Biomimetic Fish

Final Proposal

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DISCLAIMER

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Executive Summary

This document details the progress of the design and manufacturing of a device to mimic the oscillations a flat fish uses to bury itself. To bury itself a flat fish utilizes a process called fluidization in which fast streams of fluid particles cause the substrate to act as a fluid. The client Dr. Alice Gibbs is looking into the applications of rapid fluidization and requested that a test apparatus be built to mimic a flat fishes movement. The client wants to apply the knowledge gained of fluidization to create self-burying anchors and drones that can monitor ecosystems unnoticed. The client requested a device that could control both the frequency and the amplitude as well as be controlled via a microcontroller. The team has refined their designs based off these requirements creating many different designs before settling on one shown below. The design has a cost of around $800 and consist of three main subsystems. First, the 1-D movement which is created via the T-slot that spans the entirety of the tank, this allows for the system to move along the center of the tank to find the optimum position. Second, the amplitude adjustment and motor mount, this allows for variable amplitudes that must be adjusted manually. Finally, the rotational to linear device that utilizes a crank-slider to convert the rotational motion of the motor from rotational to linear motion.

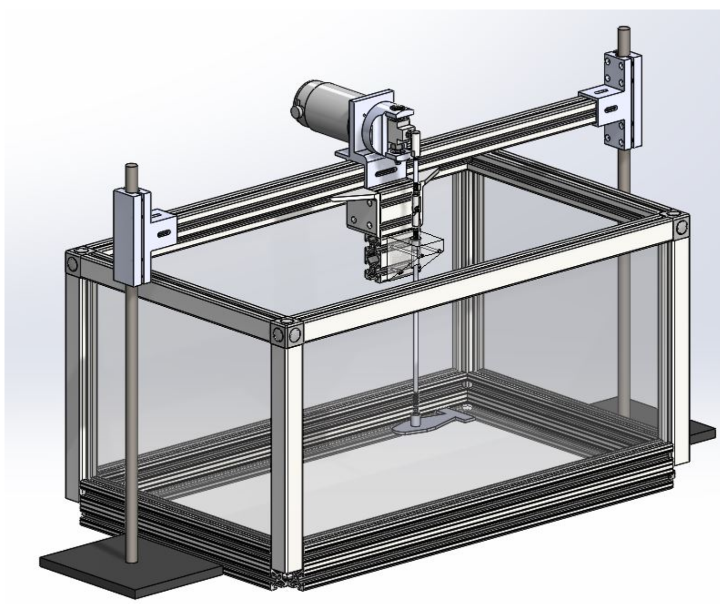

Figure 1 Isometric view of the design

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1 BACKGROUND

1.1 Introduction

The team will develop a machine which oscillates a specimen up and down. The specimen will be in the shape of a fish and made of a material called ecoflex. The objectives are to make an Arduino controlled device, where the frequency and amplitude of the oscillations can be manipulated by the user. The device will fluidize the substrate to mimic the forces exerted by the fish. The client, Dr. Alice Coulter Gibb, needs the device to determine how fish are able to generate the force needed to fluidize water, as testing real fish does not yield consistent data. The device will help determine which shapes are the most efficient at fluidizing substrate, and how the position of the force applied to the specimen directs that momentum into the substrate. By mimicking the movements of the fish researchers will be able to incorporate the ideas into future designs in security surveillance and boating. A drone that can quickly hide under sediment in water can be useful for surveying for military as well as ecological purposes. An anchor that can quickly bury itself can be useful in reducing the damage they cause to coral reefs when they're dragged around.

1.2 Project Description

The following is the description of this project as given by the client is:

"Many animals bury in substrate to avoid predators, to hide and ambush prey, or to escape unfavorable environmental conditions. A variety of fishes are able to bury by forcing water into the substrate to convert the solid-like substrate (particles) into a liquid-like substrate, a process termed fluidization. One model system for studying how fishes are able to bury themselves is the flatfishes: flounder, halibut and sole. During the burial behavior, these laterally -compressed fishes undulate their bodies against the bottom, which forces water down, into the substrate. As the water rebounds from the substrate, it carries substrate particles up into the water column, above the fish. When the water velocity decreases, the substrate particles fall out of suspension, covering the fish's body. In the Gibb lab at Northern Arizona University, we are interested in using behaviors of living animals to inspire biomimetic robots. For this project, flatfishes would be used as a template for a simple, self--burying robot that may eventually be modified into a more sophisticated mechanism to complete human centered tasks. For example, self--burying robots could be used to camouflage surveillance drones or serve as a component of boat anchors that are able to sink themselves into sandy bottom habitats. In addition, "flatfish" robots could allow us to test ecologically relevant questions about the limits to this behavior that are often not tractable to address using living organisms (for example, what substrates are too heavy to fluidize? what body shape is best to facilitate rapid burial? etc.). [1]"

The project description has since been modified, to no longer create a robotic fish instead the fish will be connected to an actuator above the tank to create the same motions. This was done to gain consistent data on the fish's movements in order to create a more functional robot in the future.

1.3 Original System

This project involved the design of a completely new biomimetic fish. There was no original system when this project began.

