TOADFISH BEHAVIORAL ROBOT FOR FISH AGGRESSION STUDY

A Design Project Report
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In Partial Fulfillment of the Requirements for the Degree of
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ABSTRACT

Master of Engineering Program

School of Electrical and Computer Engineering

Cornell University

Design Project Report

Project Title: Toadfish Behavioral Robot for Fish Aggression Study

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Abstract:

This project is intended to help Professor Andrew H. Bass research team from department of Neurobiology and Behavior studying and understanding aggressive behavior between fishes. Our group's MEng project is building a small toadfish model that researchers can put in the tank to study fish behavior. This project can be divided into two parts. One is the toadfish model, which is manufactured by 3D printing technology and soft silicone casting technique, and can be moved around by a mechanical connection to the toadfish model. The other part is waterproof speaker system, which can produce a loud sound underwater. The environment that the fish robot model must survive includes seawater and rough handling by real fish. This toadfish model with underwater speaker system could bring a lot benefits for scientists to study the aggressive behavior between toadfish.

Executive Summary

This project is designed to build a toadfish model that can be put into real living environment of toadfishes to study their aggressive interacting behaviors. The sounding system of the toadfish model is the key element to simulate the behaviors of the fish, since most of the communication between toadfish is conducted by making sound. The toadfish model can help biological researcher to study the toadfish aggressive behaviors and other further researches in learning and understanding the toadfish species.

Multiple 3D model processing softwares are utilized to create a bionic 3D toadfish model, including Seg3D, ImageVis3D and Meshmixer. Source data are obtained by putting a real toadfish in a 3D scanner. The fish is scanned slice by slice, in which way generating dozens of dcm-format files. Those slice-unit files are assembled in Seg3D to form a whole virtual model, and the model is loaded into ImageVis3D for preprocessing. Noise-eliminating and model refining in Meshmixer is the last step before the virtual model finds its way to the RPL lab for printing. With the hard 3D model printed, a mold is built on top of it to cast a flexible silicone model.

An audio amplifier and a sealed sound system are built to give the fish model the ability to make sound like a real toadfish. Both audio amplifier module and waterproof speaker module are essential in this project. Audio amplifier module amplifies the input sound signal by a factor from 0 to 20. The sound system module is developed to make it possible to deploy the toadfish underwater. In general, the whole project mainly consists of three parts: a toadfish model, an amplifier system to amplify the input sound source, and a speaker system to generate sound underwater. The final result of the whole speaker system is able to generating 75 dB sounds underwater.

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1. Introduction

1.1. Motivation

Toadfishes, as called "champion species" of vocal communication, have been the subject of biological researches on how vocal signals are produced under the control of a vocal pattern-generating network in the brain, and how the sense of hearing can detect and encode those vocalizations under different social contexts.[1]

Successful communication depends on a sender's ability to produce a signal and a receiver's ability to detect that signal and respond appropriately. As part of the research understanding the neural basis of communication, a bionic toadfish model with a sound system is indispensable to simulate the sender's ability to produce a signal.

This project is designed to build such toadfish model with ability to make clear and legitimate sound for the acoustic communication researches of the biology department. The model can be put into the real living environment of the toadfish and interact with live toadfishes to study their communication and aggression behaviors.

1.2. Overview

The two key components of building a bionic toadfish model are:
1. Building the 3D model of toadfish in real size
2. Building the sound system that can produce sound under water

Multiple 3D technologies are utilized in the process of building a 3D toadfish model from scratch. A real toadfish was put into a 3D scanner and scanned in a slice-by-slice manner. The source data obtained are processed on a computer, during which the slice-unit files are assembled and made ready for printing. The separate sliced data are first put together and transformed in Seg3D. After that the model is loaded into ImageVis3D for preprocessing, including isosurface rendering and mesh computing. Meshmixer is used for fine-tuning, including removing noisy points, transforming, establishing auxiliary lines, etc. The output file is in stl format, which is ready for printing. With the help of

[1] http://nbb.cornell.edu/andrew-bass

Cornell RPL Laboratory[2], a hard 3D toadfish model came into being. After that, a mold was built on top of it and a flexible silicone model was casted.

