MBARI New Anti-biofouling Shutter

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***Abstract*- The first MBARI shutter was developed to reduce the effect of biofouling (barnacles, etc.) on a variety of optical instruments in use on MBARI's oceanic moored platforms. While the first shutter has been quite effective, the second shutter is smaller, consumes less power, and is contained in a simple package, making it easier to integrate into other MBARI platforms.**

I. Introduction

The shutter was developed to reduce the effect of biofouling (barnacles, etc.) on a variety of optical instruments in use on MBARI's oceanic moored platforms. The concept is to cover the optical windows of the optical instruments with a copper disk (a natural deterrent) when not making a measurement, thereby inhibiting the growth of fouling organisms on the window.

The new shutter is a system comprising two parts; the mechanism that contains the motor, gears, drive shaft feedback, drive shaft and copper plate; and the controller that consists of the motor drive electronics, the microprocessor, and the embedded control software. The mechanism is attached to the side of the optical instrument and is submerged. The unit interfaces to a central processor via RS-232. The entire mooring runs on a typical lead-acid battery, so this shutter runs off the battery as well.

The embedded electronics consist of a linear power supply, serial communications, an H-bridge, some non-volatile memory, a light sensor, a CPLD quadrature decoder and a microcontroller. Outside the main PCB, a motor with a shaft encoder drives the copper plate open and closed and two hall sensors, one at each end, operate a limit switches for initial calibration.

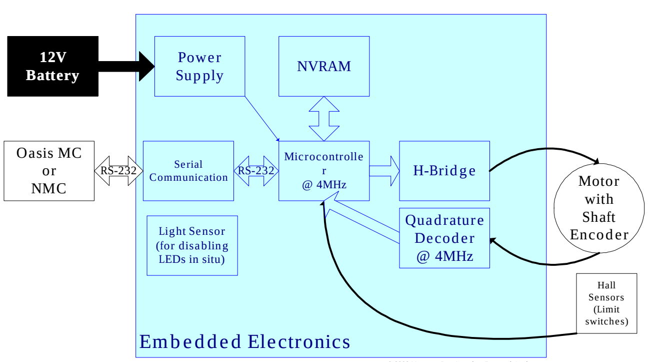

Figure 1. The electrical functional block diagram for MBARI's new anti-biofouling shutter.

Figures 2a & 2b. a.) The shutter is a watertight housing composed of a base with a copper plate that opens and closes over an instrument's optical window. b.) Within the watertight housing, an embedded controller triggers a motor with a shaft encoder to drive the copper plate open and closed.

II. Design Requirements

The functional design requirements were quite straightforward:

- ✓ The shutter must minimize bio fouling of it's sensor head.
- ✓ Electronics shall allow the motor to Open/Close the shutter door over the sensor view port
- ✓ The Open/Close process shall take no more than 40 seconds
- ✓ The Open/Close process shall not occur more often than every 10 minutes
- ✓ The shutter shall not occlude the optical window of the sensor
- ✓ The shutter must be small enough to fit in the mooring elevator cage
- ✓ The shutter must survive deployment duration of 1 year.
- ✓ The shutter must withstand a depth of 20m.
- ✓ The shutter must be compatible with both the old OASIS and new MOOS mooring controllers.
- ✓ The shutter should be controlled via a serial (either RS-232 or RS-485) 9600-8-N-1 data stream.
- ✓ The shutter should run off of a 12V battery (15V max.)

- ✓ The shutter must consume no more than 2A (nominally 0.5A).
- ✓ The shutter must be able to be power cycled while deployed.
- ✓ The shutter must run in a temperature range of 0^{o}F to 90^{o}F.

Since the unit would be submersed, we decided we needed a water sensor to detect if the housing flooded. If the unit catches the water fault early enough, it sends an error back to the central processor, which can isolate the unit from the rest of the mooring.

III. Electronics

The electronics are based around a flash based Microchip PIC as the microcontroller. To minimize power consumption the design is all +3.3V, and the processor is a PIC16LF877. The PIC16LF877 is compatible with in-circuit programming and debugging tools available to MBARI and offers low-power performance. It also offered enough I/O to meet the initial requirements and allow expansion if required.

Two problems arose as a result of pursuing an all +3.3V design. First, the in-circuit serial programmer / debugger (ICSP/D) used a +5V interface, so the signal lines for that operation required special consideration. Second, the target bootloader, Working Technologies' bootloader, doesn't support low-voltage reprogramming so we decided to abandon the bootloader concept.

Rather than design a constraints specific solution for the motor control, the design implements a generic H-bridge and uses a limit-switch/shaft encoder for position/velocity feedback. Since the device operates underwater, two watertight magnets and two Micronas unipolar hall-sensors (HAL114) provide the binary limit encoding.

