Integration of Depth Data onto a Video Camera Backpack for Use with California Sea lions

A Capstone Project

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in the

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Bachelor of Science

By:

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Cover Letter:

Studying marine mammals in the wild continues to challenge scientists because they live in an environment that is very complex and relatively difficult to access. Instrumentation can be attached to captive marine mammals and can be used as a new tool to study their behaviors in the wild. Our current understanding of many marine mammals in the wild is based almost entirely on observations when they are at or near the surface. Obtaining video footage of marine mammal activities that take place up to several hundred feet below sea level will add greatly to the present small body of knowledge about marine mammal behaviors. Instrumentation attached to captive marine mammals for open ocean research is an innovative approach for studying marine mammals in the wild. These studies of these animals in their natural habitats provide and contribute essential information relating to their health, survival, and conservation. The purpose of this project is to develop and test a system for the recording and playback of sea lion dive depth data using the audio channel of an underwater video camera. This project will help the SLEWTHS project as well as other scientists explore and learn about an environment and animals that we know very little about.

SLEWTHS (Science Learning and Experimenting With The Help of Sea lions) is an innovative project of sea lions and people working together to further marine education, conservation, and research. The important groundwork for all the research performed by the SLEWTHS project was founded on the idea of a cooperative relationship between sea lions and people.

For the last two years I have interned with the SLEWTHS project, and have been an assistant trainer for one year. In this time I have worked closely with the Director of training and research, Dr. Jenifer Hurley, and head trainer/volunteer organizer, Stefani Wurts-Skrovan. I have also attended two classes taught be Dr. Hurley, Working With Marine Mammals and The Theories and Techniques of Animal Training. These classes and my hands-on experience with the project have given me a greater understanding of marine mammals. I have gained practical knowledge of marine mammal husbandry, training, basic physiology, and different issues in marine mammalogy.

Many controversial issues arise about the idea of keeping marine mammals captive and using those animals for public display or research. Many of these issues arise due to the general publics' lack of education in the area of marine mammal research. An informed public is good for conservation and research and, without education; it is nearly impossible for society to be able to appreciate wildlife and conservation.

This project is important to me because I am very interested in marine mammal training and research. For this reason I bring many biases into this project. I am a young female student that attends an environmentally aware university. I am also a marine mammal trainer and I work with captive animals. I am educated about the controversial issues that continue to emerge about keeping animals in captivity. Knowing that my biases exist I will try to put my love for animals aside in order to incorporate other people's opinions and incorporate those concerns into my project.

My capstone will incorporate the ESSP core outcomes.

MLO #6 & 10: Systems analysis and interdisciplinary interactions competency & Systems approach to applied problem solving.

I will present and discuss a model of a system in such a way that it demonstrates my ability to analyze interactions between the political, technological, biological and social dimensions of the environmental problem. I have designed and implemented a project that will improve our understanding of marine mammals in the wild. The effectiveness of this project will be evaluated in meeting its goals.

MLO #3: Applied scientific knowledge competency

Questions and hypotheses based on scientific knowledge will be addressed throughout the capstone through extensive review of scientific literature. The main question will be; what does a female California sea lion do underwater (in terms of depth)? A number of hypotheses can be proposed. Does she cruise just under the surface? Does she cruise along the bottom? Does she go up and down between the top and bottom without breaking the surface? My scientific knowledge as well as my skills will be used to test these questions.

MLO #5: Data acquisition, analysis, and display competency.

An experimental design will be described in detail. The data collected from this project will be displayed in a table as well as a graph. The strengths and weaknesses of the project will be discussed in the discussion section of this capstone.

Abstract:

Instrumentation attached to captive marine mammals for open ocean research is an innovative and valuable approach for studying marine mammals in the wild. Direct real-time underwater observations are still needed for a variety of research projects. The goal of this project was to develop and test a system for recording and playback of sea lion dive depth data using the audio channel of an underwater video camera. A pressure transducer was installed into an aluminum waterproof camera housing. A signal conditioning circuit was built to translate pressure (depth) signals into audio signals that could be recorded on the audio channel of the video camera. Designated access to at least one audio channel of the video camera was located. A preliminary decoder circuit was built. The unit was calibrated by submersion to known depths and then placed on a trained California sea lion (*Zalophus californianus*) for open ocean experiments. The data revealed that the sea lion mainly cruises along the seafloor bottom and breaks the surface roughly every 20 seconds to take a breath.

Background and Goals:

The California sea lion (*Zalophos californianus*) is perhaps the most familiar of all pinnipeds because of its appearances in zoos and aquariums (Riedman, 1990). However, little is known about the diving and physiology of these remarkable marine mammals because of the dangers and challenges that arise with deep sea diving. Because these complexities continue to hinder humans from performing studies through direct observations or by video cameras controlled at the surface, instrumentation attached to marine mammals is often used as a new tool to study behaviors in the wild. Technological devices such as time/depth recorders and satellite transmitters have been developed and are constantly being improved (Ridoux, et al, 1997). However, underwater observations are still needed for a variety of research projects.

Protection and conservation of marine mammals is a concern among many. Marine parks, zoos, and the media can be credited in generating public awareness and appreciation of these remarkable animals. The Marine Mammal Protection Act (MMPA) recognizes the essential contribution of marine mammal research is assuring health and stability of the marine ecosystem. Understanding the physiological adaptations of these animals will contribute to successful conservation and management strategies (Elsner, 1988).