The fish is too small to fit a speaker inside its body, which is why a sound system is necessary to solve this problem. The sound system consists of an audio amplifier and transmission passage. LM386 is the core component of the amplifier circuit, which multiplies the audio signal by a factor of 20. A simple sound transmission system is developed to make it possible to deploy the fish underwater. The system mainly consists of the following parts: a speaker to generate sound, a box to make sealed space, a tube as the passage, and an inflated balloon inside the fish model as the interface underwater.

2. Implementation

2.1. 3D Model

There are four steps to build a real-size toadfish model:
1. CT Scanning of a real fish
2. Processing the scanned data on computer.
3. Using 3D printer to print the model
4. Casting a soft silicone model.

The second step is the most complex and vital in building the model.

2.1.1. CT Scanning

Professor Bass from the Biology Department had a real toadfish specimen warped in a container. The specimen was then put into a CT scanner and went through a thorough scanning. The scanner works in a slice-by-slice manner, which means the fish is taken apart into tiny slices, each output corresponds to a slice of the fish. The granularity is so small that that scanned data contains highly detailed information of the toadfish physical shape. After scanning, we had at hand a huge set of files in DCM format, and each file contains information of a slice of the fish. The next step is to reassemble these sliced data.

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[2] http://cornellrpl.wixsite.com/cornellrpl

2.1.2. Data Processing

Processing the scanned data is the most important step in building the 3D model, yet it is also the most complex step. Multiple tools are needed to work together to produce the final print-ready file.

1. Seg3D

We use Seg3D to assemble the sliced files, visualize and process the data. The Seg3D is a volume segmentation and processing tool developed by the NIH Center for Integrative Biomedical Computing at the University of Utah Scientific Computing and Imaging (SCI) Institute[3].

We used the Seg3D to accomplish the following tasks:
1) Load the numerous DCM files and combine them in the same work space
2) Adjust the feature range of the transfer function for volume rendering
3) Smooth the model with data filter of type Gaussian Blur.
4) Tune the feature range again to get a desirable visualized model
5) Export for subsequent steps.

The trickiest part among these is the to adjust the feature range of the transfer function for volume rendering. We had to be extremely careful when modifying the range to generate model. The wider the range is, the more irrelevant data is involved in the model. On the other hand, the narrower the range is, less irrelevant data is there in your model, however it becomes more likely that the model is losing the valuable useful data therefore the integrity of the model is compromised, since the useful data and irrelevant data are so interleaving with each other, there's never a clear line that separates them perfectly. We had to do the trade-off between introducing noise and maintaining the integrity of the model.

To deal with the inevitable noisy data, our first measure is to use the data filter tool as described above in task 3. Multiple choices are there for filter, we finally picked Gaussian Blur which had the better result after trying out several of them. The parameters to choose when implementing the Gaussian Blur filter determines how strong the filter is, in other words, how precise the model will be and to what extent the noise will be neglected.

We repeated step 2-4 until we finally obtained a desirable model for the next step. This process took a long time to finish, because there were many parameters to be adjusted

[3] Seg3D: Volumetric Image Segmentation and Visualization. Scientific Computing and Imaging Institute (SCI), Download from http://www.seg3d.org

and the fact that parameters are not independent of one another had aggravated the difficulty to build a good model.

