The Pier Portal – a Web Controlled Underwater Profiling Camera

Aaron Jen, Misha Balingit, Cory Spieler, John Ridgely
Mechanical Engineering
California Polytechnic State University
San Luis Obispo, USA

Brian Markwart, Andy Lam, Bridget Benson
Electrical and Computer Engineering
California Polytechnic State University
San Luis Obispo, USA

***Abstract*— Although piers have been used as platforms to collect oceanographic data for decades, few piers have incorporated the use of an underwater camera in their permanent suite of instrumentation, and to the best of our knowledge no pier has incorporated the use of a profiling underwater camera in its permanent suite of instrumentation. A profiling underwater pier camera would provide scientists access to high temporal resolution, long-term visual data which could be used to observe, in-situ, how ocean color and ocean life (along pier pilings) changes across depth and time. The camera would also provide a 'portal' to the public to see what lies beneath the ocean's surface. This paper describes the design of the Pier Portal, a profiling underwater pier camera, to be deployed at the Cal Poly Pier in Avila Beach, CA.**

I. Introduction

Piers serve as an effective means to observe and monitor ocean life and processes by providing a stable platform for sensors to collect data throughout the entire water column over large temporal scales. The high temporal resolution, long-term data collected from piers and other ocean observing platforms capture a broad dynamic range of oceanic variability and provide important information concerning episodic and periodic processes ranging in scale from minutes to years [1-2]. Such data greatly enhances our understanding of the earth's oceans and contributes to solving world problems such as natural disaster prediction and global warming.

Although piers have been used as platforms to collect oceanographic data for decades, few piers have incorporated the use of an underwater camera in their permanent suite of instrumentation [2-3] and to the best of our knowledge no pier has incorporated the use of a profiling underwater camera in its permanent suite of instrumentation. A profiling underwater pier camera would provide scientists access to high temporal resolution, long-term visual data which could be used to observe, in-situ, how ocean color and ocean life (along pier pilings) changes across depth and time. The camera would also provide a 'portal' to the public to see what lies beneath the ocean's surface.

This article describes the mechanical and computer system design of the Pier Portal, shown in Fig. 1, a web controlled underwater profiling camera system, which will augment the capabilities of a pier as an ocean observing platform. The objective of the Pier Portal is to allow educators, students, and the general public to have a new way to observe sea life, right from the comfort of their own homes. The system will stream live video to the World Wide Web, and viewers will be allowed to control the depth and viewing angles of the camera.

The rest of this paper is organized as follows: Section II describes the overall system configuration of the Pier Portal and sections III and IV detail the mechanical and computer system components respectively. We conclude with a discussion of future work in Section V. It is important to note that the Pier Portal project is a multi-year (started Fall 2011), multi-disciplinary undergraduate senior project between the Mechanical Engineering Department, Electrical and Computer Engineering Department, and the Cal Poly Center for Coastal Marine Sciences. The system has yet to be fully integrated and deployed.

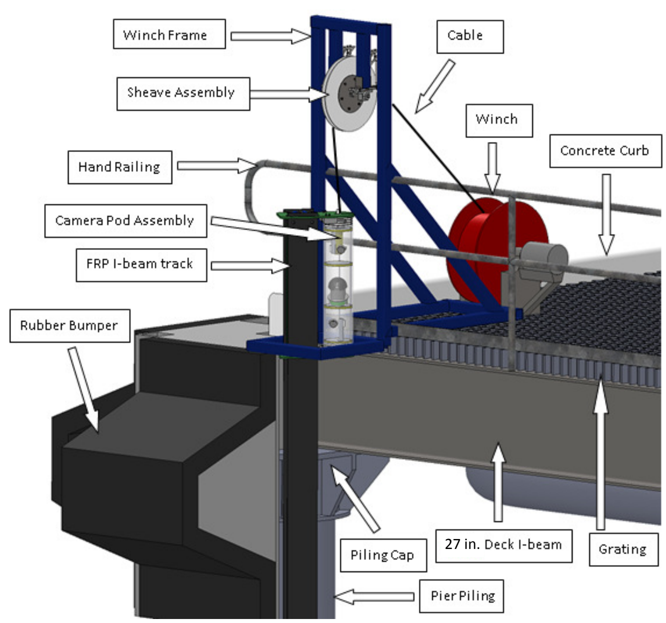

Fig. 1. The Pier Portal layout showing the track, camera pod and cart, winch frame, and winch drum. This model was made by the first Pier Portal team.