Under the Endangered Species Act (ESA) and the Marine Mammal Protection Act, federal permits are required to conduct most types of field research using threatened, endangered, and marine-mammal species. The complexities involved in obtaining permits for field research using protected species continue to increase. In October 1988, Congress amended the MMPA to increase the documentation required to obtain a scientific research permit. Applicants for scientific research permits must now submit, "information indicating that the taking is required to further a bonafide scientific purpose and does not involve unnecessary duplication of research."(Ralls, 1989). Increased difficulty in getting permits tends to discourage research on protected species, and it may be to their disadvantage over the long term. The effective conservation of these species is gained through cumulative knowledge of their biology: knowledge gained through scientific research.

The 1988 amendment to the MMPA may make it more difficult to conduct basic research on marine mammals. The amendment was intended to help ensure that marine mammal research will not have “unnecessary undesirable effects” (Ralls, 1989). This amendment could be put into action in such a way as to impair the freedom of scientists and delay the gain of knowledge needed for effective conservation strategies

Many political and social issues arise when using animals in research. One ethical problem is whether specific experiments involving animals are morally justifiable and whether they should be permitted. Animals have a significant moral status. They cannot be treated as mere objects, and the effect of an experiment on them must be considered when we decide whether the experiment is ethically justifiable. Each animal experiment that involves pain, suffering, death, or even holding animals in captivity creates an issue of justification (Evans, 1990). It is important for marine mammal scientists to share concern for both the species in their natural habitats and for the healthy condition of experimental animals to produce reliable results.

Many studies that have already been conducted on marine mammals have been limited by the physical restrictions of the facilities (Evans, 1990). Marine mammals are extremely large compared to most animals used in laboratory experiments. Providing enough space to study diving capabilities and unrestricted swimming behavior is unreasonable and even perhaps impossible. One solution to this problem is to use the animal's natural environment, the ocean.

There is a constant effort to find new tools to study marine mammals at sea. The purpose of this project is develop and test a system for recording and playback of sea lion dive depth data using the audio channel of an underwater video camera. This underwater video camera is used by the SLEWTHS (Science Learning and Experimenting With The Help of Sea lions) project. Once the depth recorder is installed into the camera pack, this device will be placed on specially trained California sea lions (*Z. californianus*) and taken to the open ocean to collect data on ocean phenomena and also sea lion diving abilities. Because these sea lions are trained to go out to the open ocean they are able to help us scientists explore and learn about an environment and an animal that we know very little about.

This innovative approach to science that the SLEWTHS project utilizes not only eliminates stress artifacts from forcing subjects to participate, it also allows for many questions that could not be asked any other way than through willing participation of the animals. A blood sample from a stressed animal for example, would be less representative of a relaxed animal in the wild than would a sample from a trained animal who has experienced the sample in a previously positive way. Not only would much of animal research be difficult without animal cooperation, it would be impossible. The advantage of using trained sea lions to observe and record other marine mammal behaviors as well as their own behaviors over either human divers, submersible vehicles, or boats riding along side the animals is that many marine mammals are accustomed to sea lions swimming near them and the behavioral activity of the animals is often modified by the presence of the diver. The equipment used can be simplified as can the number of people involved and the time required to obtain the necessary data. The animals at the SLEWTHS project have helped in studies ranging from how their own bodies work while diving (heart rate, metabolism, and heat flow), to calibrating instruments to be used on wild counterparts, to filming the underwater behavior of other animals in the open ocean.

Project Description:

This project contains three parts. The majority of my contribution is emphasized in the development of the first part. Parts 2 and 3 will be sufficient enough to prove that the first portion works adequately. The first element of the project will be to install a pressure transducer into the camera housing, building a small signal conditioning circuit for the pressure transducer, and locating designated access to at least one audio channel of the video camera and then recording dive depth data during real sea lion dives. The second element of this project will be to develop a decoder circuit. The third element of this project will be to use the underwater video camera to test the circuit by collecting dive data on a female California sea lion (*Z. californianus*).

Methods:

Depth was calculated from pressure measurements. A pressure sensor was placed onto the waterproof housing which hold a video camera. The depth data from that sensor was recorded on the audio channel of a Sony digital camcorder. By encoding a series of tone pulses these values can be decoded into binary values. These binary values can then be sent to the serial port of a computer for interpretation and display based on sensor calibration data stored in that computer.

Pressure Transducer:

The system determines depth by measuring water pressure. The weight of seawater and atmosphere above any submerged object exerts a pressure on that object. The atmosphere contributes 14.7 pounds per square inch (PSI) at sea level. Seawater adds an additional 14.7 pounds per square inch for every 33 feet of depth (Hecht, 1996). For example, objects 66 feet underwater are exposed to a pressure of 44.1 PSI. Some pressure transducers (sensors) are designed to measure "absolute" pressure, which includes the contribution of the atmosphere. Thus, absolute pressure sensors give a reading of 14.7 PSI at sea level. Other pressure sensors are designed to measure the difference between a pressure and 1 atmosphere of pressure. These sensors are said to measure "gauge" pressure. They give a reading of 0 PSI at sea level. In this project, I have used a sensor that is of that "gauge" type, so it reads zero (or nearly so) at the sea's surface.