2 REQUIREMENTS

This chapter discusses the various design criteria's given by the client and converts them into engineering requirements in order to better understand the scope of the project. The engineering requirements are then placed in a house of quality to determine their relevance importance to each other. This chapter begins with section 2.1, customer requirements.

2.1 Customer Requirements (CRs)

Listed below are the customer requirements that related the customers' needs to the project. Through various meetings the team has decided on 6 customer requirements. They are Variable oscillation, Arduino controlled, Biomimetic, Repeatable Data, Variable sizes. Each designed was ranked 1-6 to understand their importance to the project. All requirements are described below in the sub-section. Below are the customer requirements that related the customers' needs to the project.

2.1.1 Variable Oscillation

Flatfish can oscillate seven to fifteen times a second to generate the momentum needed to fluidize substrate and allow the fish to bury itself inside the substrate. The device will allow users to input multiple oscillation frequencies to determine an efficient way to fluidize substrate and allow a specimen to bury itself. This was rated 6 as it is the main goal of the project.

2.1.2 Arduino Controlled

Arduinos offer a platform which can enable user inputs into the motors of the device, as well as direct signals back to the user with data on oscillation frequency and more. Our device will use an Arduino to control the inputs and outputs of the device, which allow the user to manipulate the amplitude of the stroke, and oscillation-rate. This was rated 2 as there are many different microcontrollers that could be used for this design.

2.1.3 Biomimetic

It is possible to fluidize substrate without using the mechanisms which fish use. The test equipment will analyze if nature has more efficient means of fluidizing substrate than current conventional methods. This was ranked 4 as it is important to try and mimic the fishes movements.

2.1.4 Consistency

The test equipment needs to produce data that is consistent, which follows the guidelines of the scientific method. If the test equipment cannot produce repeatable data, the test equipment will be a failure. This was rated 5 as it is important to have repeatable data when testing the fish's movements.

2.1.5 Can test variable sizes

The rod which moves up and down will connect to different specimens. The rod will include features which allow it to quickly detach and attach to varying test specimens. This was rated 1 as the variable sizes are small enough that most motors could move it.

2.1.6 Durability

The device must be able to withstand multiple tests as well as various forces. The client asked that it must withstand a force of 1-5 lbs without breaking. This was ranked 3 as the oscillations created by the machine should minimally affect the joints.

2.2 Engineering Requirements (ERs)

This section details the various engineering requirements (ER) derived from the customer requirements (CR). These ER's are crucial to meet the client's goals as well as keep the team focused. The requirements are listed in table 1 and further detailed below.

Table 1 Engineering Requirements

Requirment	Target
Amplitude	≤ 0.5 in
Frequency	5-20 Hz
Load	1 - 5 lb
Cost	≤ $1000
Surface Area	450 in^2
Assembly Time	≤ 1 min
Voltage	≤ 12 V
Success Rate	≥ 75%

2.2.1 Amplitude (in)

The client requests a range of 0 to 0.5 inches, in order to match the most common amplitudes found in flat fishes. The client also specified for further designs that the amplitude will increase.

2.2.2 Frequency (Hz)

The client requests a range of 5 to 20 Hz, in order to match most common flat-fishes frequency. The client also specified that in future designs the frequency range will increase.

2.2.3 Load (lb)

The client requests a range the device be able to hold a load of 1-5 lbs for initial testing. For future designs the client wants the load to increase to a higher a range. This relates to the durability CR as it sets the maximum load applied.

2.2.4 Cost ($)

The client requested that no part cost more than $100 in order to make it easier to replace broken parts and the team put the constraint that the budget not exceed $1000. This relates to the durability CR as it controls how items are designed.

2.2.5 Surface Area (in^2)

The client requested the team use an already owned 20-gallon tank whose surface area is 450 in^2. The client does not see the surface area changing for the rest of the project.

2.2.6 Assembly Time (s)

The client requested that the time to replace the specimen on the device to take less than a minute and to be able to be completed under water.

2.2.7 Voltage (V)

The client requested that the device can either be battery powered or plugged into the wall which runs at a voltage of 120V.

2.2.8 Success Rate (%)

The client requested that the device will be used to perform multiple tests. It is considered a success when the device successfully attempts to fluidize the water. A failure is when the device does not move the specimen in the designated way. This related to the reliability customer requirement.

2.3 House of Quality (HoQ)

The house of quality shown in table 2 compares the customer requirements, section 2.2, and the engineering requirements, section 2.3. The CR's are weighted on a scale of one through 6 with five being the most important and one being the least. The ER's relationship to the CR's are then compared on a 0 - 1-3-9 scale with nine meaning highly correlated and one being low correlation. The data is calculated with the weights from the CR and then turned into a percentage. These percentages are then ranked to find the most important Engineering Requirement. The team found that the most important ER is the success Rate followed by amplitude and frequency. These rankings are important as it allows for sketches to be designed with the most important ER's in mind. The ER's are then compared to each other to see which ER's are most reliant on each other. The Frequency and Amplitude have the most connections to the other requirements. The customer requirements were also compared to three similar designs, the M.I.T.S Fish [2] , the SHOAL robotic fish [3], and the Undulating jigsaw [4]. The comparison was based on a 1-5 scale and it was shown that all designs were good at variable oscillations but failed when tested with variable sizes. This information obtained from the QFD will help guide the designs in section 4.