A Xilinx Coolrunner CPLD (XCR3064XL-6-VQ44C) contains a quadrature decoder found in a Xilinx application note. The output of the decoder runs into the parallel port on the PIC. The CPLD also contains the shoot-thru protection logic to prevent a state when both the top and bottom switches in the H-bridge are active.

The H-bridge uses two P-channel and two N-channel MOSFETs and optoisolators to isolate the bridge from the high-voltage source. This basic structure allows any high-voltage source to be coupled to any logic level.

Beyond the basic requirements, the unit's internal mechanism won't see daylight during 99% of it's life, but status LEDs, indicating proper operation, were required during debugging. An automatic light switch, based on a photovoltaic IC, minimizes power consumption by turning off the LEDs when the housing has been sealed - an important consideration since the entire buoy runs off of one solar-charged lead-acid battery for a year.

IV. Software

For manual operation of the device, it is powered from a 12V benchtop supply and connected to a PC's serial port using HyperTerminal at 9600-8N1. Upon power-up, the device issues a "RDY" status. In order to see what's being entered as a command the user types "echo<CR>" and then the unit will echo the commands. Two diagnostic commands "jog_o" and "jog_c" provide an easy way to move the copper plate into it's open and closed positions and pressing the space bar interrupts the movement.

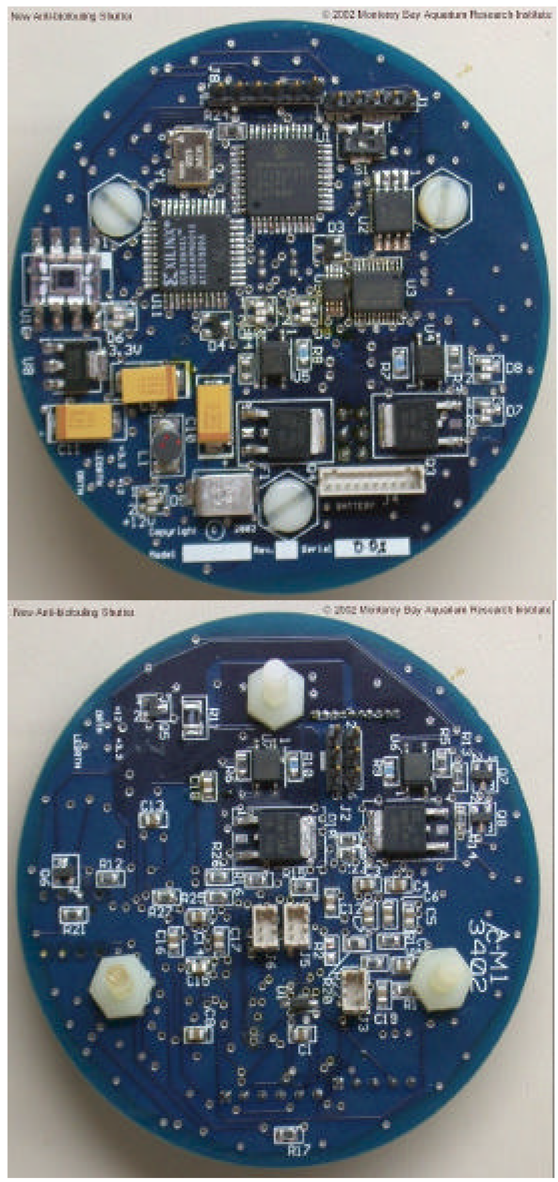

Figure 3a & b. a.) The top side of the controller board for the new anti-biofouling shutter and b.) the bottom side of the controller board

For deployment, the device is homed using the command "set_stop". This allows the user to provide a 50% window or some other occluded view. Once the plate has been homed, the "open" and "close" commands are issued to open and close the shutter accordingly.

The first version of the shutter was just a simple motorized plate that opened when power was applied. It provided very little feedback to the mooring controller if something went wrong. At one point, this led to completely draining the buoy battery because the plate jammed on a zip-tie and the unit wasn't smart enough to shut down. To mitigate that problem, the embedded software senses the velocity of the plate and reports an error if an unexplained halt occurs. The velocity is calculated by sampling the motor encoder every time the RTCC timer rolls over. If a minimum difference in motor position is not maintained between consecutive samples the motion is halted and a minimum velocity error is returned.

If there are any problems with the shutter during normal operation, like a water alarm, the device responds with "ERROR [error code]<CR> followed by a "RDY<CR>". Errors include water alarms, unknown commands, velocity mismatch, hall sensor limit or a number of command syntax problems.

V. Mechanical

An early design decision was made to try and incorporate the most basic and robust mechanism available for closing a door over the viewport in the smallest package feasible. The overall size of the package was an issue because sensor deployments are typically on MBARI moorings where space is severely limited. The sensors are usually attached to existing cages that can range from one meter underwater to 20 meters below the surface. This existing condition drives the requirement for the smallest feasible package for all sensors.