The pressure transducer (EPX-V02-250P-/Z1/V05) made by Entran. This device is designed to measure up to 250 pounds per square inch for normal operation, which is equivalent to 561 feet, and can go to twice this depth without damage. It requires 5 VDC to operate. Refer to table 1 below for a brief summary of the characteristics of the pressure transducer.

Table 1: Pressure Sensor Details

Manufacturer	Entran
Model number	EPX-V02-250P-/Z1/V05
Sensitivity	0.318 mV/PSI
Input impedance	990 ohms
Output impedance	326 ohms
Installation torque	10 inch-pounds
Normal working range	250 psi
Maximum (before damage)	500 psi
Reference	Sealed
Excitation	5 VDC

Table 2 below describes the wiring for the pressure sensor.

Table 2: Wiring for EPX-V02-250P-/Z1/V05

Red	+5 VDC
Black	Ground
Green	+OUT
White	-OUT

Camera:

The video camera used is a DSR-PD1 Sony digital camcorder (Figure 1 below). Battery life and length of videotapes will allow up to one hour of recording. One of the microphone channels has been disabled so that the channel could be used for the encoded signal (a series of tone pulses). The other microphone channel has been disconnected to reduce interference, since both channels get superimposed at the 3.5mm stereo jack output, where one channel is used for video and the other is for audio (both channels merged). See Appendix 4 for instructions for restoring the function of one or both microphone channels to normal use.

Figure 1: DSR-PDI Sony digital camcorder

Housing:

The housing is 6 x 6 inch aluminum case (Figure 2 below). The case is attached to a plastic frame, which is lined with black foam to protect the animals' body when it is being worn. Four clips are attached to each corner of the frame, which connect to the harness worn by the sea lions. The camera is bolted inside the housing to reduce movement of the camera once inside.

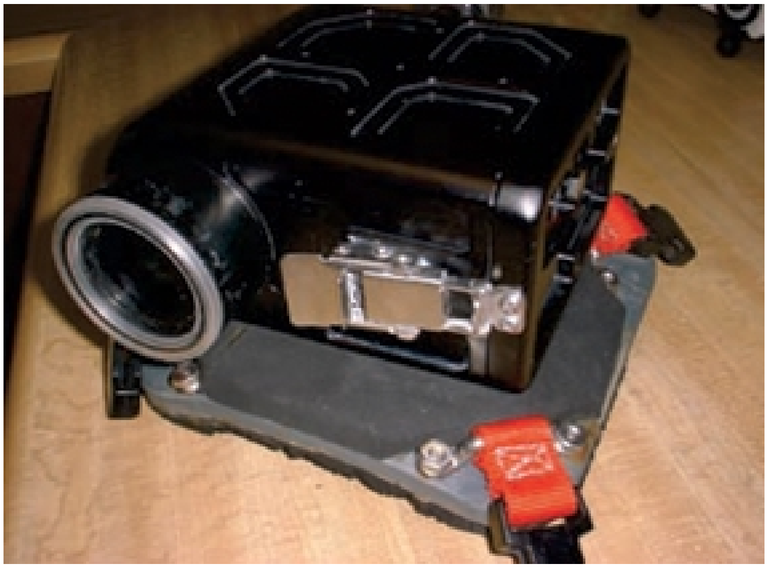

Figure 2: Waterproof camera housing

Encoder:

The encoder circuit (Figure 3) takes readings from the pressure transducer and converts them to a series of tones that can be recorded to the audio channel of the underwater video camera. The pressure transducer sends the data to an instrumentation amplifier sensor (Burr Brown, INA118P), which amplifies the small signal from the pressure sensor. The output of the instrumentation amplifier is then sent to an analog to digital converter (National Semiconductor, ADC0834BCN), which converts the analog signal coming from the instrumentation amplifier into a digital binary number. The BASIC stamp micro-controller controls the converter and collects the bits. The converter outputs that data to the tape by encoding it as an audio signal and recording a filtered version of that signal onto one of the video camera's audio channels. The encoding is done by a micro-controller (Parallax Inc., Basic Stamp, BS1-IC), see appendix 1 for program. It sends 8 tone pulses to the audio channel of the camera for each 8-bit number. The filter was used to extract the signal from the background noise, such as noise from the motors that run the tape in the camera. The output from the stamp is sent into an attenuation circuit. The output data is binary numbers as a train of eight pulses approximately 5.6 kHz. Ones are represented by a tone approximately 24 ms long. Zeros are represented by a tone approximately 12 ms long. Pulses are separated by a roughly 10 ms gap. The series of tone bursts lasts approximately 150 – 230 ms, depending on the number of 1's and 0's. See appendix 2 for encoder circuit diagram.