Table 2 House of Quality

Amplitude								
Frequency		9						
Load		1	3					
Voltage		3	3	1				
Surface Area		0	1	0	0			
Cost		1	3	3	3	1		
Success Rate		9	9	3	1	0	9	
Assemply Time		0	0	9	1	3	9	0

Legend	
A	MIT Fish
B	Shoal Robotic Fish
C	Undulating Jigsaw

Customer Needs	Customer Weights	Amplitude	Frequency	Load	Voltage	Surface Area	Cost	Success Rate	Assemply Time	1 Poor	2	3 Acceptable	4	5 Excellent
Durability	3	3	1	9	0	1	3	3	3		C	AB		
Consistency	5	9	9	3	0	1	1	9	1			B	AC	
Variable Oscillation	6	3	3	3	3	3	1	3	3					ABC
Arduino Controlled	2	3	1	0	3	1	3	3	3	C	A	B		
Biomimetic	4	9	9	1	3	3	9	9	1		C		B	A
Variable Sizes	1	1	3	9	1	3	9	3	3	AB			C	
Technical Requirement Units		In	Hz	Lbs	V	in^2	$	%	sec					
Tolerance of Ers		± 0.2	± 5	± 2	± 10	0	± 250	± 25	-45					
Absolute Technical Importance		115	107	73	37	43	71	117	39					
Relative Technical Importance		0.19	0.18	0.12	0.06	0.07	0.12	0.19	0.06					
Rank		2	3	4	6	8	5	1	7					

Technical Requirements

3 EXISTING DESIGNS

Chapter 3 consists of the research and functional decomposition created to better understand the project. The research consists of 3 main devices that most related to the project and 3 subsystems that had specific functions that related to the project. The project is then broken down into its basic functions in the functional model in order to better understand how it works.

3.1 Design Research

To understand how to best mimic the movements of a flatfish, various fishes as well as robotic fishes were researched. Through notes from the client the team found that the burying movement of a sole (a common flatfish) is linear at high frequencies. An average size sole (8.3 to 12 cm) produces a frequency of 6.8 to 10 Hz. The fish raises to a distance between 3 and 10 mm for each oscillation. In the research article "undulation frequency affects burial performance in living and model flatfishes" [3] the team found that the wave created is very similar to a sinusoidal wave and the majority of the force created by the sole is located in the head of the fish and is then translated across the body. The team then focused on finding the optimum factors in which to fluidize sand. From an article on fluidization when sand is fluidized it undergoes a change in which the sand particles are rapidly accelerated causing the sand to move and react as a fluid. The fluid "increases the space between the sand particles" [4] and allows for heavier items to fall through".

The team then looked at examples that mimicked fish's movements. For example, in the article on the MIT robotic fish the designers based the fish off of common red snappers due to its being a fish common to many different environments. An article from the Shoal Research lab shows that to more closely mimic fish the robots keep most of the mechanical devices in the head. Most designs also include an arrangement of fins as they're the quietest and most efficient to produce motion. In both fish designs examined the MIT and SHOAl, the fishes use sensors to detect water temperature, ph level, and composition, this data allows scientist to closely examine the environments the fish are in. The prices of the robotic fish vary from ranges of $2000 - $10000 depending on the sensors and range of motions needed.

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3.2 System Level

This section details the existing designs that share similar traits to the test fixture. While all designs are similar they share many different approaches that will allow the team to develop ideas in section 3. Each section details what they do similarly and what makes them different.

3.2.1 Existing Design #1: MIT robotic Fish

Researchers out of M.I.T. created a fish capable of monitoring the ph level in the ocean [3]. The fish uses electric signals and motors in the "head" of the fish to create movement. This "fishes" ability to produce

waves is similar to how the test apparatus will mimic the movement. By applying the force to the head, the fish oscillates back and forth pushing water away allowing for it to move. This can applied to the project by making the motor similar in its oscillation motion to the fish.

3.2.2 Existing Design #2: SHOAL robotic fish

The SHOAL [4] project has developed a series of robotic fishes that form schools to monitor the ocean. The fish shown in figure 3 mimic the movements of fish by using their "tailfin" to produce movements. This movement is beneficial to the teams designs as it allows for more accurate representations of fish-based movements. The fish also utilizes sensors to measure the waters ph levels. The project can use

Figure 2 MIT Robotic Fish [3]

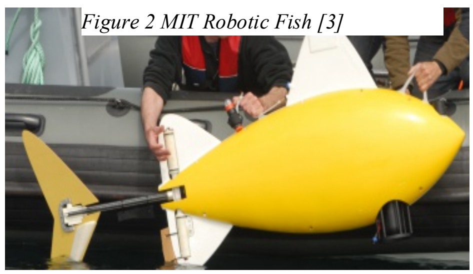

Figure 3 Shoal Robotic Fish [4]

sensors to get accurate data for the client to process further.

