M B A R I

Preparing the Sedimentation Event Sensor for the integration of control software from the Benthic Rover

John S. Virrey III, Bakersfield College
Mentors: Rich Henthorn, Paul McGill
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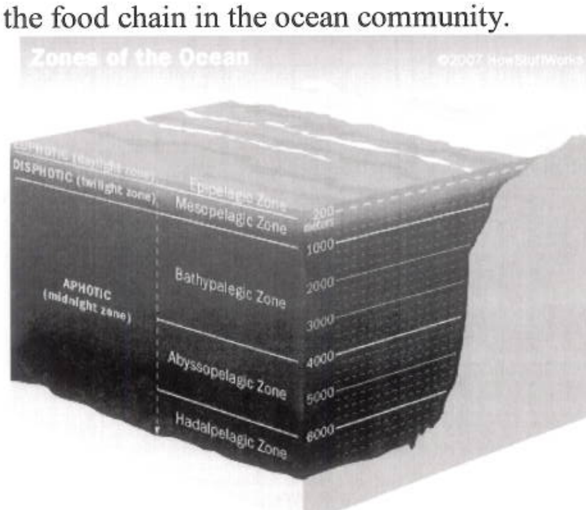
ABSTRACT

Long term data sampling devices used for deep sea monitoring are necessary when studying the on going changes at all depths in the ocean. These devices, while being deployed for an extended amount of time, must be accurate and reliable. Due to the continuous and costly maintenance that traditional sediment traps require, the innovation of the Sedimentation Event Sensor will be an effective and enduring means of data sampling in the great depths. Originally developed at the SCRIPPS Research Institute several years ago, the Sedimentation Event Sensor contains electronics that have become obsolete. MBARI has taken on the task of updating the design as well as the electronics on board. My summer internship has involved preparing the Sedimentation Event Sensor for the integration of software used by the operating system of the Benthic Rover, a similar autonomous device used for data sampling.

INTRODUCTION

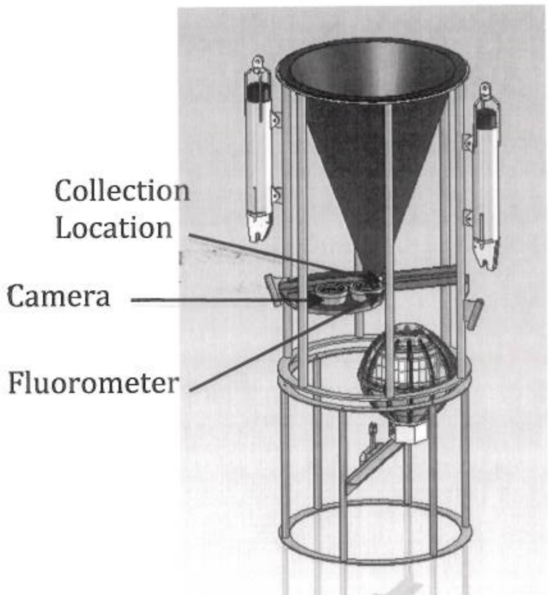
The dramatic impact of globing warming has an effect on the entire planet. Many individuals associate the rise in carbon dioxide to being relevant only with land and atmospheric changes, but in fact the ocean community feels this increase in gas production as much as every other ecosystem. The equilibrium that the atmosphere and our oceans share means that the carbon dioxide that is being so rampantly introduced into our environment is also being introduced into our ocean at an alarming rate. This in turn will cause a drop in the PH levels of ocean waters as well as a rise in marine temperature. With the PH levels of the ocean falling, this will create a rise in ocean acidification, which in turn will be extremely harmful to the biology of many sea dwelling organisms. The rise in temperature will also adversely affect the biology and ecosystems of the oceans ecosystems. These two factors will play an important role in shaping the future of the ocean as well as the world.

An increase in ocean temperature will alter the food chain in the ocean community. Climate variation affects surface ocean processes and the production of organic carbon, which ultimately comprises the primary food supply to the deep-sea ecosystems that occupy approximately 60% of the earth's surface. (Smith et al., 2009). The lower depths of the ocean, known as the midnight zone, are void of sunlight thus lacking the basic tools for photosynthesis to occur. The inability to host a suitable environment for plant life limits the amount of organic carbon produced thus creating a dependency on phytoplankton, microscopic plant life that are abundant in surface waters. It is this phytoplankton that creates the cycle of food production that will eventually be the basis for carbon and detrital material that will make its way down to the deep-sea floor. Water temperature

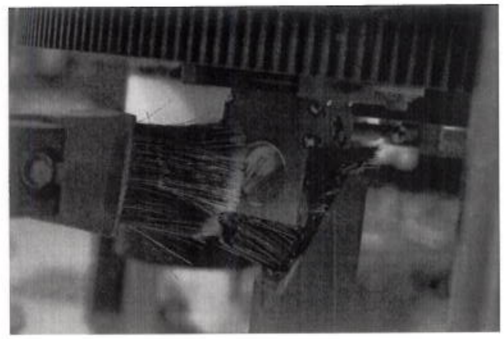


variations could result in influxes in phytoplankton production thus creating an imbalance in the overall ocean ecosystem.