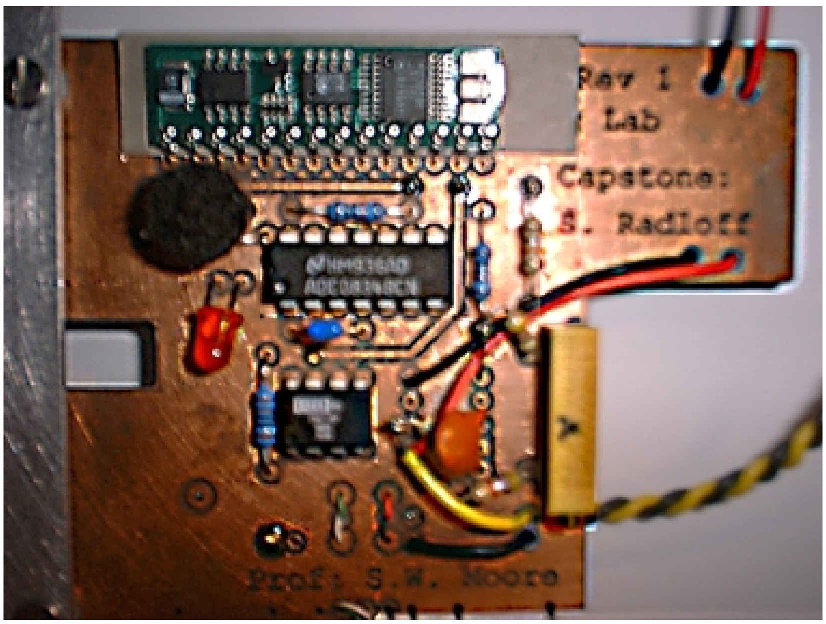

Figure 3: Encoder Circuit

Installing the Pressure Transducer:

Once the encoder circuit was established and I verified that it works, a hole was threaded onto the door of the waterproof aluminum camera housing. The pressure transducer (EPX-V02-250P-/Z1/V05) was installed.

Decoder:

The decoder circuit listens to the coded audio signal upon playback and converts the code into a digital display of depth. A temporary prototype circuit was built to do this. The output from the camera is a series of high frequency pulses ranging about 1 volt. This was amplified by a 11-fold gain. A peak detector with a bleed off resistor was used to shrink the pulse frequencies into clean series. See appendix 3 for decoder circuit diagram.

Calibration:

A 100 ft rope was measured and duct tape was placed at every 25 feet. The camera and encoder were turned on and attached to the rope. It was lowered over the side of the boat and held at each depth (0ft, 25ft, and 50ft) for 1 minute.

Collecting Dive Data:

Dr. Jenifer Hurley, director of training and research of the SLEWTHS project, has trained four California sea lions (*Z. californianus*) to wear a harness that holds a video camera, inside a waterproof aluminum housing (figure 4). The housing and camera are slightly buoyant in the water to reduce the weight on the animals and to allow for recovery if it should detach from the harness. The harness has a corrosive bolt, which will allow the detachment of the harness within two to three days if the animal should become separated from the research team while working in the open-ocean. The animals at the SLEWTHS project are routinely trained to do open ocean research. A thirteen-year old female California sea lion, Sake, was be escorted into the open ocean, off the beach of Moss Landing State Beach.

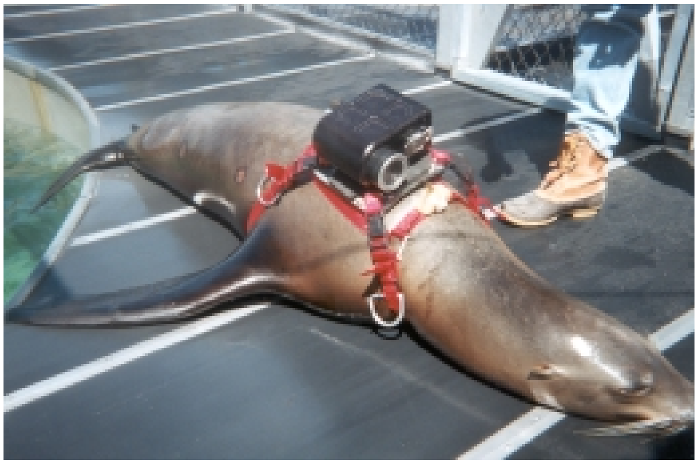

Figure 4: Female (*Z. Californianus*) wearing harness and camera housing

Results:

A signal conditioning circuit was successfully built for the pressure transducer. The pulses were recorded on the videotape. A temporary prototype decoder circuit was built, and successful digital display of depth was recorded onto a computer screen. A calibration data was completed. Table two below, shows the output for the calibration data collected.

Table 2: Calibration data

Approximate Depth (ft)	Binary Number	ADD counts
0	00000100	4
50	00110010	54
75	01001011	83
79	01001111	93

The output from the calibration dive was displayed onto a computer screen. The graph below reflects that output (figure 5).