3.2.3 Existing Design #3: Undulating Jigsaw

Scientists developed a design to oscillate a foil in a tank using a jigsaw power tool [1]. The design is restricted to the right side of the tank and is susceptible to water splashing on the device. The jigsaw movement can be used in designs to mimic the fish's oscillation. It takes a rotational motion and turns it into a linear movement which can be used to make a more compact design. The test fixture also uses a small range of frequency that are controlled by a switch. To improve on that function an Arduino can be

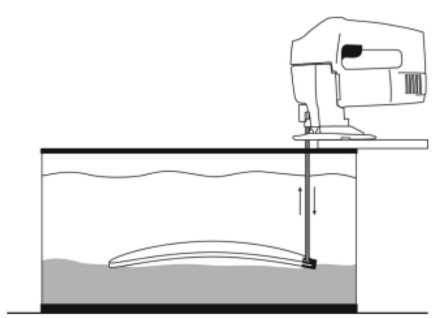

Figure 4 Jigsaw Oscillator [1]

used to give accurate oscillations and frequency.

3.3 Functional Decomposition

For the Functional Decomposition of the test equipment to be built for Dr. Gibb, Team 18F13 created a Black Box Model and a Functional Model. These two models represent the inputs and outputs that the device will need, in order to meet the customer's needs.

3.3.1 Black Box Model

The black box model, in figure 5 is used to show the general inputs and outputs of the device, without considering how the device performs those tasks. There are three types of inputs and outputs: material, energy, and signal. The main function of the model is to oscillate samples as that is the goal of the client. While the Black Box model provides a simple explanation for what our project's device will do, it will

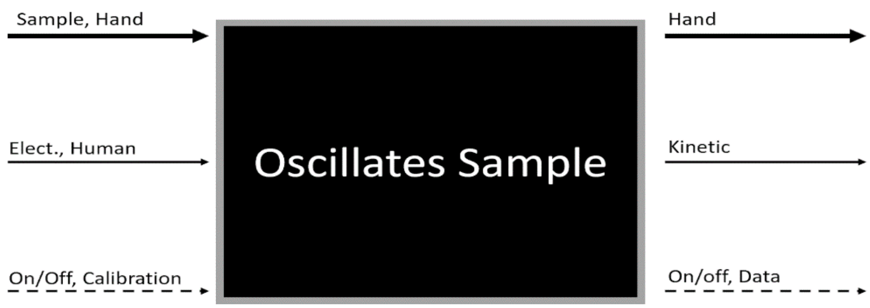

Figure 5 Black Box Diagram

also provide direction for the functional model.

3.3.2 Functional Model

A Functional Model shows all the inputs and outputs the device will receive and perform to meet the client's needs. For the Functional model below, there are three types of inputs and outputs: material, energy, and signal. We examine the functional model by reading from left to right; by doing this we can tell that the first step to using the test equipment will be to import a sample into the device, import a camera, and actuate electricity. Once the device is on, and the previous steps have been taken, the test equipment will ensure the sample is secured, and the user is then able to set the calibration for amplitude and oscillation rate. Once those steps are complete, electric energy is pumped into the motor to convert electric energy to kinetic energy, the calibration is displayed, and the camera is able to capture visuals of the kinetic energy. Once those steps are complete, the test equipment performs its final processes and lifts substrate, buries the sample, and converts visual of KE to data. This is important for the project as it details the relative idea of what are design needs to do. For example, bury the substrate comes after sample must be secured so designs must be based around knowing that the sample must be secured first.