Sponsors: Yaskawa America, Inc.; Remote Oceans System; Seafloor System, Inc; Cetacean Research Technology.

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II. System Configuration

The final configuration of the Pier Portal and how it works, starting on the viewer end, is as follows:

1. A viewer changes the position/depth of the cart by clicking on buttons on the Pier Portal website. This sends a command from their computer to a computer at the pier.
2. The pier computer relays the command to a motor controller through an Ethernet cable.
3. The motor controller interprets the command and controls how much a motor should rotate and in which direction. The motor controller is connected to the motor by a 20 meter cable, which also provides power to the motor. This cable will be in a protective conduit to reduce electrical noise.
4. The motor moves a winch drum after a total gear reduction of 140:1 – a 20:1 planetary gear drive and a 7:1 chain reduction. Rotational movement of the winch drum will translate into linear movement of the cart through a main winch cable.

   If the cart needs to move downwards, the winch drum will give slack in the cable, and the cart will sink. To move the cart upwards, the winch drum will wind up the cable and pull the cart.
5. The main winch cable starts at the winch drum, goes over a winch frame with a pulley, and connects to the cart. This cable is 0.62 inches in diameter and has 21 conductors inside for the camera and pod electronics.

If the viewer sends a command unrelated to the position/depth of the cart, such as a command to change the angle of the camera or to turn on the LEDs in the pod, a command will still be sent to the pier computer. However, the computer will relay the command to a microcontroller board inside the pod. These commands are sent to the board through the main winch cable. The board connects directly to and controls the pod electronics

III. Mechanical System Components

The main mechanical system components of the Pier Portal include the fiberglass reinforced plastic (FRP) I-beam track, the camera pod, the main winch cable, camera cart, servomotor, safety enclosure, motor controller, and track cleaning system. Each of these components is described below.

A. *FRP I-Beam Track*

The 60-foot FRP I-beam track extends from the top of the pier to the ocean floor, approximately 40 feet underwater. The track is held in place with six stainless steel brackets. The lower five pile brackets are attached to the pier piling, and the top bracket is clamped onto the pier piling cap since there is no pier piling to attach to. The clamp portion of this bracket will be made out of galvanized aluminum instead of stainless steel to avoid corroding the steel pier deck. In other words, the clamp will be a sacrificial anode to the pier deck, not the other way around.

The I-beam track is made up of fiber reinforced plastic. This type of composite material was chosen mainly because of its ability to resist corrosive environments, although strength and cost were also factors.

The I-beam track is composed of three separate 20-foot sections, which are bolted together using mid-span brackets. To install the track, the parts were assembled on the pier deck and then lowered into the water by a crane. Student divers from Santa Barbara City College Marine Technology then attached the track to the piling brackets by drilling directly into the FRP with pneumatic drills.

B. *Camera Pod*

The purpose of the pod is to enclose the electronics, camera, and lights. It is designed to keep water out while being transparent enough to allow the camera to get a clear view underwater. The pod walls are made out of an 8-inch outer diameter, 0.25 inch thick, cast acrylic tube. The top cap is permanently sealed with acrylic glue, and the bottom cap with O-rings is removable so that the components inside can be accessed. The inside of the pod is split up into four different levels, each separated by Delrin® platforms. The pod communicates with the pier computer via the same main winch cable used to lift the cart. The two caps are made out of acrylic like the pod walls, so that the thermal expansion coefficients are as similar as possible, which will minimize leakage through the O-rings due to thermal expansion. Each cap is approximately 2.5 inches thick.

The top cap has a hole through the center so that the main winch cable can access the pod. The hole is tapped to allow a waterproof Subconn plug prevent water-damage to the inside of the cable. A shaft was press-fit into the hole with a 0.001-inch interference. There is also a gear and bearing fixed to this shaft inside the pod with the same 0.001-inch interference. Both the gear and bearing are used for the internal rotation system. The bearing sits in a groove cut into the uppermost Delrin® platform and limits the distance the internal pod structure can be pushed into the pod, so that the upper fixed gear and motor pinion gear are aligned. There is also a magnet installed in the top cap. This magnet is used in combination with a Hall Effect switch to limit the rotation of the pod. A standard printer cable was repurposed to function as the transition cable between the pod electronics and the main winch cable.