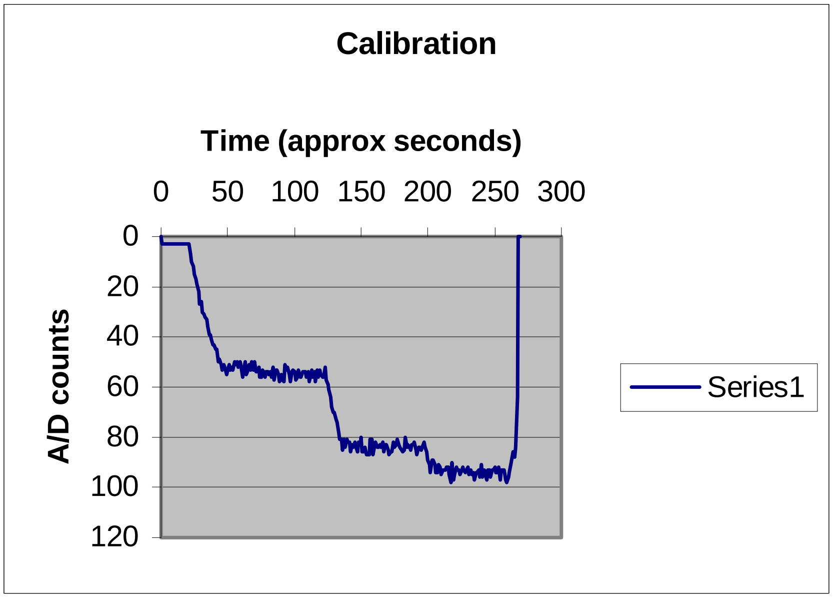

Figure 5: Calibration data

Figure 6 below describes the data revealed from the sea lion dive off the coast of Moss Landing State Beach. The maximum depth that the sea lion reached was approximately 10 feet. She came to the surface two times in a 54 seconds time frame.

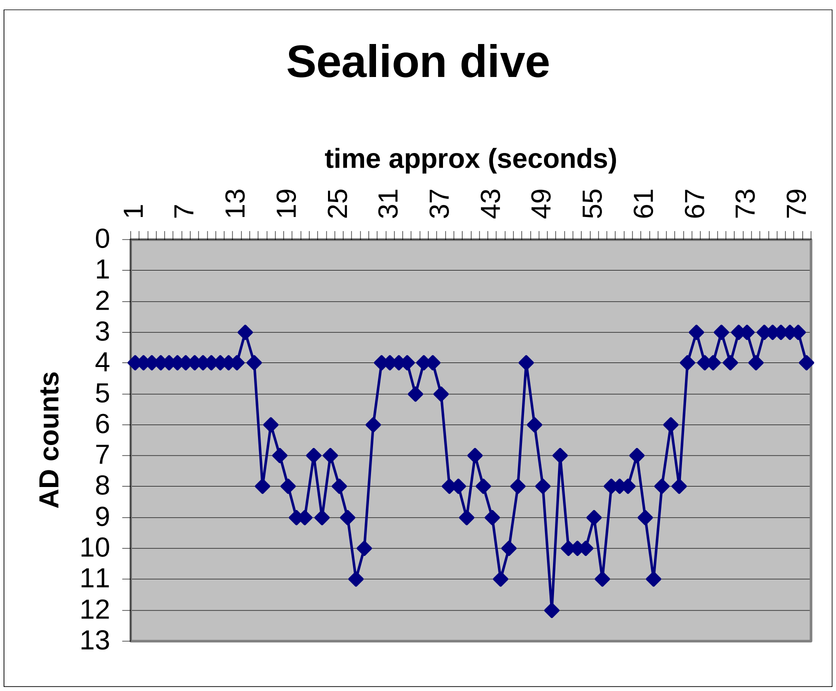

Figure 6: Sea Lion Dive

Project Analysis/Discussion:

The goal of this project was to develop and test a system for recording and playback of sea lion dive depth data using the audio channel of an underwater video camera. A pressure transducer was installed in the camera housing, a small signal conditioning circuit was built for the pressure transducer, access to the audio channel of the video camera was obtained, and the circuit was tested at various depths to verify the performance of this apparatus. Our current understanding of many marine mammals in the wild is based almost entirely on observations when they are at or near the surface. This underwater video camera allows for real-time underwater observations.

The maximum depth that the pressure transducer can sustain is 251 feet, approximately 1 count per foot and a maximum of 255 counts. The sea lions at the SLEWTHS project do not exceed this depth while acquiring data in open ocean research projects. If this particular device wanted to be used in other research projects either with the SLEWTHS project or with other research teams, the species of concern might be limited. For example, the Wedell seal (*Leptonychotes weddelli*) can dive to maximum depth of 600 meters, which is clearly beyond 561 feet (Kooyman et. al, 1997). However, this circuit could be modified to give better resolution if the sea lions at the SLEWTHS project never exceed 100 feet or it could be modified for greater depths if the sea lions routinely went to 400 feet. This approach would still work but a different pressure sensor would have to be purchased that contains a working range to support those depths. The battery life of the camera and the length of videotapes will allow up to one hour of recording. This particular circuit will last approximately 40 hours on a fresh 9-volt battery. Assuming a fresh 9-volt battery holds about 400mAh, and this circuit draws roughly 10mA. However, many cetaceans and a few pinnipeds make long, deep dives to obtain their prey, some longer than 40 hours. The range of this device is restricted by water visibility and light penetration. Video sampling will be limited to daylight hours consequently restricting activities that occur during the night. The camera has a built in filter on the audio channels that blocks out anything above 20kHz so anything above this will not be recorded.

The current sampling rate of the encoder circuit is about 1 Hz, and is not exactly once per second, so the system cannot reliably detect changes in depth faster that this, and Sake is an extremely fast diver. However, the sampling rate could be doubled or a second channel of data, for example speed, could be added without major modifications to the existing encoder. If more than 2 bytes of data need to be recorded per second, the pulse durations will need to be shortened. At some point you can't get much shorter without increasing the frequency. Because of the 20 kHz filters that are probably built into the camera's audio channels, you cannot increase the frequency of the tones by more than about 4 times. Even though all of these constraints exist, it should still be fairly easy to record 8 bytes per second, allowing four data channels at 2 Hz sampling. Any of the above changes would require adjustments to the basic stamp program and to the decoder circuit.