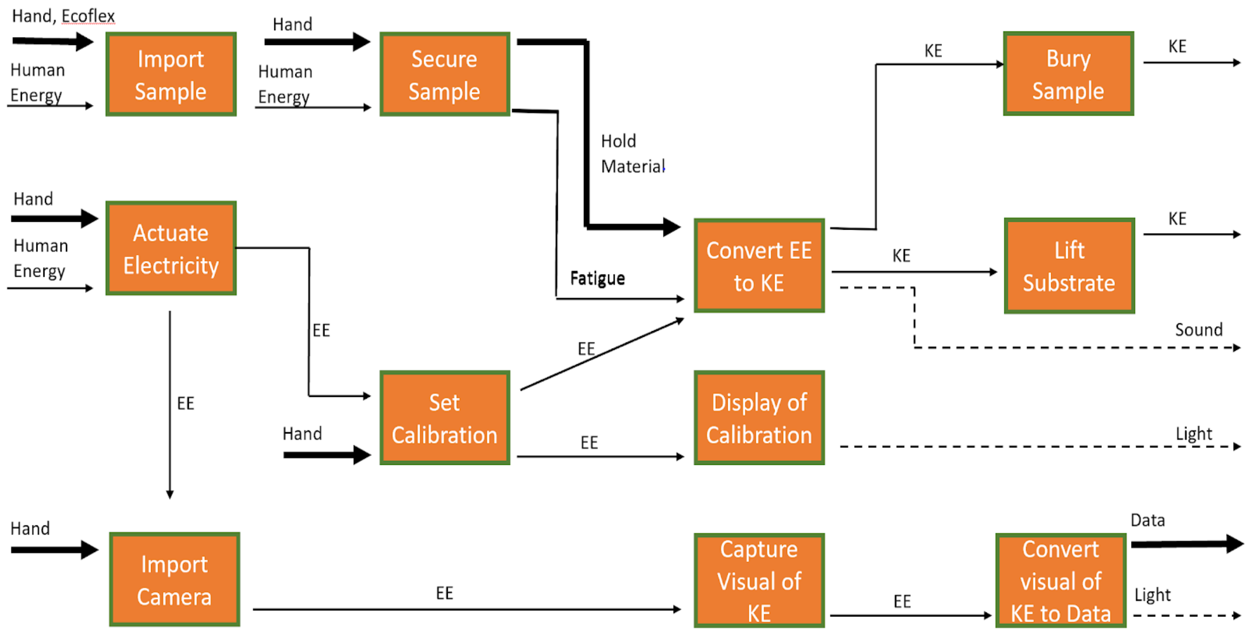

Figure 6 Functional Model

3.4 Subsystem Level

This section is based on the subsystems needed for the design of the project which include actuation, micro-controllers, and 1-D movement. Since there has been very few attempts to create a device similar to the one in this project the subsystems are more generalized.

3.4.1 Subsystem #1: Actuation

The device needs to mimic the movements of a flatfish, most common flatfish move by actuating up and down. Each device looked at has different ways of moving up and down very quickly.

3.4.1.1 Existing Design #1: Jackhammer

A jackhammer uses a motor to oscillate a hammer up and down and very high speeds. Its most common main use is in construction in order to break down large pieces of concrete. Jack hammers are powered by air and thus are pneumatic. An advantage to this is that there is only a minimal amount of electronics needed to control the hammer and thus making relatively waterproof. [5].

3.4.1.2 Existing Design #2: Wave Pool Generator

A wave pool actuates very quickly back and forth to create massive waves in a pool. It takes large amounts of energy and has two main methods to create waves. First being through large pistons that pushes and pulls the water back. Secondly by using gravity to let a small amount of water be drained very quickly which creates a cavitation that is filled with water and creates waves. The advantages of this is that both are fast, while the first design is more compact it can only output a given amplitude. while the second method can change the amplitude of the waves by changing how much water is drained. [6].

3.4.1.3 Existing Design #3: Jigsaw

A Jigsaw grips onto a saw blade and oscillates the saw up and down to cut through wood. It uses a motor that is converted from rotational motion to linear. The advantage of a jigsaw is that it is small compact and can use any motor due to the motion conversion. [7].

3.4.2 Subsystem #2: Microcontrollers

Our client requested that the device created be controlled by a microcontroller. Microcontrollers are easy to control a wide variety of devices, such as motors and sensors. For the design the microcontroller will power motors that control the oscillation of the device.

3.4.2.1 Existing Design #1: Arduino

An Arduino is a common diy microcontroller that runs on C and C++ code. The advantage of it is that the controller has large libraries of code that can be used, as well as many attachments to fit the specific needs of the project. [8].

3.4.2.2 Existing Design #2: Raspberry PI

A raspberry pi is a small-board computer that runs on python. The pi has many attachments specifically microcontroller attachments. The advantages is that the pi can communicate online without any needed coding and can be used with any HDMI monitor. [9].

3.4.2.3 Existing Design #3: SparkFun SAMD21 Mini Breakout

The sparkfun is a newcomer in the microcontroller world, it runs on the same coding software as the arduino but has double the processing power. The device is cheaper than the arduino but isn't as supported for addons. Like the arduino though it can use the vast libraries created by the users [10].

3.4.3 Subsystem #3: 1-D movement

The client requested the device to be able to move across the tank for ease of use. The client does not see 2-D movement as necessary as any movement close to the edges of the tank would cause disruptions in the collected data.

3.4.3.1 Existing Design #1: T-slot

A T-slot is a usually metal bar with a "T" shape cut into it this allows for small bars that match the shape to freely slide in and out of it. The advantages of this is that they're already pre-milled and easily bought from different suppliers. All though larger amounts can significantly raise the budget [11].

3.4.3.2 Existing Design #2: Conveyor Belts

A conveyor belt is a device that uses rotation to move a belt in 1 directions, it is most commonly used for manufacturing. This device is cheap to implement and easy to replace if any part breaks. The downside is that the device can be hard to finely and adjust and may need to motor for optimum moving speed [12].

3.4.3.3 Existing Design #3: Slide Rails

A slide rail is a device that consist of a long shaft and mounts to hold in in place. A device then put on the shaft allowing it to move freely across one axis. The advantages are that the components are simple so they're easier to replace. The downside being that the shafts must support all the weight of what's being moved meaning it can have severe bending deflections [13].

4 DESIGNS CONSIDERED

The following section outlines the top 10 designs created from various idea generations such as the 3-5-1 method (appendix A). Each design lists the pros and cons of the design as well as the features that make it unique. These designs are then compiled into a decision matrix to find the top designs.

4.1 Design #1: Stationary Oscillator with Gaming Controller

The first considered design is Concept 3 from the decision matrix seen in appendix A . This design features an oscillator which can move around the fish tank, using 3-axis that are controlled using a Sony Dualshock-3: 6-Axis controller. The advantage of this design, as it can perform more experiments than one where the oscillator is stationary. one disadvantage to this design, is that it is more expensive to design than one where the oscillator is stationary. Other disadvantages are that it may produce inconsistent results with more variables to look at, and movement is not the desire of the project's sponsor.