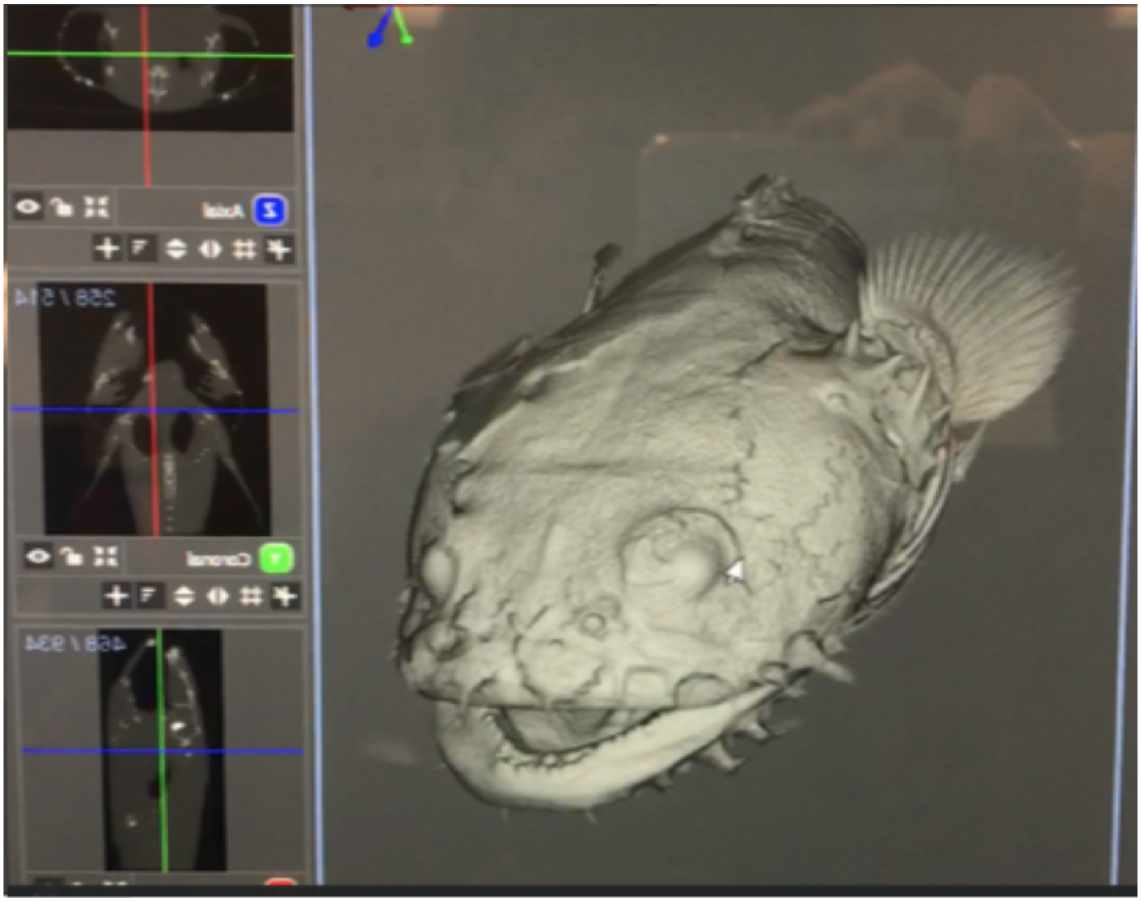

Figure 1. Visualizing the Model in Seg3D

2. ImageVis3D

We use ImageVis3D as a complementary tool to further process the virtual model. ImageVis3D is a volume rendering program developed by the NIH/NIGMS Center for Integrative Biomedical Computing (CIBC)[4]

The scanned model contains data of distance depth, from the inner entrails to bones, skins, fins and the inner shape of the container. We used the isosurface tool to select only the part of the data we needed, i.e. the shape of the fish, and get rid of the rest. Then, after finishing computing the mesh, we passed the data to Meshmixer for final processing.

This part is not that hard as the previous step or the next step, however by fine tuning the parameters when deciding the isosurface could potentially save you a lot of work in the

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[4] ImageVis3D: An interactive visualization software system for large-scale volume data. Scientific Computing and Imaging Institute ({SCI}), Downloaded from: http://www.imagevis3d.org

next step in Meshmixer. This was the reason why we once went back to ImageVis3D from the Meshmixer to readjust the isosurface configuration.