This project will help the SLEWTHS project as well as other scientists explore and learn about an environment and animals that we know very little about. This dynamic process allows humans to become aware, gain knowledge, expand our understanding, and developing skills that will contribute to essential information relating to the health, survival, and conservation of these remarkable animals

In the fall of 2001, two sea lions from the SLEWTHS project will be participating is a study comparing diving physiology (heart rate) between pinnipeds and humans. The worlds most renown human free divers will be diving side by side with the sea lions in the ocean diving to depths up to 100 feet. The SLEWTHS project continues to explore applications of using the sea lions as ocean survey tools for subjects ranging from marine archeology (Texas A&M Institute of Nautical Archeology) to benthic community monitoring. Swimming mechanics studies both in the pools as well as in the open ocean are being used to study the effects of field instrumentation on the swimming and diving capabilities in sea lions. Comparisons will be made with instruments varying in weight, shape, buoyancy, and body placements. The results from this study should help establish a calibration for field studies using instrumentation and provide a baseline for the future of instrumental design.

Future Recommendations:

A digital camcorder should be purchased that has a microphone jack. The Sony digital camcorder (DSR-PD1) used in this project did not have a microphone jack. As a result, both of the microphone channels (left and right) have been disabled in a reversible manner, to wire the encoder circuit directly into the camera’s internal audio circuitry. This process was extremely time consuming and could have damaged the product if done wrong. The camera’s circuit had to be determined and a compatible circuit was then designed. The waterproof aluminum housing should be built to allow accessible room for circuits. The housing used in this project was extremely small. As a result, the space was limited for circuits to be installed.

Some additions to the video camera can be made to improve field studies. An internal clock will allow recording of time. A hydrophone will allow recording of sound if the audio channels are not disabled. A velocity meter will allow the recording of speed. All of these additions will be very useful to the SLEWTHS project in future research projects.

Acknowledgements:

I would like to thank Professor Steve Moore for all of his guidance, patience, and especially for all of the technical assistance. Dr. Jenifer Hurley for inspiration and pursuance of my dream. I would like to thank the SLEWTHS staff and animals especially Sake. Amber Stephens, Allison DeShane and ESSP 330 fall 1997 and fall 1998 for their work laying the groundwork for this project.

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Appendix 1

'PROGRAM:SLEWTHEN.BAS
'By Steven W. Moore
'April 2001

'SLEWTHS SEA LION DEPTH ENCODER PROGRAM

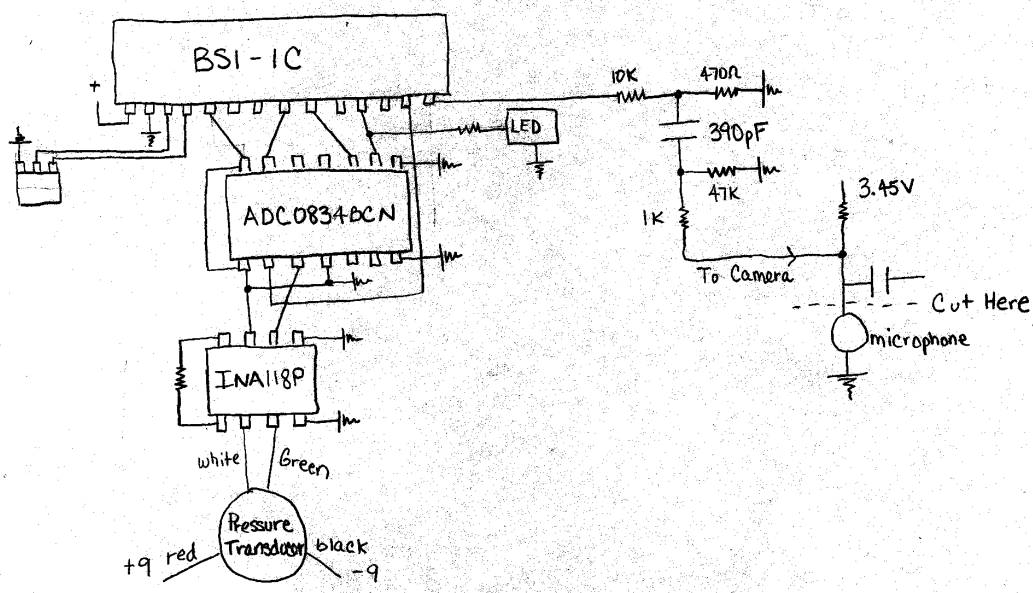
'THIS PROGRAM CONTROLS THE BASIC STAMP "BRAIN" OF SLEWTHS DEPTH
'DATA ENCODER CIRCUIT CONSTRUCTED TO STORE SEA LION DIVE DEPTH
'DATA ONTO THE AUDIO CHANNEL OF A HOUSED UNDERWATER VIDEO
CAMERA.
'A SISTER PROGRAM/CIRCUIT "SLEWTHDE.BAS" IS NEEDED TO DECODE THE
'AUDIO SIGNAL UPON PLAYBACK OF THE VIDEO TAPE. BASICALLY, THE
'CIRCUIT SAMPLES AN A/D CONVERTER HOOKED TO A PRESSURE
TRANSDUCER
'AND CONVERTS THE A/D COUNTS INTO A SERIES OF AUDIO PULSES
WHERE
'A LONG TONE = 1 AND A SHORT TONE = 0.

```
'BASIC STAMP pin names and connections
Symbol DI=0     'pin 0 (output) = data from Stamp (input to ADC0834)
Symbol CLK=1            'pin 1 (output) = clock for ADC0834
Symbol DOP=pin2         'pin 2 (input) = data into Stamp (output from ADC0834)
                'pin 3 (input) = [not used]
Symbol LED=4            'pin 4 (output) = output for LED/debug
                'pin 5 (input) = [not used]
Symbol CS=6     'pin 6 (output) = chip select for ADC0834
Symbol AUD=7            'pin 7 (output) = output to audio channel


'Basic stamp memory allocation & labels
Symbol data = b0        'used to hold each byte from ADC
                        'using b0 because it is bit-addressable
Symbol i = b2   'loop counter within A/D conversion routine
Symbol j = b3   'spare loop counter for debug/testing operations
'b4-b11 used to store data for tone (see below).

'Other symbols
Symbol F = 126          'sets frequency for tone bursts (see Stamp manual)
                '126 gives approx 5.6 kHz (measured)

setup:  let pins = %01000000 'p6=1 to deselect ADC, others low
        let dirs = %11010011 'p2 input from ADC, p5&3 unused,
                             'all others active outputs
```