The lower cap has a Lazy Suzan bearing installed for the internal pod structure to rotate on. In addition, the lower cap has a vent plug. This is necessary so that air has somewhere to escape when the pod caps are pushed into place. Another component of the lower cap is the leak detection circuit pocket. A hole was drilled through the cap in the radial direction so that leak detection leads could be threaded through from the inside. Then, the holes were filled with acrylic epoxy so that in the event of a breach, the water does not have an easier pathway to travel to penetrate the pod.

Each Delrin® platform is 0.5 inch thick, with a 7.38-inch diameter. Three 30-inch threaded support rods are spaced out around the camera so that there is sufficient support for the pod structure. Two nuts threaded onto each rod above and below each Delrin® disk hold the platform in place.

The top level of the pod is dedicated to one of the two light arrays and a 24-volt DC motor, which rotates the entire internal pod assembly to increase maneuverability and scope of the camera. Each light array is composed of three Cree XML warm white LEDs with a spotlight lens attached. These 900 lumen LEDs will give off excessive heat, so aluminum heat sinks and small fans are attached to help dissipate that heat. Each array is also attached to a servo, which allows the lights to be rotated up and down 90 degrees. Each LED array has a tower-mount made from 0.12-inch stainless steel sheet metal.

The second level houses the camera, which is capable of rotating in the vertical and horizontal directions. This camera is a dome camera that is specified for high resolution in low lighting situations; and allows pan, tilt, and zoom control through Ethernet commands. One Ethernet cable plugged into the camera assembly is used for power, while the other is used for communication. The camera can stream 1920x1080 video with up to 10x optical zoom. A phototransistor is located at the front of the camera so that the amount of light seen by the camera can be measured by the electrical system for automation of the LED brightness. The camera mount is made from two pieces of stainless steel 0.020-inch sheet metal.

The third level houses the second LED array and the microcontroller board required to run the internal system of the pod. Felt strips are glued to the Delrin® platforms in order to block light reflections from the LEDs from interfering with the camera.

Finally, the bottom level of the pod includes the removable plug and water leak detection circuit – two unconnected wires. This plug relies on three different O-rings to help keep the pod sealed. In the event of a leak, the water will connect the two wires and complete the simple circuit, set off an alarm in the system, and cause it to immediately extract the camera pod from the water to avoid further leakage and damage to the internal components.

C. *Main Winch Cable*

The main winch cable is 100 feet long with a 0.62-inch diameter, fabricated and donated by Remote Ocean Systems. It has a 1000-pound breaking strength due to the Kevlar braid just beneath a waterproof polyurethane jacket. It also has a minimum bend radius of 10 inches and weighs 28 pounds. An Amtec cable grip distributes stresses placed on the cable to a steel cable sheathed in vinyl plastic, which is part of the pod cart. This ensures that the Subconn connector, which is much more sensitive than the Kevlar reinforced cable, will not see the forces that the rest of the cable is subjected to.

D. *Cart*

The purpose of the cart is to hold the pod and allow it to move up and down on the I-beam, seen in Fig. 2. The frame is made out of two FRP end plates that are held together with two FRP connecting supports. Lead ballasts have been added to the cart to overcome the buoyancy from the hollow acrylic tube. The cart rolls up and down with eight roller blade wheels that