3. Meshmixer

Using Meshmixer to further eliminate the noise of the model and fix the flaws is the last step of data processing, after which the model is wrapped up in a STL file and ready for printing. Meshmixer is a general-purposes tool for model processing and modification before 3D printing.

The model still contains a lot of noise and flaws after the previous steps of processing. With the power Meshmixer, we carefully refined our model in the following ways:
1) Remove the discontinuous segments and noisy points.
2) Fix the flaws from the previous steps, such as holes and redundant fractions
3) Establish auxiliary lines for printing
4) Set the dimensions of the model
5) Output the model as STL file for printing

The noise then was mainly in term of disjoint pieces/points after all the efforts of the previous two steps. In this step, we used inspection tool of Meshmixer to locate the noise parts and then manually select and delete the noisy data. The inspection tool is not clever enough, it sometimes tags the wrong parts, or ignores some noisy pieces, we had to use our discretion to debug.

Since the 3D printer is not big enough to print the whole fish in one operation, we had to cut the model in half and made two half-fish models, print them separately and glue them together.

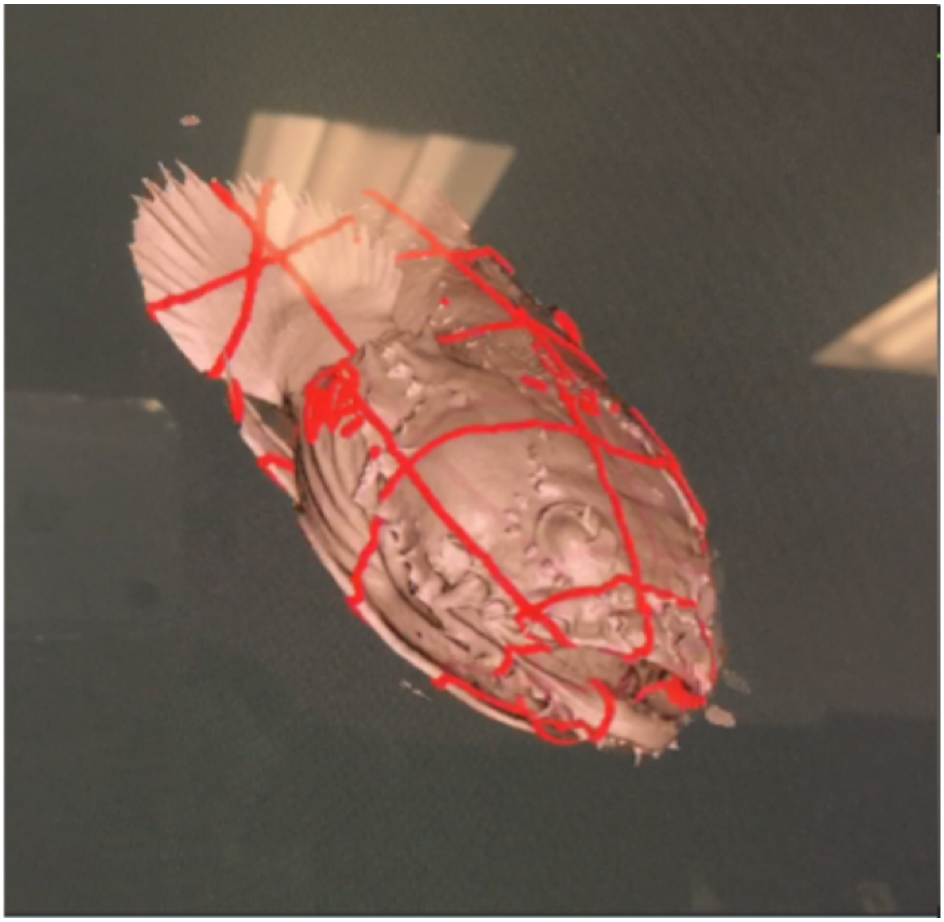

Figure 2. Fish Model with Auxiliary Lines in Meshmixer

2.1.3. 3D Printing

After all the data processing procedure, the model was ready for printing. We submitted the STL file to Cornell RPL Lab to print the 3D model. After two week waiting, we finally got our 3D toadfish model. The 3D printed model vividly restored the physical shape of the toadfish with reasonably high accuracy.