This project is aimed at the development of new methods for studying the organic carbon and detritus that falls to the deep-sea bed. Long time-series studies are essential to monitor the stability and health of deep-ocean communities, especially as climate changes exert increasingly more influence on the deep ocean (Sherman and Smith 2009). Typical sediment traps measure approximately 5 feet in height, have a diameter of 3 feet, and are constructed from a titanium frame that can be deployed anywhere from a few hours up to 18 months. The limitation of these monitoring devices is the finite number of samples that may be collected. Generally having between 13 and 21 sampling cups, deployment times are directly correlated to the amount of time a sample is to be collected. As the sample-collection time is lengthened, the accuracy of the sample is diluted and the research is given to generalizations rather than detailed time scales. In order to fully understand the annual cycles of food supplying the deep ocean, constant annual monitoring as well as accurate sampling must be implemented.



The Sedimentation Event Sensor, or SES, is a modified sediment trap that has been designed to have a deployment time of roughly one year while accurately documenting sediment levels and abundance. This is a great advancement in the area of deep-sea research, eliminating the time/accuracy trade offs typically required with traditional sediment traps. The SES has been stripped of the sample cups typically found rotating around sediment trap carousels. Instead, the SES has been fitted with an entirely different carousel, containing a lens, a fluorometer, and a camera. The first behavior of the SES is to collect falling material onto a lens for a duration assigned by the researcher. The proposed time for collection has been estimated at a 12-hour cycle. After collection, the lens would automatically rotate to sit underneath a fluorometer where the fluorescence of the detritus could be measured. This is typically one of the tests that would be conducted by researchers after receiving the traditional sediment traps sample cups from deployment. Next, the lens of the SES would make another rotation where it would sit underneath a high definition camera. This camera would take a picture of the detritus in order to characterize the physical aspects of what has been collected. The final rotation would involve two behaviors. The first would be to pass the lens through two brushes. These brushes would clean the falling particulate matter from the lens so that a new sample could be collected. After moving through the brushes, the SES moves to a hall effects switch that resets the starting position of the electrical system so that accurate placement of the lens is assured on every rotation. By having the ability to collect a sample, measure the fluorescence with the fluorometer, and document what is being measured by taking a picture with a camera, and continuously repeat this cycle, the SES has eliminated the need to bring samples back to the lab, thus eliminating the need for constant maintenance and costly deployment and collection missions.

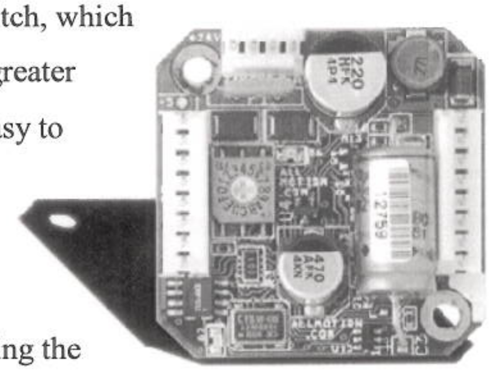


MATERIALS AND METHODS

Upon arrival at the Monterey Bay Aquarium Research Institute (MBARI) I was informed that my software engineering internship had the potential to be transformed into something more. Not only was I to be given the opportunity to help adapt the software need to operate the SES, but I would also have the chance to understand the mechanical and electrical aspects of the equipment. The methods used would quite different than other engineering projects I have worked with. This was due to the SES already being a completed project and our team having to re-engineer the work of someone else.

My first task was to familiarize my self with the Ruby programming language. While it is difficult to learn a new programming language from the basics to the finished product, it proved to be very cumbersome to decipher an already completed program for a very complex piece of robotics. The beginner's tutorials did not provide much help for me to comprehend the work of a software engineer that had been developing this code for a number of years. After a number of days tinkering with the code from the Benthic Rover, I managed to create one program that would be used at the final stages of the project, and with any other project involving the Ruby programming language. One of the drawbacks to this language is that there is no available compiler to check the pages and pages of code. When a software engineer is faced with the task of writing an extensive code, he has no way of checking his progress other than running the program and hoping that it works. In collaboration with Rich Henthorn, I was able to resolve this issue and a compiler for Ruby was developed that checks the syntax of each page of code.