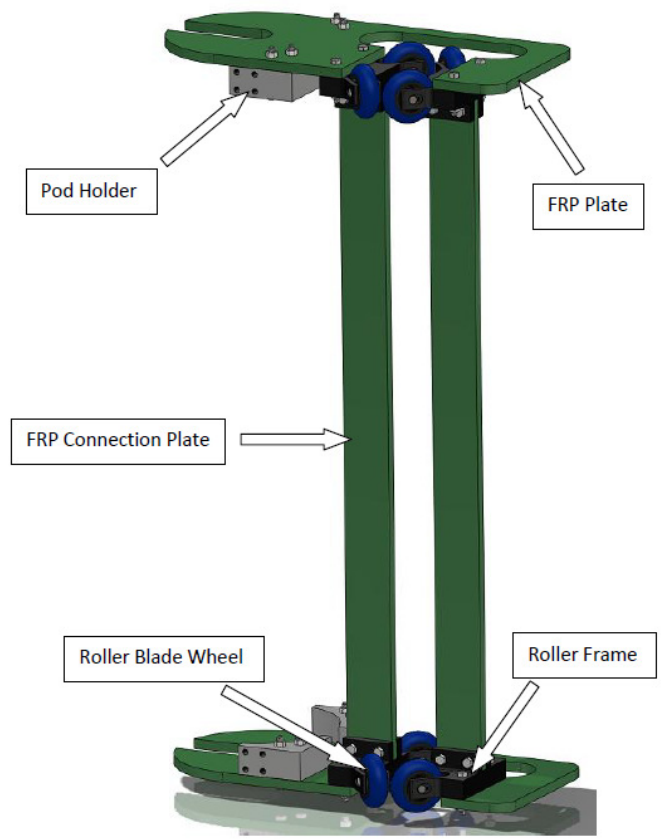

Fig. 2. A CAD model showing various important parts of the cart. This model was made by the first Pier Portal team.

sandwich the I-beam. Stops and strapping are used to hold the pod in place on the cart.

Fabrication of these FRP pieces was very tricky due to the layered nature of the FRP material. All cart plates were cut using a water jet. However, the water jet was only able to cut the material when it approached from an edge rather than starting in the middle of the material. Attempting to cut a profile from the middle of the anisotropic FRP causes the water to explode into the plate, fracturing and damaging the material rather than cutting straight through it cleanly. Holes in the plates were pre-drilled, cut to diameter with the water jet, and then reamed to specifications.

The weights used to counteract the buoyancy force of the pod are 1/8 x 32 x 2.5-inch lead sheets. These strips were cut out of a larger sheet with a shear, while the 3/8” holes were punched into the material. They are cut into strips so that they can be attached to the long, thin connection brackets of the FRP pod cart.

E. *Servomotor*

Yaskawa donated an SGMGV-05 servomotor for this project. This servomotor is a 450 watt motor with a brake and oil seal.

450 watts is enough power to move the cart, even with any unexpected additional loads like seaweed. With this amount of power, the motor can easily move a max weight of 150 pounds at a speed of one foot per second. The brake feature is a nice addition to the motor just in case the gear reduction and the friction of the winch drum is not enough to keep the cart in a constant position. The brake will also prevent the motor from overheating when holding the cart in place for an extended period of time.

F. Gear Reduction

The system will have a 140:1 total gear reduction from a 20:1 gear reduction drive and a 7:1 chain reduction. The gear reduction drive is a Shimpo planetary gear drive. This gear drive is pre-assembled with a motor flange that allows it to be bolted directly to the servomotor. The chain reduction is already part of the winch drum. However, the sprocket of the chain reduction was changed to fit the output shaft of the gear drive.

A 3/8-inch thick aluminum bracket was designed to bolt the Shimpo reduction drive onto the winch. This bracket was made to eliminate the need to machine directly on the winch. Currently, the chain reduction is slightly skewed, because the two sprockets do not line up perfectly and may need additional modification upon testing the system.

G. Safety Enclosure

Even with the oil seal, the servomotor is still susceptible to damage from the damp, ocean environment. To protect it and extend the project's lifespan, the motor will be placed in an aluminum NEMA4X safety enclosure with dimensions of 36 x 30 x 16 inches. However, this raises a couple issues. One of which is that the temperature inside of the enclosure will rise when the motor is in use. The maximum allowable temperature for the servomotor is 40 degrees centigrade. Even if the servomotor operates at 90 percent efficiency, which Yaskawa claims, a heat calculation shows that the inside of the enclosure may rise above 40 degrees centigrade on a hot day. This means that cooling aides will need to be added to increase the heat transfer through the safety enclosure.

Another problem that arises is that the servomotor and gear reduction drive cannot be connected to the chain reduction on the winch drum. A large hole will need to be cut out on the side of the enclosure. The gear reduction drive will partially protrude out of the enclosure through this hole. To keep the NEMA4X rating, a sealed bearing will be placed at the hole.