The accuracy could even be further improved if we adjust the parameters of the Gaussian Blur and some other steps. However, given that we have no need for an extremely detailed model, the current accuracy suffices.

2.1.4. Flexible Model

With the help of Professor Kirstin H. Petersen, we were able to make a soft, flexible model, instead of the solid one. The whole process is described as following:
1) Build a mold using the solid fish model we just printed

2) Cast silicone into the model
3) Wait for the silicon cooling down
4) Clean up and it's good to go

The soft model has an even more promising potential in future researches of the toadfish behaviors since it is more flexible and versatile for different experimentation environments.

Figure 3. Solid Model & Soft Model

2.2. Sound System

2.2.1. Audio Amplifier

The audio amplifier can amplify sound that is given from sound source input, such as computer and phone. The main component in this circuit is LM386, which is a low voltage audio amplifier and frequently used in battery powered music devices like radios, guitars etc.

The gain range is 20 to 200, gain is internally set to 20 (without using external component) but can be increased to 200 by using resistor and capacitor between PIN 1 and 8, or just with a capacitor. In our case, we add a 500-ohm resistor and a 10uF capacitor to increase the voltage gain. Voltage gain simply means that voltage out is 200 times the voltage IN. LM386 has a wide supply voltage range 4 to 12v. Our power supply is around 12V, which gives a relatively loud sound without much distortion. The 10k ohm potentiometer will give the amplifier a variable from zero up to that maximum.

The output signal has both AC and DC component, and DC component is undesirable and can't be fed to Speaker. So to remove this DC component, a capacitor of 1000uF has been used. This has the same function as capacitor of 1uF at input side.

- Figure 4 shows our first design of audio amplifier circuit. The limitation of this circuit was that the output signals were largely distorted and clipped. More testing details is written below in Testing and Results part.