After becoming acquainted with the Ruby programming language, I had the pleasure to work with an electrical engineer. Paul McGill directed me to now start work with a stepper motor controller. Developed by All Motion, this stepper motor controller had the movement capabilities and the power demands that our project required. Containing a 1.25 Amp Chopper (PWM) Driver with variable current output, the maximum output of this device exceeded the 837 required milliamps that our motor was rated for. The controller also had also been pre-wired for opto-switch, which proved to be of great use (this will be discussed in greater detail). The command set proved to be extremely easy to learn and I was operating the stepper motor controller within a day of using the device. Commands can be issued from any serial terminal program such as hyper terminal, or the option of using the EZStepper Windows application which is downloadable from the manufactures website. I chose to use a program named EZ-Terminal, which is very similar to Hyper Terminal.



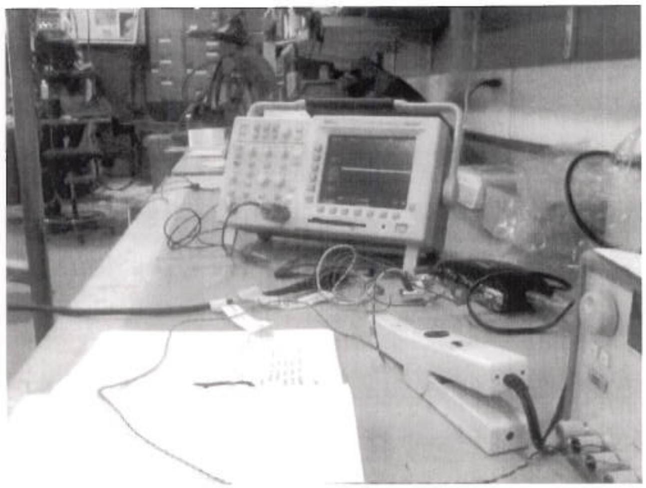
EZ-17 Stepper motor controller developed by All Motion. Measuring 1.6"x1.6" this device requires a minimal amount of space.

After being able to utilize the All Motion Stepper Motor controller, I was informed that my work would aid in determining a more accurate power budget for the electrical system of the SES. This would require the ability to operate the SES motor so that all desired operations could be achieved. Individual times for various speeds would need to be calculated and tested. The current used by the motor as well as the motor controller would have to be documented. And any anomalies would need to be addressed.

A large hindrance to the project was that much of the documentation on the SES was not available. If I were to map out the locations of the collection point, the fluorometer station, and the camera station using the stepper controller, I would need to understand the mechanics of the gears involved with the mechanical system. This required me counting individual teeth of the gears. The SES contains six gears with a total of 326 visible teeth. These gears are located on the carousel, the interface between the motor and the carousel, two gears inside of the motor housing, and finally two more gears located within the motor itself. After determining the total gear ratio and the time to make one full revolution, I was able to determine that one full revolution around the turntable consisted of 211200 half steps of the motor controller (the All Motion stepper motor controller operates in half or eighth steps). The number of steps between each location was also calculated, and by dividing the number of steps to be traveled by the speed at which the stepper motor progressed, I was able to calculate an estimated time to travel a desired distance.

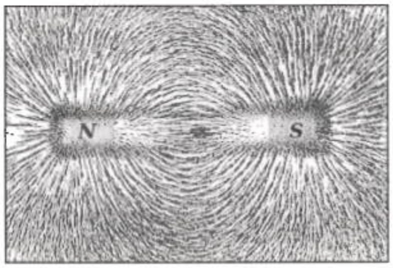
The next task was to develop a better understanding of the current necessary to operate the motor of the SES at various speeds. One interesting anomaly that occurred was that if we stepped the motor at faster speeds, the current level achieved by the motor declined. Paul and myself determined that this was due to the nature of the stepper motor to energize one coil, de-energize and energize a second coil. By continuously energizing and de-energizing, the speed at which the motor operated never allowed the desired current level to be achieved. This brought a new issue to the table. If the current level were limited by speed, then the torque capabilities of the motor would also be limited by speed. Without sufficient torque, the motor would stall and the rotation of the carousel would be halted. This would have to be tested as well. By using an oscilloscope and an amp probe, I was able to determine the current levels drawn at various speeds of the motor as well as measure the maximum amount of current each speed was able to reach. This was achieved by connecting the amp probe to one of the motor leads coming from the stepper controller. I then inputted commands to the stepper control to regulate the speed and current output. I would command the motor to move and this produced a visible waveform on the oscilloscope that I was able to observe and record.