H. Motor Controller

Yaskawa also donated an MP2600iec servopack with the servomotor. Yaskawa suggested this specific motor controller because it is compatible with the SGMGV-05 motor.

The motor controller came with a program called MotionWorks IEC 2, which was developed by Yaskawa just for their motor controllers. With this program, we are able to send commands to the motor controller, which will control the number of revolutions, which direction, and how fast the motor will rotate.

Another great feature of this program is the ability to set minimum and maximum limits to various parameters of the servomotor, such as torque and angular velocity. This will help prevent the motor from damaging the entire system by applying too much torque or rotating too quickly.

I. Biofouling Prevention

A track cleaning system will be needed to keep the track free of sea-life such as algae and barnacles. There are multiple ways to prevent biofouling including UV light, vibrations, and physical removal. Even though physical removal is the most difficult to implement, it is the most reliable option. UV light and vibrations may damage the FRP I-beam track and reduce the system's lifespan.

In order to prevent sea-life from growing, the track will need to be physically cleaned on a daily basis. Our solution is attaching a U-bracket with large brushes to the bottom of the cart. The brushes will scrub the track as the cart moves up and down. The brushes are mounted in a way where they will clean every surface of the track, except for the side with the stainless-steel pile brackets. As viewers are moving the cart up and down, the brushes will be constantly cleaning the track. However, to ensure the entire track is kept clean, the motor driver will be programmed to drop the cart all the way to the bottom and pulled back up. This automatic cleaning routine will be programmed to run at least twice a day.

The current track cleaning system is still considered a prototype. Since it is just a prototype, aluminum was used for an inexpensive and easy fabrication of the U-bracket. This prototype will test the position and shape of the U-bracket and what brushes to use. Any improvements will be made for the final design. The final design will be made out stainless steel to provide better corrosion protection.

To prevent biofouling directly on the camera pod and cart, a fresh water rinse system will be added at the top of the track. During the automatic cleaning routine, the cart will be pulled out of the water and to the pier deck. When at the top, sprinklers will automatically hose down the pod and cart with fresh water. Multiple sprinklers will be used and positioned to cover every surface and thoroughly rinse the brushes.

This automatic fresh water rinse system still needs to be completed and installed. The current design of the system involves a small microelectronic board that will signal a sprinkler valve to open when the cart is at the pier deck level. Where this microelectronic board will be placed has not been determined but will most likely be inside the camera pod.

IV. COMPUTER SYSTEM COMPONENTS

The main computer system components include the website server, pier server, camera, pier router, communication protocols, microelectronics board and motor controller, shown in Fig. 3. Each of the components (except for the motor controller as it has not yet been implemented) is described below.

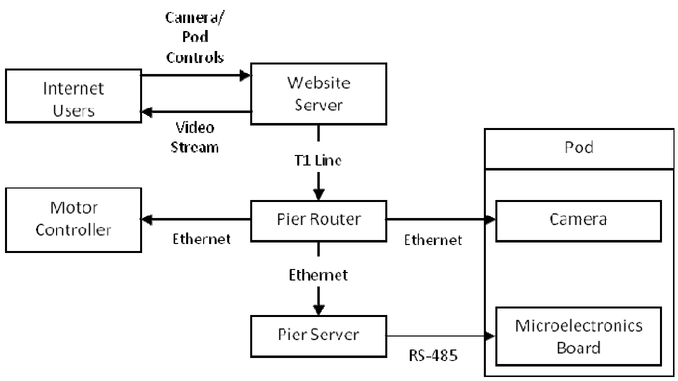

Fig. 3. A diagram mapping out the computer system configuration, including how components communicate with each other.

A. Website Server

The website server is a computer located on the Cal Poly campus that hosts the Pier Portal webpage and sends video/commands from/to the pier server and the World Wide Web. The Pier Portal webpage contains a video player, which displays a live video stream from the camera. Along with the video display, the webpage has buttons that the user can click that allow the user to control the tilt, zoom, and focus functions of the camera in addition to the position/depth of the cart.

