this in italics just for reference so people notice it...



2. Radio controlled + sensing (semi-autonomous): The second Protei platform is a radio-controlled vessel, capable of sensing and storing data about its surroundings. It requires 1 user to control it remotely, but it has built in positional and environmental sensors (including a GPS, compass, gyroscope, accelerometer and anemometer).
(Protei_006 is between this and the first category, in that Protei_006 logs GPS data).







3. Autonomous: The third platform of Protei is a fully autonomous unit, that takes in data about itself and its surroundings, and makes decisions about appropriate behavior and actions to take. This platform no longer needs a human operator. The vessel sails independently, follows way points, rights itself, tacks across the wind, and adjusts its behavior due to changing environmental stimuli.

MULTIPLE UNITS making up a complex system of vessels (4, 5, and 6):

4. Swarm: Centralized The fourth evolution of Protei is a network of multiple individual vessels that obey commands from one centralized PCU master which controls group behavior. Each individual vessel is autonomous, and knows its position with regards to the master, but there is no communication between vessels. This requires minimal network optimization, and the group moves as one unit. If one unit gets too far from the master, it will get lost.
(master-slave model: a PCU governs slave behavior, and the slaves communicate back to the master)

5. Swarm: Decentralized The fifth evolution of Protei is a non-linear, complex, self organizing system, consisting of subsystems and individuals.
Each individual possesses intelligence to compute its position in the environment, relative to nearby individuals, and to the entire group. A suite of behavioral characteristics drive each organism's actions and interactions. This platform requires that each individual makes predictions about environmental characteristics, such as wind and current, through receipt and transmission of peer-peer information. At this level, the control system of Protei moves beyond Arduino, to a more complex, multi-level operating system, such as Android.
(COMPLEX SYSTEM BEHAVIOR; Peer-to-peer communication; Input and output information sent through individuals, the network, and sub-networks)
6. Multi-Platform The most complex level of the Protei Platform brings back the human interface. This level includes multiple independent networks of vessels, with an MCU that is an interface between humans and the networks of vessels. This allows for a web platform for individuals (people) to take control of single or multiple vessels to override its control mechanisms, without disruption of the network as a whole. This allows for a robust, adaptable system, with many behavioral levels, including groups, sub-groups, and individuals. This adaptive,

Applications

Protei can eventually be appropriated for other purposes, such as cleaning other chemical pollutants and material waste off of water, as well as collecting samples for ocean research.
As we move towards Protei_007 and beyond, the build will move towards a more modular one, made from recycled materials, so that the vessel is an adaptable platform for multiple purposes. Some other applications for Protei might include:

1. Plastic collection

In the North Pacific Gyre.

2. Radioactivity monitoring

For example, of the Fukushima nuclear accident: The International Atomic Energy Agency (IAEA) compiles and analyses sea-water sample data collected by TEPCO and MEXT, two organizations with off shore stations near the site of the nuclear power station (IAEA slides, 2011). The Protei technology can be implemented for this type of marine environmental monitoring and mapping, as an alternative to sending humans to these potentially hazardous areas.

3. Water sampling and quality monitoring in coastal areas

Measuring the concentration in «invisible» toxics as PCBs, HAP in sensitive areas. In Europe the European Commission is rolling out an extensive water quality assessment program (Water Directive 2020) - but they need loads of samples. If we can help them design a cheap and reliable way to collect samples, and even measure on-site the water quality, that will be appreciated!

4. Monitoring Marine Protected Areas

(MPA's) and fisheries, for example in the South Atlantic: MPAs occupy large surface areas and it is too expensive to send manned boats with Rangers for ample enough surveillance. Alternatively, a robotic can patrol these areas, provide feedback about unexpected events, and aid to redirect an intrusion. Similarly, Protei can monitor coastal fisheries, such as those in the South Atlantic (REFERENCE). In this case, Protei could fit into a network of open-source telecom systems, as a surface information relay, in collaboration with with underwater microphones and air balloons/land based relays, used by FishNET (see Image).