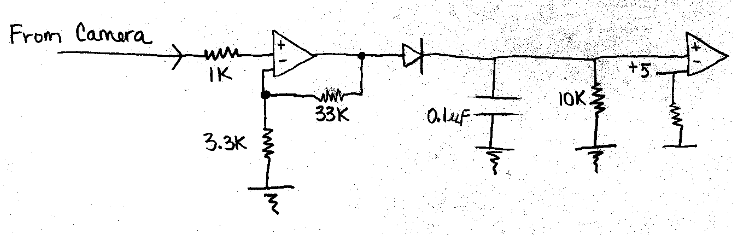
```
'Note, the following loop contains a few lines that have been
'commented out.  These can be used for debugging/testing of
'hardware by outputting a known sequence of "data" bytes,
'specifically looping continuously from 0 to 255 over and
'over again.  To use them, just remove the comment apostrophes.

Loop:   gosub conv
'       For j = 0 to 255        'disabled debug/testing code
'       let data = j            'disabled debug/testing code

'This next set of lines loads stores an 8-bit binary number
'as a 2's and 1's (rather than 1's and 0's), so these numbers
'can be used directly to specify the duration (in multiples
'of approx 10 ms) of each tone pulse.
        b4 = 1 + Bit0
        b5 = 1 + Bit1
        b6 = 1 + Bit2
        b7 = 1 +Bit3
        b8 = 1 + Bit4
        b9 = 1 +Bit5
        b10= 1 + Bit6
        b11 = 1 +Bit7

'Generate LED flash (evidence that program is looping).
'Can be used as extern scope trigger to debug tone pulses.
'Flash/trigger is optional and can be disabled if it
'causes any problems (e.g. reflections on video, or
'excessive power consumption.

high LED
pause 10
low LED

'The following lines generate the sequence of tone pulses.
'Zeros are represented by a tone approximately 10 ms long.
'Ones are represented by a tone approximately 20 ms long.
'Pulses are separated by a roughly 10 ms gap. See BASIC
'Stamp manual for syntax.

sound AUD, (F,b11,0,1)          'MSB pulse followed by gap
sound AUD, (F,b10,0,1)
sound AUD, (F,b9,0,1)
sound AUD, (F,b8,0,1)
sound AUD, (F,b7,0,1)
```

```
sound AUD, (F,b6,0,1)
sound AUD, (F,b5,0,1)
sound AUD, (F,b4)
low AUD             'forces AUD low at end of last pulse
                    'otherwise state after pulse is random

pause 750           'series of tone bursts lasts approx
                    '150 - 230 ms, so this pause results in
                    'sampling/recording at just over 1 Hz.

'next j             'disabled debug/testing code

goto loop

conv:               'reads A/D converter value into "data" variable

'prep for conversion
low CLK             'put clock line in starting state
low CS              'activate ADC
high DI             'place start bit on DI
pulsout CLK,1       'clock bit into ADC

'configure MUX for channel zero
high DI             'single ended
pulsout CLK,1
low DI              'even channel number
pulsout CLK,1
low DI              'lower of the two even channels
pulsout CLK,1

'read data from ADC
let data = 0            'clear data variable
for i = 1 to 8          '8 data bits per conversion
let data = data*2       'perform left shift
pulsout CLK,1           'request next bit from ADC
let data = data + DOP   'next bit from ADC DO into LSB of data
next i

'end conversion
high CS             'ADC off
return
```

Appendix 2
Encoder circuit diagram



Appendix 3
Decoder circuit diagram



Appendix 4
SLEWTHS Depth Encoder
Supplemental Instructions

Instructions for restoring one or both microphones on the SONY DVCAM.

Opening the camera to access the microphones:
Tools needed: VERY small Phillips screwdriver, VERY small flat-tipped screwdriver, fine-tipped soldering iron, solder, clean & clear workspace, container to hold several very small screws.so they don't get lost.