B. Pier Server

The pier server is a computer located at the pier that relays commands sent from the website to the pod electronics and motor controller. The server runs the crtmpserver (C++ RTMP Server), which is a high performance streaming server that converts the camera's ActiveX video object into a RTMP (Real Time Messaging Protocol) stream. The RTMP stream is delivered to an Adobe Flash application called JW Player that is embedded on the website. RTMP only works in Flash and not in HTML5. Even though Flash is no longer supported on mobile devices, such as Android, iOS, or Windows Phone, Flash is a better solution than ActiveX, which is only playable on a Windows PC running Internet Explorer.

C. Camera

The camera is a 2.0 megapixel IP dome camera with 10x optical zoom. This camera is capable of 30 frames per second at 1080P (1920x1080) resolution and provides up to 8 megabytes of data. It is powered over Ethernet (POE) and requires 12 volts and anywhere from 0.7 to 1.3 amperes, depending on the camera functions. The network interface for the camera is Ethernet 10/100 Base-T (RJ45) and can also accept commands and be controlled through an RS-485 port (using Pelco-D/P protocol). There is also composite video output for potential use with a digital video recorder (DVR). The camera is embedded with ActiveX controls (for both the video stream object and the pan, tilt, zoom, and focus functions) for IP control. ActiveX is a software framework created by Microsoft and, in the context of a website, requires Microsoft Windows and Internet Explorer. As this extremely restricts the usefulness of a website, the ActiveX controls for the camera video stream must be bypassed or converted to something that allows many users on different platforms, operating systems, and/or web browsers to access the Pier Portal website.

D. Pier Router

The Pier Router is responsible for sending and receiving packets between the website (campus server), the camera, and the pier server. Ethernet packets containing video data are sent directly between the camera and website server while packets containing commands for the camera pod are sent to the pier server for processing.

E. Communication Protocols

For website control, the Pier Portal system uses many different communication protocols and languages. The backend of the website communicates with the pier via a standard TCP (Transmission Control Protocol) socket. This socket provides a link between the website server and the pier server via a Python script that is running on the pier server. The website uses PHP to send data over a socket. On the pier server end of the port, there is a Python script that is running a threaded server to receive the requests from the website and communicate with the pod microelectronic board in the camera pod. The Python script uses the 'PySerial' library to communicate with the pod microcontroller board and uses the standard Python struct library for byte packing and management. Due to the length of the pod cable, RS-485 (instead of RS-232) is used for this communications line because it provides a high baud rate at wire lengths of over 100 feet.

F. Microcontroller Board

The microcontroller board will give control over various functions of the electronics inside the pod. These functions so far include:

- Rotating the pod internals left and right with a motor.
- Tilting the LEDs up and down with small motors.
- Adjusting the LED brightness.
- Adjusting the fan speed.
- Toggling control of the LED brightness and fan speed between automatic and manual.
- Monitoring the leak detection.

This board, which is inside the pod, will receive 24 volts from the main winch cable. 12 and 5-volt regulators are needed to adjust the 24 volts for various components and functions. For example, the camera and fans only require 12 volts to run. The board is custom designed and sent to OSH Park for fabrication.

V. Future Work

As stated earlier, the Pier Portal is not yet complete. It will require another year, at minimum, and another group of students to finish implementing and testing the design.

Communication between a web browser and the pod electronics was successfully made. The various command buttons on the website worked to control the camera angles, rotation of the pod, and LED brightness. A live video stream also was successfully displayed on the website's video player. However, further work needs to be done on the website itself: organizing the website, adding a queue system to limit control of the Pier Portal, and adding controls to change the cart position/depth.

Testing the motor controller and servomotor still needs to be done. Even though both components were on hand, additional electrical components were needed to power the system: a circuit breaker, a noise filter, and a magnetic contactor. These components were purchased and received at the end of the project but were not installed. Once power is available to the motor controller and servomotor, MotionWorks IEC 2 will be used to program how to control the servomotor.

The two problems mentioned above with the NEMA4X safety enclosure have not been fully resolved. The fresh water rinse system will also need to be completed. These issues will need to be revisited in the future.

Once every mechanical and computer component is completely designed and installed, a good amount of troubleshooting will be needed to ensure the entire system operates smoothly.

We are confident that with this future work, the Pier Portal will substantially augment the capabilities of a pier as an ocean observing platform and provide useful information about our local oceans to researchers, educators, and the public alike.

ACKNOWLEDGMENT

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