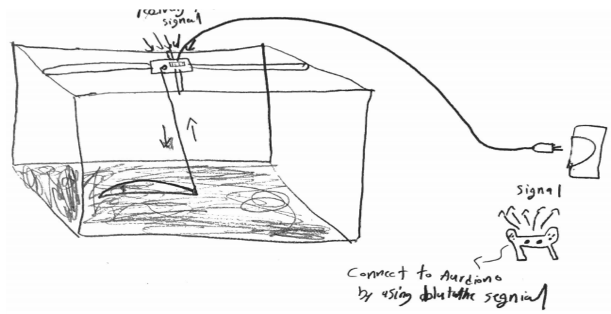

Figure 7 Stationary Oscillator

4.2 Design #2: Oscillator with Adjustable Rods

This design is capable being installed onto various fish tanks, by the inclusion of adjustable rods. There are clamps on the left and right of the device, and the oscillator is located at the center of the rods. It features two adjustable rods, to prevent rotation. The adjustable rods work by utilizing a pipe inside of another pipe, which can be secured into position by set-screws. The clamps work by manually tightening a bolt to a nut. As the device can adjust in length, the position of the motor is also held in place by set-screws and can freely slide along the larger diameter pipe used in the adjustable rod assembly. The advantages to this design are that it can be used with pre-existing fish tanks, it would be cheap, and it accomplishes all the customer needs. Disadvantages to this design are that the set-screws will scratch the adjustable rods over the years and will eventually lead to the adjustable rods not working; however, the

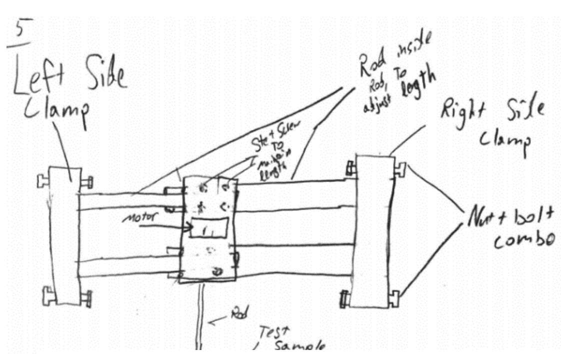

Figure 8 Oscillator with Adjustable Rods

test equipment may not be moved much.

4.3 Design #3: Rigidly Mounted Oscillator, with Magnetic Connection to Samples

For this design, the motor sits high above the water tank, reducing opportunity to get the motor wet; the way the motor is mounted also allows for greater force, as the force is distributed to the water tank more evenly, as it is dome-shaped. In addition to a dome, the sample will be attached to the test equipment by a magnet, so that samples can be quickly changed. A disadvantage to this design is that the magnet may not rigidly hold onto the sample and allow its position to slide around.

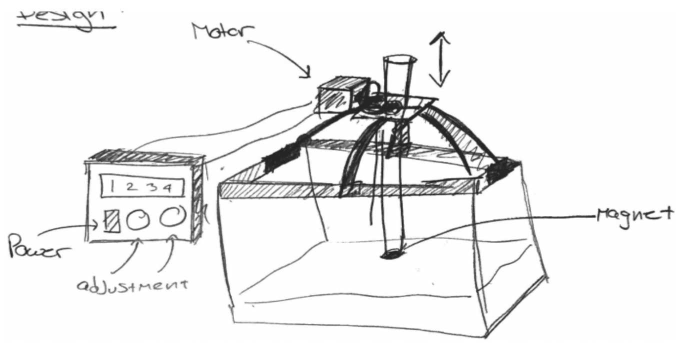

Figure 9 Rigidly Mounted Oscillator

4.4 Design #4: Linear motor, with variable amplitudes

This design utilizes a linear motor to actuate the specimen at the given frequency and amplitude. The linear motor is adjustable allowing for the user to quickly change the amplitude. The device is connected to an Arduino allowing for large amounts of data to be collected. The motor is situated on top of a two-layered support system with a ring added at two locations to support the mechanism and the various sensors to be added. A major disadvantage is that the linear motor is very expensive, especially for one that adjust the amplitude and the support system puts a lot of pressure on the tank potentially causing

Figure 10 Linear motor design

fatigue.

4.5 Design #5: Oscillator on Unidirectional Carriage

This design (appendix A Figure 1) has the oscillator mounted to a carriage, which slides along a T-slot beam, which stretches across the span of the water tank. This design has a hand-lock that will stop any movement when begin tests and will be rigidly mounted to the side of the tank. An advantage to this design, is that most of the components can be purchased direct from many different manufacturers, and it meets most of the client's needs. A major disadvantage to this design; however, is that the client does not wish for the oscillator to change positions.

4.6 Design #6: Magnetic Movement Design

This design (appendix A Figure 2) is all magnet powered that uses two main magnets, one to control the movements of the fish, and the other to maintain a strong holding position during fish burial. The main idea of this design is too trying to reach the same goal of the project without using any energy consuming equipment. The downside of this design is that it is expensive.

4.7 Design #7: Floating Oscillator

For this design (appendix A Figure 3), the motor will be attached to a floating platform which freely moves around the water tank. An advantage to this design, is that the client will save money on the hardware needed to mount the motor to a fish tank. A disadvantage to this design is that the client does not want the oscillator to move, and it won't produce re-creatable data.