1. Eject any tapes in the camera and then remove the battery pack to avoid serious damage in case of accidental shorting.
2. Close the door to the tape compartment if it is still open.
3. Remove the two black screws holding the black metal light bracket on top of the camera; remove the bracket and the gray rectangular piece beneath it.
4. Remove the single screw on top of the camera just behind the camera lens (be sure to keep track of which screws go where – they are not all the same thread type/size.
5. Remove single screw located about 2 cm to upper left of main red record button and partly hidden behind eyepiece rubber cup.
6. Carefully turn camera onto its side with the tape compartment facing up, the battery pack area against the table top, and the bottom of the camera facing you.
7. With the camera on its side as described above, remove the UPPER two screws from the rectangular plate on the bottom of the camera (to upper right and upper left of the serial number).
8. Rotate the camera 90 degrees so that the back of the camera is facing you and carefully open the tape compartment door toward you to reveal the EJECT button.
9. To the left of the blue (upside down) EJECT button you will see a silver diagonal bar with a slot down its middle. This bar slides in and out as you open and close the door. Remove the single black screw that attaches the sliding bar mechanism to the door.
10. STOP! Read this paragraph and the next several steps carefully BEFORE you proceed as some easy mistakes could spell disaster if you don't know what's coming up. First, do not attempt to pick up the camera at this point, as it can come apart in your hands and get damaged. Second, you are about to lift the cover off of the camera, but it is *still attached inside* by a very tiny and delicate ribbon cable with a connector that must be unplugged before the cover can be removed completely. Third, you are about to expose electronics that can be damaged or destroyed by contact with static electricity of the magnitude that commonly exists on human finger tips. It is imperative that you touch the camera's electrical ground system BEFORE you touch any other electronics inside.
11. Rotate the camera 180 degrees so that the front (lens side) of the camera is facing you, then VERY GENTLY wiggle and lift the cover approximately 1" until you can see a blue ribbon cable with 5 silver wires. The end of the cable plugs into a white plastic connector. DO NOT TOUCH YET!
12. To the right of the connector is a large silvery metal rectangle. Touch this first (it is grounded) to neutralize any static electricity voltage difference between your body and the electronics inside the camera.
13. The blue ribbon cable has a "T" shaped yellowish-clear plastic tab that can be used to unplug the cable by lifting on the ends of the top of the "T". DO NOT PULL DIRECTLY on the blue cable. You will probably need to use a tiny flat bladed screwdriver to back and forth from one side to the next to gently rock the plug out of the connector.
14. Once the cable is unplugged, gently lift the cover clear of the camera and set it aside. Avoid any unnecessary contact with the inner workings of the camera, as these delicate parts are now exposed and vulnerable.
15. Rotate the camera until the top of the camera faces you, and then look straight down on top of the microphone unit. To either side you will see a relatively brass-colored screw somewhat larger than those you've removed so far. Loosen, but DO NOT REMOVE these screws. CAUTION: These screws may be in fairly snuggly. Be careful what you grab to hold the camera in place while you loosen these screws. It's all too easy to inadvertently grab, squeeze, and bend or break a very

delicate part of the exposed innards at this stage. Try to handle ONLY the outside cover of the camera. And remember, if you must touch some of the interior, look for a solid area, and touch that silver rectangle to dissipate any static charge before each contact.

16. Lift the microphone unit straight up about ¼" (careful – it's attached by very short wires!)
17. Gently peel back the corners of the black sticy-foam to locate the two screws in opposite diagonal corners of a silver metal plate hiding under the foam. Be careful not to yank the wires while doing this.
18. As you do the following step, note the route of the wires, so you can restore it upon reassembly. Remove the two screws and the silver metal plate to expose a black rubber holder for the two condenser microphones.
19. Gently lift the rubber holder out of the gray plastic microhone frame and turn it over so that you can see the front of each microphone. Note that each microphone is sitting in a rubber cup with a slit in one side for the wires.
20. Here's what you should find. One microphone (the Left microphone) should have 2 black wires soldered to its ground pad and nothing connected to its other pad. The other (Right) microphone should have a single black wire soldered to its ground. There should also be two black "shrink tube" insulators, one with just a red wire going into one end of it, and the other with a red and a white wire going into one end of it.
21. The SLEWTHS data is stored on the LEFT stereo channel. To restore the LEFT microphone, the black wire exiting the camera housing to go to the SLEWTHS encoder circuit should be disconnected from the ground pad, and the black wire going into the interior of the camera should be left connected. (You may need to disconnect both, and then reattach the camera wire.) You must also cut open and discard the black "shrink tube" insulator covering the joint between the red wire (to SLEWTHS circuit) and white wire (from camera interior), disconnect these wires from each other, and then solder the white wire to the remaining (non ground) pad of the microphone.
22. To restore the RIGHT microphone, cut off and discard the black "shrink tube" insulator covering the end of the single red wire, then solder that wire to the remaining (non-ground) pad of the microphone.
23. Before reassembly, check for accidental solder shorts.
24. Insert each microphone into its correct "cup" in the rubber and route its wires so they exit the cup through the slits.
25. Put the rubber cup piece back into the gray plastic piece with the microphones facing the correct way. Make sure right (red wire) is right and left (white wire) is left (check R and L labels on other side of gray plastic piece). Also make sure the wires exit the gray plastic frame over the rubber "tongue" that is part of the rubber cups piece and fits into a small groove in the gray plastic piece.
26. Reassemble remaining parts in reverse order, being careful to be sure that the blue ribbon cable gets plugged back in, and that no tiny wires or other parts get pinched as the lid is placed back onto the camera.