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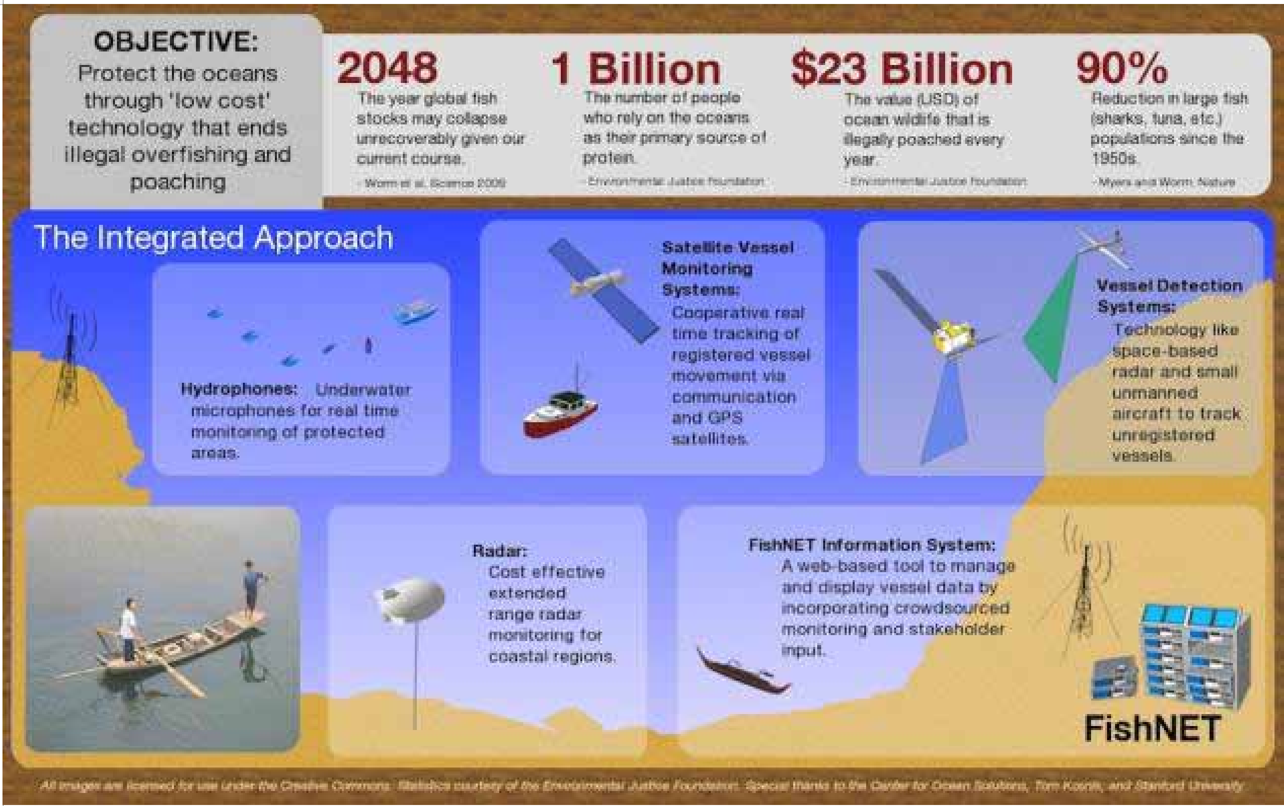

4. Marine Protected Areas monitoring

The MPAs are occupying vast surfaces and it is way to expensive to send a boat with Park Rangers to check them out. So if a robot can patrol, report any event, redirect any intrusion, like a real Park Ranger, that would save a lot of money. Same can be done to monitor coastal fisheries, where Protei fits into a network of open source telecom system as a surface information relay, together with underwater microphones and air balloons/land based relays.
(Creative Commons - Shah Selbe - FishNET - Centre for Ocean Solutions)

References

1. Richard A. Kerr (13 August 2010). «A Lot of Oil on the Loose, Not So Much to Be Found». Science 329 (5993): 734–5. doi:10.1126/science.329.5993.734. PMID 20705818. http://www.sciencemag.org/content/329/5993/734

Frequently asked questions

Appendices

Parts List

ITEM	Manufacturer	Reference	Price
Mast	Prolimit STX C60 RDM		
Sail			
Battery Tube			
Linear Actuator tubes			
RC receiver tube			
Longitudinal spines			
section ribs			
sail boom	Neilpryde 230-275 X5		
2 x Microcontroller: Arduino Mega 2560	Arduino	http://www.sparkfun.com/products/9949	$129.90
Arduino Mega Shield	Sparkfun	http://www.sparkfun.com/products/9346	$17.95
RC transcievers: 2x Xbee Pro 900 Series 1	Digi	http://www.sparkfun.com/products/9097	$85.90
2x 50A Freescale H-Bridge motor driver	Elechouse	http://www.elechouse.com/elechouse/index.php?main_page=product_info&cPath=100_146&products_id=667	$107.80
14.4V, 10Ah NiMH battery	varies	http://www.batteryspace.com/nimh	$144.95
DC motor and gearboxes, extracted from Bosch drills (14.4V)	Bosch	http://www.amazon.com/Bosch-34614-14-4-Volt-2-Inch-Compact/dp/B000VZP5W2	$349.96
Windshield wiper motor (12V)	varies	For example, http://www.amazon.com/A1-Cardone-40192-Remanufactured-Windshield/dp/B000C491BI	$56.46, varies
Misc. electrical components (resistors, capacitors, wire, etc)	varies	See electrical schematics for details	varies
Skin		http://www.panacell.de/cms/material/zellkautschuk.html	
Keel			

References

1. Kerr, Richard A.(13 August 2010). "A Lot of Oil on the Loose, Not So Much to Be Found". Science 329 (5993): 734–5. doi:10.1126/science.329.5993.734. PMID 20705818. http://www.sciencemag.org/content/329/5993/734

2. http://www.slideshare.net/iaea/marine-environment-monitoring-of-fukushima-nuclear-accident-2-june-2011

3. Fogarty, David. (14 July 2011). “Navy to help climate scientists in pirate-infested waters“. Reuters online magazine. http://www.reuters.com/article/2011/07/14/us-climate-robots-idUSTRE76D16M20110714