4.8 Design #8: Detached Oscillator

For this design (appendix A Figure 4), there is no interface between the test equipment and the oscillating sample. The sample will be the oscillator, and it will be able to swim around a water tank freely. An advantage to this design, is that the oscillator will work with any body of water. A disadvantage to this design is that the data will not be re-creatable.

4.9 Design #9: Scorpion Arm

The scorpion arm (appendix A Figure 5) has a motor controlling an arm, to move the sample up and down. An advantage to this design is that it is very maneuverable. A disadvantage to this design, is that it is made of many components, which will increase the cost to purchase components, and its assembly time is the greatest of all potential designs.

4.10 Design #10: Speaker Oscillator

For the speaker oscillator (appendix A Figure 6), the sample oscillates due to soundwaves, and the amplitude changes at different frequencies. An advantage to this design is that the test samples will not need to be directly attached to the device. A disadvantage to this design, is that the soundwaves may not reach the sample, and will disturb the water around the sample.

5 DESIGN SELECTED – First Semester

Chapter 5 will detail the use of the Pugh chart and decision matrix to obtain a final design. The chapter will also show in detail the final design to be turned into a prototype.

5.1 Rationale for Design Selection

To better decide which design to choose the team created a Pugh chart (appendix B) and decision matrix. The initial 20 designs derived from the 3-5-1 method were taken and qualitatively compared to 5 requirements the team thought most important, variable amplitude, variable frequency, cost, durability and Arduino controlled. These requirements allowed for many of the more impossible designs to be removed to better compare in the decision matrix. In the matrix (Appendix C) the team took the top 8 designs and compared them to the engineering requirements from section 2. Each requirement was weighted based on the teams perceived importance. With variable amplitude and frequency being rated the highest with a weighting of 0.19 and 0.18 respectively. The team then rated each designs correlation out of 100, 0 being no correlation and 100. The team decided that the Amplitude and success rate were the most important as they will affect the clients testing the most. While the voltage and surface area were low because they were relatively constant. Each designs score was summed and found that designs 3 (figure 9) 5 (figure 11) and 7 (figure 13) were the top designs.

6 REFERENCES

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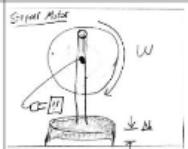
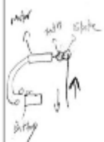
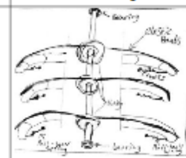
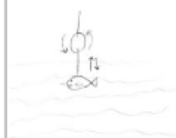
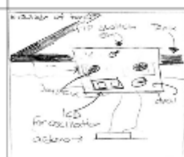
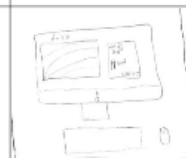
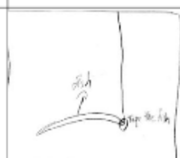
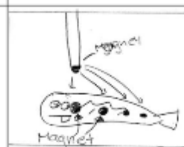
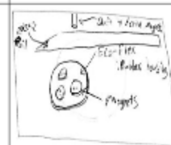
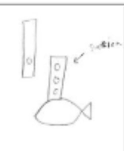
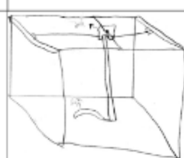
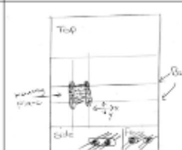
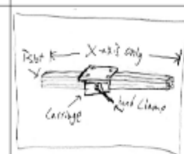
7 APPENDICES

7.1 Appendix A: Design Concepts

Table A.1 3-5-1 Method

Criteria	1	2	3	4
Mechanisms for Oscillaton				
User Interface				
Mounting of Sample				
Directionality				