Now that I had navigated through the physical components of the SES, it was time to begin my work on the software for the project. The ability to work hands on with the mechanical and electrical aspects of the SES proved to be a great benefit in understanding the Ruby program that was to be implemented. Lines of code that were previously foreign to me turned out to be commands being issued to a



previous ALL Motion Motor controller. The code that I was integrating was originally designed for the Benthic Rover. The Benthic Rover also used an All Motion controller, but instead of a stepper motor, if contained many servomotors. Although different in the nature of how they worked, the interface between the two motor controllers was extremely similar.

With the direction of Rich Henthorn, the behaviors on the movement of navigating the SES from location to location were completed. This was not an entirely easy process though. Because non-MBARI engineers developed the SES in a different lab, the electrical components and the software were extremely different. The most troublesome difference was in the management of the halls effects switch. A hall effects switch varies voltage output dependant on an interaction with a magnetic field. Used in conjunction with the opto-switch found on the stepper motor controller, we were able to determine a "home" location for the software. The engineers who designed the carousel for the SES



no doubt had the same idea in mind, but the difference resided in the software applications on how to achieve the home location. The capabilities of the All Motion stepper motor controller enabled you to step in a positive manner to achieve a position. If commanded to return home, the stepper would reverse its course and move in the opposite direction, or in reverse. The original engineers used a different type of software and achieved the home location by moving in a positive direction. This of course creates a difference in locations due to the magnetic field utilized by the hall effects switch. The magnetic field extends outwards in a circular pattern. The hall effects switch would sense the effects of the magnetic field at different proximities based on the direction it traveled around the carousel. The difference in position from reaching each side of the home location was recorded as 3360 half steps. Normally, this wouldn't be an issue since we developing our own software for the SES, but 3360 half steps move the lens of the SES into a position where it was half exposed to the collection point. This would not be an effective home position due to its partial exposure. The solution was to abandon the idea of using the All motion command to reach the home location, and instead create a command string that would step the motor in a positive direction, checking for the hall effects switch after a certain mount of steps were achieved. The number of half steps should not exceed the distance between the effects of the magnetic field, so we decided to move at 3000 half steps/sec. After the hall effects switch was located, another command string would back up the carousel, stop, and then continue forward with a similar command string but this time at a much smaller step increment. 10 half steps/sec was decided to be a small enough margin of error. The two command strings used to complete this function are listed below.

Command set used to move motor forward repeatedly at a pace of 3000 half steps/sec then stop when in contact with a magnetic field. After contact is made, the motor will reverse and move 3000 half steps/sec in the opposite direction, clearing the magnetic field