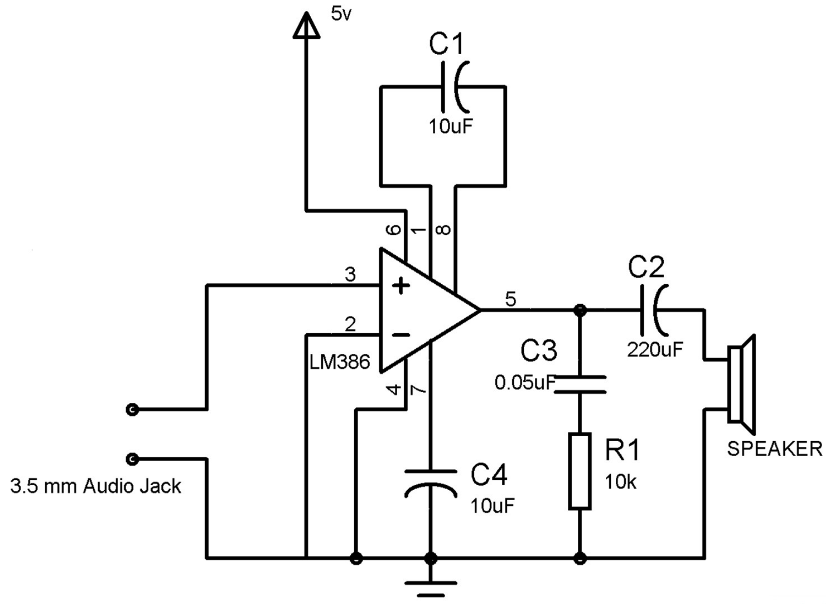

Figure 4. First version Audio amplifier circuit

- Aiming at eliminating the drawback of first version circuit design we improved the circuit and build a second version audio amplifier circuit, as shown in Figure 5 below. We added a small capacitor in parallel with power supply to handle high frequency noises and fast transients. We also added a 10K potentiometer and capacitors at input source pin in order to give the amplifier a variable gain from zero up to that maximum, and make the output waves without distortion. More testing details is written below in Testing and Results part.

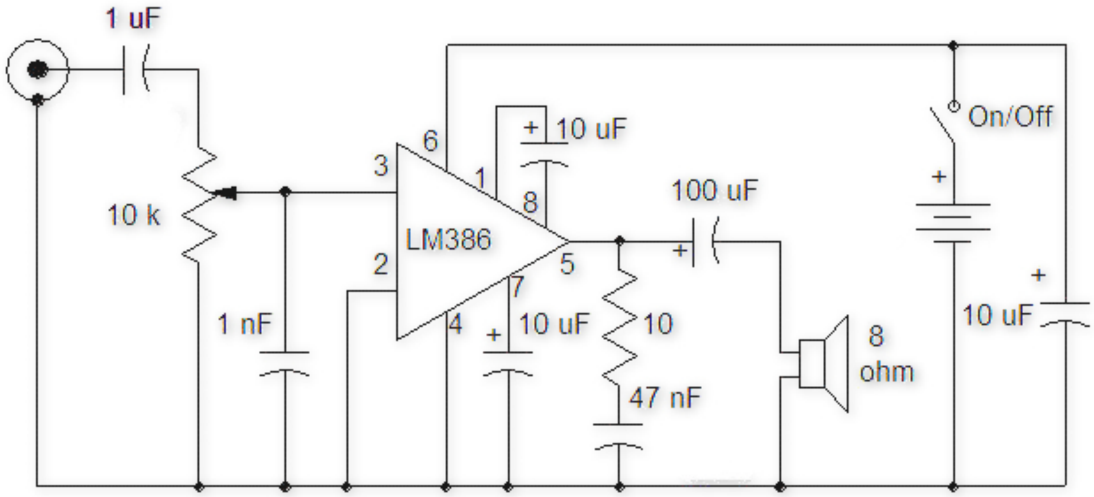

Figure 5. Second version Audio amplifier circuit

2.2.2. The speaker

To produce a loud sound underwater, the speaker needs to vibrate strongly to generate enough energy to push the water vibrates as well. However, the toadfish model is only around 15 cm in length, 5 cm in width, and 4 cm in height, which means placing a loudspeaker, which can meet the standard of vibration, into the fish body is almost impossible. To deal with this problem, we came up with a solution, using a balloon as the interface between air and water to transfer sound wave. By using this method, the small balloon could be fitted into the fish body and sound wave can also be propagated successfully. The schematic of the toadfish sound system is shown in the following figure.