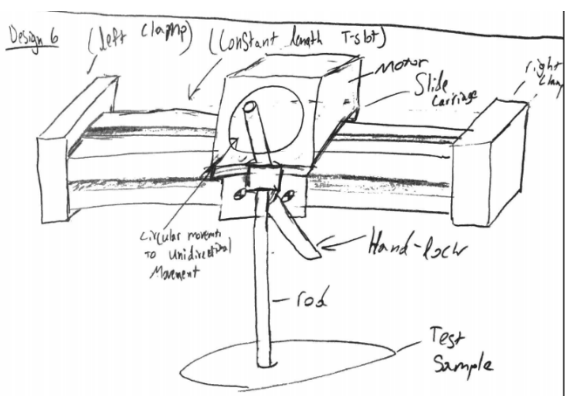


Figure A.1 Design #5 Oscillator on unidirectional carriage

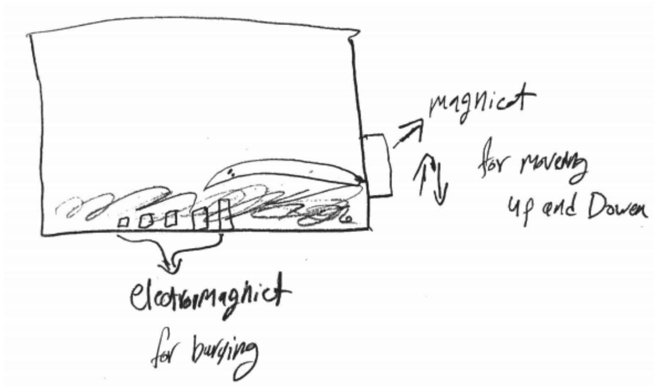


Figure A.2 Design #6 Magnetic Movement

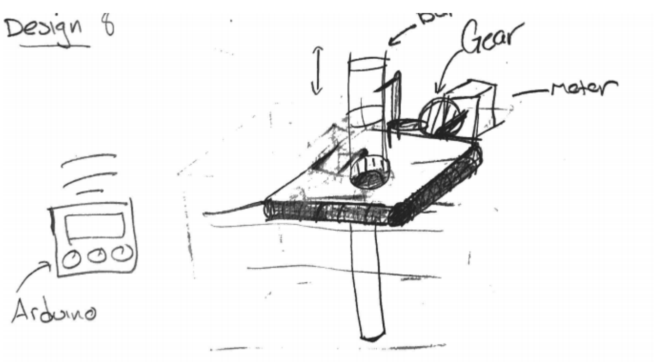


Figure A.3 Design #7 Floating Oscillator

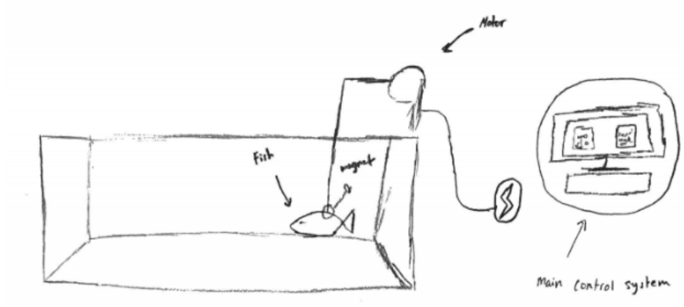


Figure A.4 Design #8 Detached Oscillator

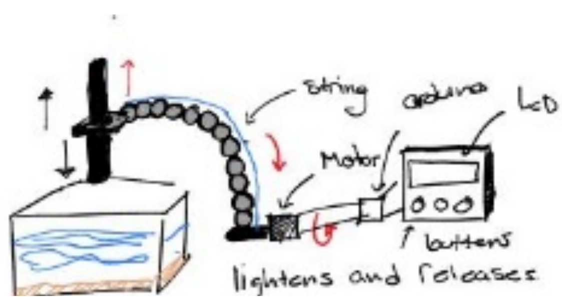


Figure A.5 Design #9 Scorpion Arm

Figure A.6 Design #10 Sound Oscillator

7.2 Appendix B: Pugh Chart

Table B.1 Pugh Chart

Criteria	1	2	3	4	5	6	7	8	9	10
Amplitude	+	s	+	s	D	+	-	+	-	+
Frequency	-	+	+	s	A	+	-	+	-	-
cost	s	+	+	-	T	-	-	+	+	+
durability	s	+	-	+	U	-	+	-	-	-
arduino controlled	-	-	s	s	M	+	s	+	s	+
∑+	1	3	3	1		3	1	4	1	3
∑-	2	1	1	1		2	3	1	3	2
∑S	2	1	1	3		0	1	0	1	0
	11	12	13	14	15	16	17	18	19	20
Amplitude	+	-	s	+	-	+	-	+	-	-
Frequency	+	-	+	+	-	-	+	+	+	+
cost	-	-	-	-	-	s	+	+	+	+
durability	+	-	+	+	-	s	-	+	-	+
arduino controlled	s	+	-	s	s	-	s	+	+	s
∑+	3	1	2	3	0	1	2	5	3	3
∑-	1	4	2	1	4	2	2	0	2	1
∑S	1	0	1	1	1	2	1	0	0	1

7.3 Appendix A: Design Concepts

Table 3 Decision Matrix

Weight																									
Criterion		Design 1			Design 2			**Design 3***			Design 4			**Design 5***			Design 6			**Design 7***			Design 8		
Amplitude	0.19	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%	25.00%	\	4.75%
Frequency	0.18	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%	100.00%	\	18.00%
Load	0.12	90.00%	\	10.80%	90.00%	\	10.80%	100.00%	\	12.00%	100.00%	\	12.00%	100.00%	\	12.00%	100.00%	\	12.00%	100.00%	\	12.00%	100.00%	\	12.00%
Voltage	0.06	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	0.00%	\	0.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%
Surface Area	0.07	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%	100.00%	\	7.00%
Cost	0.12	90.00%	\	10.80%	90.00%	\	10.80%	90.00%	\	10.80%	10.00%	\	1.20%	80.00%	\	9.60%	70.00%	\	8.40%	80.00%	\	9.60%	80.00%	\	9.60%
Success Rate	0.19	90.00%	\	17.10%	90.00%	\	17.10%	100.00%	\	19.00%	20.00%	\	3.80%	100.00%	\	19.00%	90.00%	\	17.10%	100.00%	\	19.00%	20.00%	\	3.80%
Assembly Time	0.06	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%	100.00%	\	6.00%
Totals	1		\	80.45%		\	80.45%		\	83.55%		\	52.75%		\	82.35%		\	79.25%		\	82.35%		\	67.15%