/1gP3000S03GD3000R

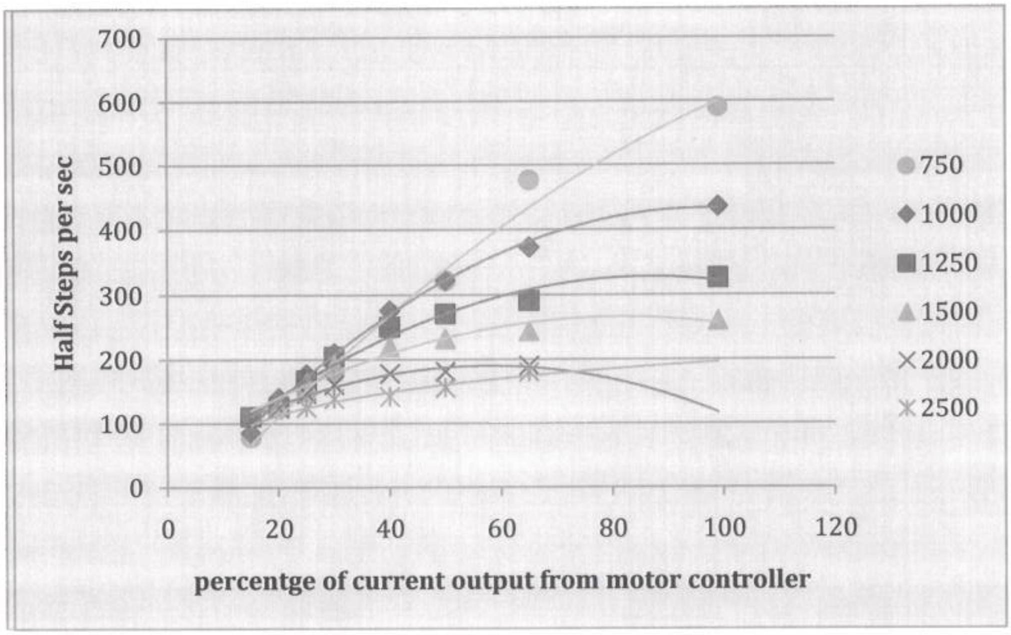
/1gP10S03GR

Command set used to move the motor forward repeatedly at a pace of 10 half steps/sec then stop when contact with the magnetic field is made. 10 half steps/sec enables the stepper controller to find "home" in a much more precise manner

The necessity to develop this method of finding the home location created an increase in the amount of time need to make on full rotation. With this final obstacle out of the way, the basic behaviors for the SES software were completed and further work on the integration of the Benthic Rover Software onto the SES may be completed. Unfortunately, the electrical equipment such as the fluorometer and the camera, as well as the relays and various other electronic devices were not available. This along with the lack of time involved in a 10-week program hindered my ability to progress further with my project.

RESULTS

Current level of motor controller	Half steps/sec					
	1000	1250	1500	2000	2500	750
15	85	111				78
20	140	126	126	124		123
25	177	168	163	147	125	149
30	210	205	191	161	139	179
40	276	251	220	178	142	247
50	322	271	232	181	156	322
65	373	291	244	190	180	476
99	435	326	260			590



The speeds of 2000 and 2500 both failed at certain points with the torque tests.
Spaces left blank are speeds and current levels where the motor would not function
or where maximum current had been achieved.

Maximum current levels for various speeds

speed in half steps/sec	Percentage of controller output	current achieved (mA)
750	99%	590
1000	99%	435
1250	98%	326
1500	74%	260
2000	64%	200
2500	64%	177

Maximum current achieved ***	822 mA @ 325 half steps/sec
Maximum current allowed ***	837 mA

Secondary information

Teeth count of given gears

Carousel	220
Gear interfacing with carousel	30
Larger gear inside motor housing	60
Smaller gear inside motor housing	16
Internal Gear Ratio of motor	80/1

Times to complete 1 full revolution

Speed of motor controller	Time in seconds	Minutes
750	281	4:42
1000	211	3:31
1250	169	2:49
1500	141	2:20
2000	106	1:40
2500	85	1:25

These times are from a continuous movement. These do not reflect time to stop at each loaction and conduct experiments. Nor does the account for the inclusion of the "home" command. The home command steps considerable slower than traditional movement so much more in-depth testing will have to be conducted after the electrical equipment has been installed.

At best estimate, a 66% increase in time is experienced from the camera location to the home position.

normal time to move between camera location and home switch = 1:33

sec
Time to move between camera location and home switch w/ command string = 2:20 sec

Around the Carousel

Location	# of teeth	# of steps
Collection-Fluoro	30.5	29280
Fluoro-Camera	36.5	35040
Camera-Home	146	140160
Home-Collection	7	6720
Distance between hall effects switch		3360
Total	220	221200

CONCLUSIONS/RECOMMENDATIONS

The initial project outlines for the Sedimentation Event Sensor had several specifications that were to be a guide in determining the duration of deployment. The power consumption of the stepper and driver were estimated at approximately 38% of available battery life. This required in-depth studies into the motor and its capabilities. Bt testing the motor and measuring current consumption and times, a better understanding of the over-all power budget could be determined. It is my conclusion that the original time allowance of 2 minutes to travel one revolution while completing tasks cannot be met. Due to the torque requirements, a speed of 1500 half steps per second should be implemented making the time for one full revolution considerably higher. My estimate at a final time allowance is roughly 3:10 seconds. It should be noted that this time does not reflect stops between locations to conduct tests.

I have also found that the completion of integrating the Benthic Rover software to operate the SES will be an easy task. The two systems are nearly identical, with the exception that the SES has quite a few tasks to complete.

ACKNOWLEDGEMENTS

I would like to thank my mentor **Rich Henthorn** for showing me an infinite amount of patience. **Paul McGill** for taking me under his wing and helping me to develop testing procedures to complete my work. **Alana Sherman** for showing me that there is more to electrical engineering than the science. *Ken Smith* for taking time to give me an understanding of the biological processes that we have been trying to study. **George Matsumoto** for heading this program and guiding us each step of the way. And last but certainly not least**, Linda Kuhnz** for making this summer exceptional in every way.

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