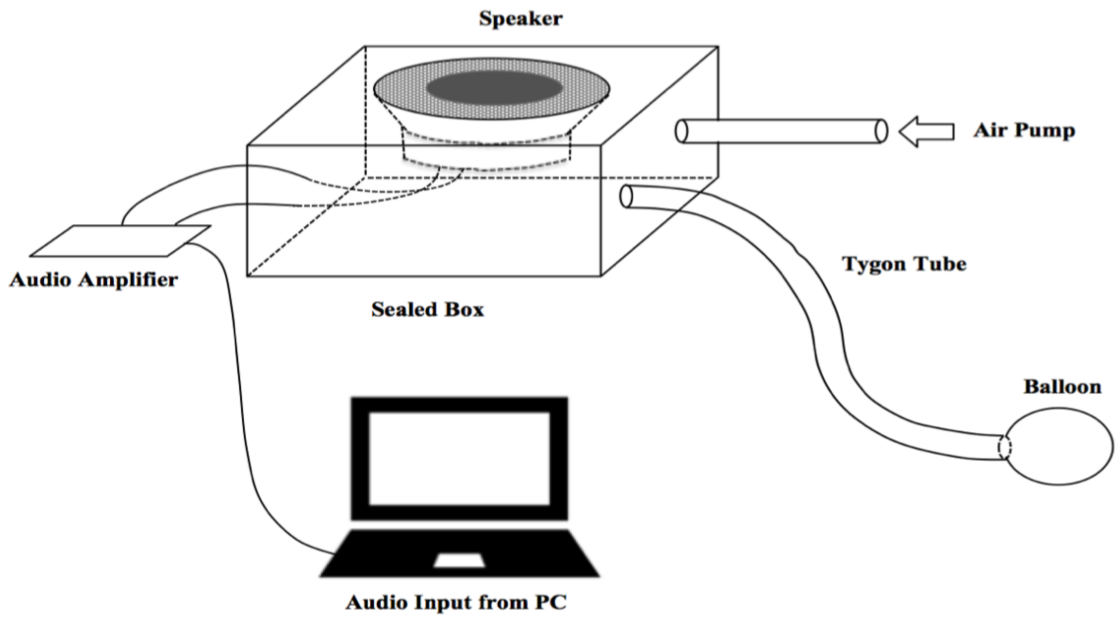

Figure 6. First version of toadfish sound simulation system

The key point is that the sound simulation system must be completely sealed. Air leaking is not allowed during the sound producing process. To achieve this, we use a waterproof sealed electric cabled entries junction box and sealed it tightly using waterproof glue. To blow the balloon, another tygon tube is attached to the box with an air pump at the end to pump air into the box. When sound is produced, sound wave will be propagated through the tygon tube to let the balloon vibrates, and then sound wave is transferred into water. This system works fine, however, when we tested this design underwater, the maximum sound intensity is still very low and does not satisfy the minimum requirement.

The major reason of the first version design's failure is that the air vibration underwater was still not strong enough. To deal with this problem, we came up the second speaker system design, as shown in Figure 7. In this design, we chose to use a micro speaker instead. We sealed the micro speaker in a small balloon to make it waterproof. In this design, the micro speaker could be directly put underwater, and as a result the vibration was much stronger than the first version design. This design is simple and even more efficient. The detailed testing information is discussed below in Testing and Results part.