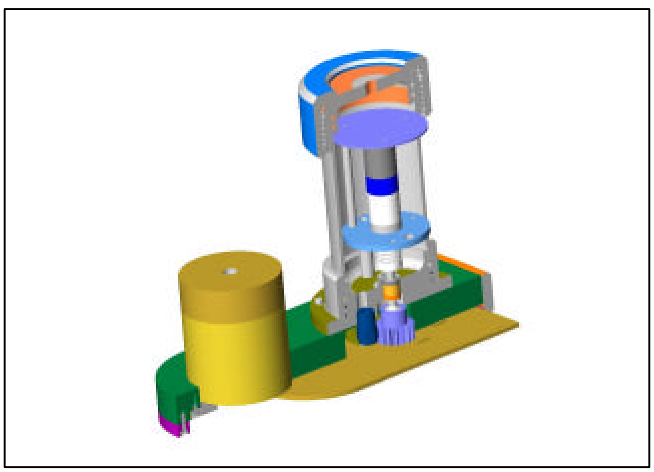

Figure 4. Mechanical Cross Section showing the open copper plate, small optical instrument and inner workings of the shutter mechanism.

Early technical review of various actuation mechanisms for the shutter closure included an iris design similar to a camera shutter and a rotating paddle mechanism. Investigation of the iris mechanism concluded with the package envelope being too large to be useful and the multi-piece mechanism too complicated for deployment in a hazardous environment. Previous MBARI designs had incorporated a rotating mechanism that rotates a paddle blade around and over the sensor window, but the package envelope required for the rotating paddle was prohibitive for this particular application.

The mechanism chosen was a simple rack and pinion design using plastic gear components and a copper plate as the door or shutter blade. A Micro-Mo motor is the motive force, which is enclosed in a one-atmosphere housing made of aluminum 6061-T6. The housing is Hard Black Anodized to help protect against corrosive attack. The motor shaft protrudes from the housing and is sealed by a Parker U-cup Flexiseal, and it has a plastic spur gear pressed and keyed onto the end. The design makes use of Micronas HAL114 UA-C Hall effect limit switches that are potted into pipefittings on the motor housing top plate. Neodymium Iron Boron magnets activate the switches. The magnets were embedded and potted into the copper blade that is enclosed in a plastic delrin housing.

The anti-biofouling characteristic of copper is well known and MBARI experience with using copper as an anti-fouling mechanism led to the selection of copper for the blade material. For the 20-meter sub-surface application in seawater the copper plate material slowly corrodes over time and goes into solution. When two dissimilar metals are placed in electrical contact and placed in seawater this galvanic reaction will start. For this application this can be an advantage, with the use of stainless steel 316 fasteners that are nobler in comparison with the more active copper plate. The larger copper plate becomes the anode and the smaller fasteners act as cathodes. The area where this galvanic reaction occurs is enclosed by the plastic geometry of the assembly. This enclosed portion houses the view port through which the sensor will be taking measurements. It is crucial to keep this area clear of bio-fouling and other matter that may obscure the view port and affect measurements. Since the area is enclosed for large time periods during normal deployments the galvanic reaction solution is contained, and the reaction slows due to less seawater circulation at the view port site. The result is a closed view port area containing a solution that resists fouling.

VI. Initial Results

When it's running, not opening or closing, the unit consumes ~100mA, and it consumes ~160mA when it's opening and closing.

The device has met the original design criteria, and is being tested in the field. As a simple package, the shutter occupies a known, small space. It also uses less power than the original shutter.

VII. Future Improvements

Several things could be done to improve future versions of this unit. First, the Hirose connectors used on the circuit board left a lot to be desired. The main 10-pin connector consistently had broken wires and the other connectors exhibited broken wires as well. This was partly due to the fact that they were originally assembled using solid rather than stranded wire, but even the stranded wire had a tendency to break over time. The pin diameter and spacing were also more designed for a 5mil PCB rather than a less expensive 7mil PCB. The next version should use a standard 0.100" connector and sacrifice the space.

Second, implementing a sleep mode and a switching power supply could significantly reduce the nominal power of the device. This would allow the device to constantly monitor the water detection circuit and provide immediate feedback to the central processor.

Third, a +5V design would allow the current version of Working Technologies' bootloader to work with the design. It is currently necessary to open the housing to reprogram the microcontroller and keeping the housing closed for any future updates would increase the reliability. This would also allow code revisions to be forwarded from the central processor.

VIII. Conclusions

Biofouling on oceanic moorings continues to be a problem, but instruments that incorporate the concept of a copper shutter should have a clear view of the ocean they're observing.

Acknowledgments

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Figure 5. Biofouling on the MBARI's M2 mooring, the number one problem for moorings. The moorings are pulled in on a regular basis for maintenance: rebuild, cleaning and replacing instruments. Routine maintenance is also done in situ, with technicians boarding the mooring while out at sea.

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