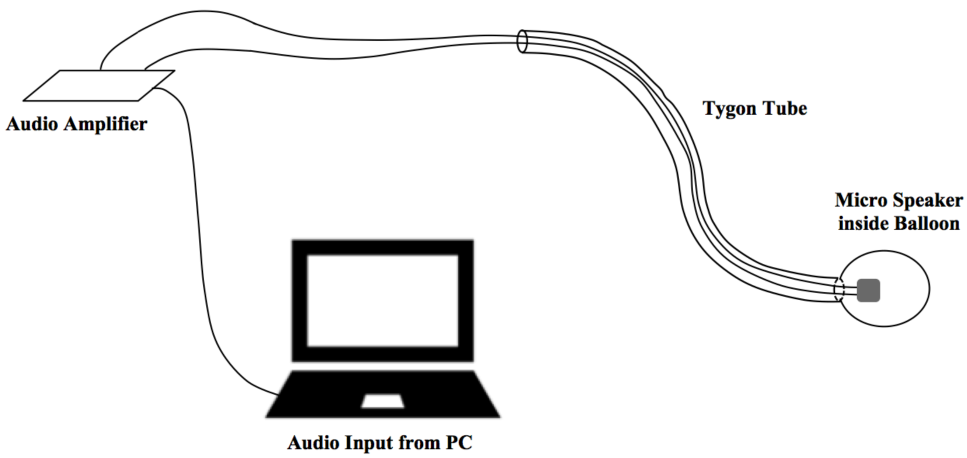

Figure 7. Second version of toadfish sound simulation system

2.2.3. Sound Transmission Mechanism

Sound is basically produced by vibrations, which propagate as mechanical wave of pressure and displacement through transmission medium. In our designed sound system, with the strong vibration produced by the speaker, the air in the sealed box is contracted and expanded, and its vibration intensity is the same as speaker. Then, the air in the sealed box propagates to the thin Tygon tube and balloon. While the air vibration propagates from the sealed box into the Tygon tube, the air pressure largely increases and the vibration intensity becomes larger, and in turns produces a louder sound.

3. Testing and Results

The testing for the system was done in an accumulative way. We first test the audio amplifier module, and then add the speaker module, and test the whole sound system underwater. To test audio amplifier module, we chose to use 100 Hz sine waves as audio input, and check the output waves by using oscilloscope.

The first version of audio amplifier module we used was a simple audio amplifier circuit, as shown in Figure 4 above. Although the output sound was loud enough, the testing results of this circuit were still not good as expected. The output waves were severely clipped and contained a lot of noises.

Then we designed a second version of audio amplifier, as shown in Figure 5 above. After this improvement, we tested it the again. The output waves were perfect 100 Hz sine waves with no distortions and clips for this version of audio amplifier. In order to test the highest sound intensity the audio amplifier could reach, we kept increasing the power supply voltage during testing process. When the power supply reached 18 volts, the total power was too high that LM386 chip was burned and destroyed. With this failure, we further improved the audio amplifier. We decided to use a fixed 12-volt power supply, in order to keep the whole circuit working in safe power range. This final design fixed the problems of output distortion and circuit safety issues.

After making sure the audio amplifier module worked fine, we combined the speaker module with audio amplifier module. With the help of biology graduate student Joel Tripp, we tested the whole sound system underwater. We measured the sound intensity level by using underwater recorder, and the strongest sound intensity underwater of first version toadfish sound simulation system was about 20 dB for 100 Hz test tone, which does not meet the project minimum requirement.

After improvement of sound intensity issue, we tested the second version design of toadfish sound simulation system. This design's performance was much better. The highest sound intensity underwater was about 75 dB for 100 Hz test tone and real toadfish sound, and this result perfectly met the project requirement.

4. Conclusion

In conclusion, in this project we did research on aggressive behavior of toadfish, such as, physical attack, growling, and grunting. Also, we spent a significant amount of time on 3D printing, micro waterproof speaker, and acoustic interface issues, etc. We built a small fish model that can be used for studying fish behavior, and an underwater loud speaker system. Out project meet the requirements, and the final results and outcomes of our MEng project are that the fish robot model is able to produce a loud sound underwater and to move around by a mechanical connection to the model; the fish model is able to survive includes sea water environment and rough handling by real fish. Though this project, we acquired technical skills and also the ability to work with scientists to produce a research product, which we cannot learn from any classes.

4.1. Future Work

This project can be further improved by adding more features to make the fish model able to interact with real toadfish.

- Improvement on toadfish model to make the fish fins and tails automatically move underwater like real fish.
- Improvement on audio amplifier circuit to produce louder sounds.
- Adding an underwater video camera embedded in the fish model to make it interactive.

5. Acknowledgement

We would like to thank our advisor Bruce R. Land for his constant guidance and encouragement and patience, to Prof. Andy H. Bass for his support and idea in biology area throughout the project, and to Prof. Kirstin H. Petersen for her support on soft silicone robot model casting processes. All three professors gave us a lot of valuable suggestion and help us to overcome the difficulties we met during this project.

6. Appendix

Datasheets:
Texas Instrument LM386: http://www.ti.com/lit/ds/symlink/lm386.pdf

Side view of 3D-printed toadfish model and silicone toadfish model: