DESIGN OF A SELF-FEEDING FISH DEVICE
FOR RESEARCH REARED DANIO RERIO

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ABSTRACT

This work details the design of a self-feeding device for research-reared zebrafish (danio rerio). One device feeds 1-25 zebrafish, and it attaches to the side of straight edged fish tanks. As zebrafish enter the device, their movement triggers a sensor that then signals a small DC motor to release food into the tank. This process allows zebrafish to receive food when they desire, instead of timed intervals throughout the day.

After various prototypes and designs, it was determined that the most practical sensor for the device consists of a photoresistor (light dependent resistor, LDR) and laser, and the most practical food dispenser involves a DC motor in conjunction with ReSun’s timed food dispenser container. An Arduino UNO connects the system together and tracks data.

A prototype of the design was tested at The Pennsylvania State University, and although it was not long lasting due to leakages and electrical malfunctions, the initial test proved that zebrafish can successfully interact with the device within the first several minutes of implementation. Within the first eight minutes of inserting the device in the tank, the device released food 19 times due to motion triggers, and on average, 67% of the fish in the tank were interacting with the device at any given time.

Future work includes implementing prototype improvements, long-term behavioral testing, and manufacturing a mass-marketable device.
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Chapter 1

Introduction

Using animals for human medical research is not a new topic; it dates as far back as the Ancient Greeks. However, research on how to treat these animals humanely is relatively new, only emerging around the end of the 1800s. Even then and still today legislative policy is configured around “reducing the numbers of animals used for experimentation, unnecessary duplication of experiments, and minimizing pain” none of which includes the quality of life the animals experience while in captivity (Sechzer 1). That being said, there is a global push to increase research on improving the welfare of fish while in captivity. In particular, this project emerged as The Pennsylvania State University Biology Department reached out to the Department of Mechanical and Nuclear Engineering to co-create a device to enhance the quality of life for fish in aquariums. This work describes a mechatronic device, which provides zebrafish the ability to feed on their own accord, which in turn provides a stimulating environment to improve their physical and mental development.

1.1 Motivation

The device provides an autonomous feeding to researched reared zebrafish because zebrafish are used in large numbers around the world, it is proven that fish perform better physiologically and mentally when given stimulating environments, and despite research proving the benefits of self-feeding, there are very few options on the market.

It is estimated that over 5 million zebrafish are used in research annually spanning over 3000 laboratories (Lidster 1). There are several reasons for using zebrafish in scientific research.
Instead of testing genetic and behavioral theories directly on humans, zebrafish offer a surprising similar genetic and behavioral alternative. They share 70% of the same genetic code as humans and follow the same behavioral tendencies as humans such as drug addiction and withdrawal. They are transparent in their developmental stages, which makes it easy for scientists to see changes in growth while avoiding any invasive surgeries (McKie). They also grow quickly, the full growth cycle from fertilized egg to adult being about 90 days (JoVe), reproduce several hundred eggs per cycle (Encyclopedia of Life), and have relatively easily manipulated genes. Zebrafish have been in studies associated with Epilepsy, Muscular Dystrophy, Melanoma, Parkinson’s Disease, Tuberculosis, and drug addiction. Ahlbeck Bergendahl and Braithwaite state “where once the go to model species were laboratory rodents, we now find that zebrafish have become one of the most widely used biomedical model vertebrates” (Ahlbeck Bergendahl and Braithwaite 11).

It is also proven that fish perform better physically and mentally when given stimulating environments. A study in 2016 found that zebrafish who experienced a complex environment by periodically changing the plants in the tank and mild stress through daily net chasing were less stressed in their later developmental stages. The study also found that fish in the stimulating environment had larger more complex brains than fish in a static tank (DePasquale et al. 1). As these fish are used in medical research, it is imperative that they are fit both physically and mentally for a productive study.

One method to increase stimulation in tank environments is to allow the fish to have their own self-feeding device, but self-feeding devices for zebrafish are rather uncommon. Self-feeding in fish research dates back to the 1950s and 60s and “provides a tool for matching feed delivery to appetited variation” (Huntingford et al. 79). The issue with zebrafish in research
facilities is that due to a lack of funding they are often exploited and kept in unstimulating static environments (Aerts et al. 2). From a survey of 98 laboratories using zebrafish across 22 countries in Europe, North America, South America, Asia and Australia, not a single laboratory reported using self-feeding techniques with their zebrafish (Lidster 5). The biggest constraints to adding enrichment techniques are “the additional labour required, increased risk of disease, consistency of scientific results and high financial costs... [There is also the] paradoxical concern that adding enrichment to the tank could induce stress... and a view that further evidence... [is] required to help inform the best choice for environmental enrichment” (7). There are also very few options out there for laboratories to implement, even if desired. This research aims to fill the gap in the market, lessen the labor required, decrease the required cost, and prove that self-feeding devices are beneficial while offering a device that provides research-reared zebrafish autonomy.

1.2 Literature Review

Before delving into the design of the device, this section offers a general understanding of zebrafish, previous zebrafish behavioral studies, self-feeding benefits, and existing self-feeding designs.

1.2.1 Danios Rerio

Zebrafish, formally known as Danios rerio are native to the Southeastern Himalayan region of Asia and on average are 2.5 inches long in the wild and 1.5 inches in aquariums (Kish). In the wild, they are primarily visual predators (Guthrie 1986) and eat zooplankton; although,
overall their diet is varied (Spence and Smith 585). They feed in the water column, at the surface, and from the substratum. Wild zebrafish live in shallow river basics with "aquatic vegetation and silty substratum" and visibility about 30 cm from the surface (Spence et al., “Behavior and Ecology” 83). They tend to inspect novel objects cautiously, and typically stay in groups as "solidary zebrafish sometimes show signs of distress" (Spence and Smith 584). The average lifespan is about 42 months.

As expected, zebrafish in captivity have very different surroundings than zebrafish in the wild. As there are over 5 million zebrafish kept in captivity for research purposes, their feeding and housing varies. A survey of 67 zebrafish laboratories around the world found that all of the laboratories fed the zebrafish two to three times a day with more than half of the facilities feeding the zebrafish three times per day. The food choice per laboratory varies, but 47 of 67 used live food at least once a day such as brine shrimp, Artemia and rotifer Brachionus, and most of the 47 laboratories also used dry or frozen food in addition to live food (Lidster 5). As for housing conditions, Braithwaite and Ahlbeck Bergendahl cite that zebrafish "are typically maintained in commercially supplied, plain glass tanks with flow through recirculating water systems" (12). These tanks may or may not be supplied with enrichment objects such as synthetic plants and pictures of gravel under the tank.

1.2.2 Are Zebrafish Smart?

A major question that surrounds this project is if zebrafish can be trained. When people think of training animals to interact with a device they often think of dogs or even cats but rarely fish, especially fish as small as zebrafish. One reason that the public does not widely recognize
fish as smart is that fish do not have facial expressions (compared to dogs, cats, and humans). This is a huge misconception as fish have been taught to do various tasks for decades.

One of the earliest studies to train fish was when P. Rozin and J. Mayer taught goldfish to press a lever to climate control their own tank in the 1960s. Within two hours of training, seven goldfish learned to press a lever to release cool water into their tank. As the researchers increased the temperature in the tank, they found that the trained goldfish "regulated the temperature of their environment, keeping the temperature between 33.5C and 36.5C most of the time" (Rozin and Mayer 942). Another study taught zebrafish to navigate mazes and found that zebrafish who were exposed to stimulating environments as juveniles learned to navigate the maze much quicker than zebrafish who were kept in static environments. (Spence et al., “Spatial Cognition” 611).

Zebrafish, in particular, are so similar to humans that The University of Utah was able to teach zebrafish how to self-administer opioids, and they quickly became addicted (Kish). Another study conducted at Ithaca College cites that zebrafish brain composition is so similar to humans that professors use zebrafish to study potential treatments for anxiety disorders (Friend).

1.2.3 Benefits of Self Feeding

Although the benefits of self-feeding have not been studied for zebrafish in particular, it has proven physiological and mental benefits for other fish such as Tilapia and Rainbow Trout.

A study on Tilapia conducted by Makoto Endo et al. found that Tilapia raised with the self-feeding system have less stress and better health. They used Adocom Electronics switch-feed box to supply food to the fish when the fish pulled a rope, which hung two centimeters
below the water surface. At the end of the study, they found that the "self-feeding fish had a significantly lower cortisol level in their blood plasma than that of scheduled feeding fish.... [and] immunological analyses revealed that the self-feeding fish significantly exceeded the scheduled feeding fish in... [immune responses] (Endo et al. 1).

Another study around self-feeding found that Rainbow Trout grow faster and larger with self-feeding techniques. Anders Alanara with the Swedish University of Agricultural Sciences used Sterner Products AB's fish feeder to dispense food when Rainbow Trout pulled and bit a rubber knob-ended pendulum, which hung below the water surface. They found that the average specific growth rates... of trout fed using the unrestricted demand feeders was 0.93% per day... and of fish fed using timer-controlled technique was 0.72% (Alanara 352). This was not due to a lack of food in the timer-controlled technique as with the timer-controlled set up, a larger portion of food went to waste than the demand feeders (351). The researchers concluded that the "timer-controlled feeding with short intervals and small food portions increased the competition for food, and led to a higher stress level throughout the whole day" which lead to lower growth rates despite the additional amount of food released (347).

The concept of self-feeding helps prevent the fish from overeating or undereating and gives them a better chance of survival if they are released in the wild (Huntingford et al. 135).

1.2.4 Existing Designs

The most common type of feeding device used in aquariums that do not require human interaction are timer-controlled feeding devices. These devices can be manually set to release a certain amount of food at certain times of the day and are used both for research and commercial
markets. Essentially, instead of the owner feeding the fish multiple times a day, the owner only has to refill the feeder once or twice a week. They sell for anywhere from $13 at commercial pet stores to hundreds of dollars (PetCo). Figure 1 shows one example of a commercialized timer-controlled feeding device.

![Timer-controlled fish feeding device](image)

**Figure 1: A timer-controlled fish-feeding device sold commercially at PetCo (PetCo)**

Although these timer-controlled feeders are rather common and cost efficient, they do not give fish the autonomy to eat when they want like self-feeding devices. Typically self-feeding devices are only used in research facilities such as the aforementioned bite pendulum to train Rainbow Trout and the rope pull to train Tilapia. In some cases, they may also be used in fish farms that breed fish for human consumption as larger fish mean higher profits.

The most similar design to the device outlined in this work is the device used in The University of Utah's zebrafish opioid study. It uses sensors to detect zebrafish movement in a certain area of the tank and if the fish entered the area, it releases either food or opioids. Figure 2 shows the experiment’s set up.
Our device varies from the previous devices as it will be specific for zebrafish, unlike the bite pendulum and rope pull, will offer choice between different foods, and will be easily manufactured/replicable.
Chapter 2

Project Planning

Although the design team formed in December 2016, the project plan and scope changed multiple times. The original plan, which was the focus of spring and summer 2017, involved creating a stimulating environment for codfish at the Norwalk Maritime Aquarium. Unfortunately, the connections with the aquarium were lost when our representative took a leave of absence due to medical needs. This work is not outlined in this paper. From there, the scope was changed to creating a self-feeding fish device for zebrafish. This would be the most beneficial for The Pennsylvania State University Biology lab, which became the new customer in place of the Norwalk Maritime Aquarium. This work was the prime focus of fall 2017 and spring 2018 and is outlined in this work.

2.1 Customer Needs

Through close communication with The Pennsylvania State University’s Biology Department and in depth research of current practices it was determined that the self-feeding device must:

1. Allow the fish to interact with the device
2. Dispense food into the tank when properly interacted with
3. Collect data for research purposes
4. Be cost efficient
5. Be easy to install
6. Be dynamic in two or more ways

The needs are listed in order of importance and are explained with more detail in the design section of this paper.
2.2 Major Constraints

Although there are many biological, mechanical and logistical considerations to take into account when designing this device, this section highlights some of the most prominent foreseeable constraints.

From a biological welfare standpoint, the device must not hurt the fish or create any alarming disrupts to their environment. Large turbulences in the water (Palstra and Planas 268), sharp changes in the lighting of the environment (Ahlbeck Bergendahl and Braithwaite 13), and broad foreign motions can increase the stress levels in zebrafish (Huntingford et al. 52). Increased stress levels often cause the fish to perform poorly behaviorally and physically both in the study and years after, and extremely stressful disturbances can even cause near immediate death (53).

From a mechanical design standpoint, the largest foreseeable constraints are that the zebrafish are rather transparent and small about 1.5 x 0.5 inches (38.1 x 12.7 mm) maximum when raised in aquariums (Kish). Figure 3 shows an image of an average young adult zebrafish reared in an aquarium. Another mechanical constraint is that the device must interact with the fish in the water, and most of the common detection devices are not designed for underwater use.

Figure 3: A typical young adult zebrafish reared in an aquarium (MacRae).
Finally logistically speaking, the device shall be cost efficient and completed over the course of two semesters. A survey conducted with zebrafish research facilities around the world concluded that one of the biggest constraints for their facilities is cost. This cost can be from the device itself or the costs required for implementation and transportation. A budget of $300 was allotted for prototyping and testing.

2.3 Target Audience

This device is designed for zebrafish in both commercial and educational research facilities as researchers will have the skills necessary to successfully implement the device (train the fish how to use it). It can be used in scholarly research and at pharmaceutical companies. It is designed to be used with open top aquariums rearing 1 - 25 zebrafish, which was determined to be common practice in research laboratories (Ahlbeck Bergendahl and Braithwaite 12). Fish tanks housing more than 25 zebrafish can use additional devices for each additional 1 – 25 zebrafish.

The voice of the customer was designated as The Pennsylvania State University Biology Research team lead by Professor Victoria Braithwaite, as the team initiated the project, is responsible for the zebrafish in the experiment, and a research expert in the field of zebrafish behavioral studies.
Due to constraints, the short term goal of this project is to have a working design and prototype used in The Pennsylvania State University Biology research laboratory that allows zebrafish to feed themselves with multiple food options.

Pending the conclusion of positive physiological and psychological effects of the device on research reared zebrafish, the long term goals of the project involve mass production and large scale global use of the device.
Chapter 3
Prototypes and Concept Selection

The design process consisted of two focus areas: (1) concept validation with a working prototype at The Pennsylvania State University and (2) a finalized design that can be manufactured and produced for zebrafish facilities around the world. The concept validation stage is to prove that the device works with zebrafish and allow The Pennsylvania State University Biology Research facility to conduct additional research before investing the required money for full-scale production. This is important as one of the biggest drawbacks in wide scale self-feeding is a lack of research stating that self-feeding is beneficial (Lidster 12). Another reason the design process was split into two stages was because the constraints for each varied significantly. The most impactful constraints for concept validation are time and tool availability, while the biggest considerations for the mass-produced design are ease of install, cost, and longevity. This section outlines the design process for the prototype.

The prototype’s design process was split into five main components, sensing, triggering, dispensing food, electrical connections, and structure. Each of the components involved brainstorming and rapid prototyping.

3.1 Sensing

Three areas of sensing devices were looked at for the prototype: physical interaction, pre-manufactured sensing equipment, and non-physical interaction.

It was originally desired for the fish to physically trigger the device by gently nudging a paddle, similar to a human pushing a button. This method would make it easy to determine if the
fish learned the behavior as paddle nudging is not a common action and would be relatively cost efficient. Despite the initial desire, an initial prototype determined that creating a physical device with the available tools (outlined in Appendix F) and time would be rather imprecise and inconsistent and therefore hard to accurately detect the slight nudge of a small fish. A goldfish was used in this experiment as it was the first available in the research laboratory, but even with the additional force of the goldfish compared to zebrafish, the device did not work well. The flow of water when increasing the water levels in the tank and the action of inserting/removing the device often lead to miss-triggers when the device was calibrated low, and nudges were often neglected when the device was calibrated high enough to not be triggered by the water. This prototype is depicted and further explained in Appendix A. Figure 4 shows an image of the goldfish and paddle.

Figure 4: Goldfish and paddle prototype to trigger the release of food into the tank.

With the hope to make the sensor more reliable, pre-manufactured sensors designed specifically for fish detection were taken into account. Fish farms and research facilities often use fish counters to measure the number and mass of fish in the wild or in their respective farm,
and as the name implies, these counters must be able to identify fish moving through a certain area. Azo Sensors breaks fish counters into three types: resistive counters (using the difference in resistivity of fish and water), optical counters (based on the pattern of light beam-breaks), and hydrostatic counters (relying on sonar). Although most of these sensors would work for the experiment, their costs were in the thousands of dollars and most are designed for much larger set ups counting thousands of fish. Most of these counters are also based on one on one communication with the manufacturer which would have involved additional time and delays.

Finally, it was determined that creating a small-scale sensor set up would be the most efficient for cost and time. Originally, the waterproof ultrasonic sensor, JSN-SR04T, was tested as it could be placed in water and measured distances of around 30 centimeters. After an initial test, it was concluded that ultrasonic sensors do not travel through water efficiently and even outside of water, JSN-SR04T is rather finicky. An image of JSN-SR04T and sample of the code can be found in Appendix A, Figure A-2 and Figure A-3 respectively.

Despite being harder to setup, as the devices needed to be manually waterproofed and connected, lasers and photoresistors offered the potential for a reliable underwater trigger. Figure 5 depicts an initial test setup of a laser and photoresistor combination.
The photoresistor, GM5539, was wrapped in a tube to block out natural light and paired with a 10k ohm resistor to create a voltage divider. The additional resistor allowed the Arduino to have a reference point to create a comparison between voltages and prevented the chance for a short circuit if the resistance in the photoresistor became too low. It was powered using the Arduino’s 3.3V output and sent signals to the Arduino’s analog input “A0”. The expected input from the photoresistor followed the formula:

\[ V_o = \frac{V_{cc} \cdot R}{R + \text{Photocell}} \]

Essentially, as the light decreased, the analog readings reached closer to zero. It was also important that the photoresistor was directly connected to the Arduino’s ground or the readings would be skewed. The schematic diagram of the photoresistor along with the code used during testing are depicted in Appendix A, Figure A-4 and A-5, respectively. The data sheet for the photoresistor is shown in Appendix B.

Although blue travels through water better than red (NOAA), a red laser was chosen because studies prove that zebrafish associate the color red with food (Spence and Smith 582) and red lasers tend to be the least expensive. The laser was connected to digital output pin 8, so the laser could be turned on and off if there was no food in the dispenser or for other research purposes. Finally, as the photoresistor and laser set up worked both above and below water, it was decided that it would be the best sensor for concept validation. The complete decision matrix is depicted in Table 1.
Table 1: Scoring Matrix for Sensor Choice

<table>
<thead>
<tr>
<th>Component: Sensing</th>
<th>Time to Test</th>
<th>Ease to Detect Trigger</th>
<th>Helpfulness to Study</th>
<th>Cost</th>
<th>Total Score</th>
<th>Estimated Cost</th>
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<td>4</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>$9,000.00</td>
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<tr>
<td>JSN-SR04T, waterproof ultrasonic</td>
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<td>1</td>
<td>4</td>
<td>4</td>
<td>14</td>
<td>$15.00</td>
</tr>
<tr>
<td>Red Laser and Photoresistor</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>16</td>
<td>$1.00</td>
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<tr>
<td>Blue Laser and Photoresistor</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>15</td>
<td>$15.00</td>
</tr>
</tbody>
</table>

3.2 Triggering

In contrast to The University of Utah’s opioid test (Kish), which allowed zebrafish to trigger the release of opioids when they entered a general area of the tank, the Pennsylvania State University wanted to allow the zebrafish to trigger the device individually to help data tracking and to see if the zebrafish preferred eating relatively secluded from the group. This makes it more clear in the experiment if the device was triggered purposefully.

It was determined that a funnel would fulfill the desire to allow individual triggering, but there was some hesitancy on whether or not the zebrafish would enter the funnel as they typically work in groups (Spence and Smith 584). A funnel allows individual zebrafish to enter at the small entrance of the funnel but also allows enough space for the zebrafish to move around and dispense food on the opposing end. To get a general idea of how zebrafish interact with a funnel, two funnels were situated with the larger end pointing towards the top of the tank in two separate tanks. The funnel was pointed downwards so as the fish triggered the sensors they would be
swimming towards the food reward, which helps animals learn behaviors. Two different funnel shapes were tested; they are shown in Figure 6.

![Figure 6: Funnels tested to better understand zebrafish’s interaction with new device](image)

Within the first minute of introducing the funnels into the tank, zebrafish approached the structures. After inspecting the funnel, oftentimes one or two fish would enter the funnel. When food was dispensed at the top of the funnel, a few more fish would approach the entrance. Typically, 1-5 fish would enter the funnel while a majority of the fish would inspect the funnel from the outside and eat food as it dropped out of the funnel. This occurred for both the rounded and straight shaped funnels. One issue with the rounded funnel was that fish often had a hard time exiting the funnel as they would get caught trying to push against the rounded notch when looking for the exit. This did not occur in the straight funnel as it was sloped and the zebrafish were guided out along the straight slope. The trouble exiting may be because the zebrafish had a hard time seeing the transparent casing. In conclusion, the zebrafish were not afraid to enter the funnels, and the straight funnel proved best.
3.3 Food Dispensing

Per The Pennsylvania State University’s Biology Department’s request, the method of food dispensing needed to be versatile to allow for various food types, reliable, and cost efficient. Allowing for different food types not only makes the product more marketable, but it is also healthier for the fish. Facilities often vary the types of food they feed fish throughout the week to help them maintain a healthy diet (Lidster 5) and the opportunity to have two devices in the tank allowing the fish to choose which food they prefer offers the potential for additional scientific research. In addition to being versatile, the device needed to be reliable as when animals are learning a new behavior, it is extremely important that the reward is consistently given to ensure that the behavior is long-lasting.

Pre-manufactured robotic arms were originally considered as they would be reliable and versatile, but their cost compared to a simple motor setup made them an undesirable option.

To be more cost efficient, a simple retractable servo acting as a lid and container to hold the food was prototyped. When the servo was at 90 degrees, the servo arm acted as a lid for the cardboard container, and when the servo was at 45 degrees, the container’s opening would be free to dispense food with the weight of gravity. Images of the device opened and closed are shown in Figure 7.

![Figure 7: Initial prototype of food dispensing using a servo and gravity to dispense food](image)

Unfortunately, due to the variance in food sizes, the food often became jammed in the opening of the container. Small fish pellets were used, and although the hole could have been made bigger to make it
easier for pellets to fall through, it was imperative that only a few pellets were released at a time to not waste food. It was also extremely difficult to dispense the same amount of food each time with only the opening and closing of a lid, so to help the food consistently dispense, the servo was moved inside the device to act as a blockage over the hole and as a stirrer to ensure that the pellets were not jammed at the opening. An image of this setup is shown in Figure 8.

![Figure 8: Servo inside food dispenser to shake and release pellets](image)

This method offered a more reliable set up, but it still did not allow for as much control over how many pellets were released. The amount of pellets released ranged from about one to fifteen, and as this prototype was tested with a single goldfish, fifteen pellets were far too many for one fish.

Similar to the sensing design process, it was determined that all handmade food-dispensing devices would have a hard time offering the desired amount of versatility and reliability, so it was decided that using the food container from ReSun’s Auto Feeder, AF-2009D, would be a good option. The AF-2009D is a timed self-feeding device designed for small fish food, and costs about $14 from Amazon.com. It comes with a small LCD screen that allows users to program the device to dispense food up to four times a day at the desired time intervals. More importantly, its food container is a small cylindrical compartment, which rotates 360 degrees to dispense food. When the cylinder reaches 180 degrees of rotation gravity
causes a small door to open and dispense food. An adjustable compartment inside of the cylinder collects the desired amount of food per trigger as the device rotates, so the amount released is relatively consistent and adjustable for different sizes of food. An image of the complete device is shown in Figure 9.

![Figure 9: Resun’s Timed Automatic Fish Feeder](image)

The timed fish feeder was taken apart and attached to a small DC motor to allow the Arduino to control the revolutions. An image of the prototype is shown in Figure 10.

![Figure 10: Modified food dispenser using Resun’s container and a small DC motor](image)
The motor and container proved to provide reliable and consistent results for various food types. Food pellets and dried brine shrimp were used during testing. A complete scoring of each design is shown in Table 2.

### Table 2: Scoring Matrix for Food Dispensing Component

<table>
<thead>
<tr>
<th>Component: Food Dispensing</th>
<th>Time to Test</th>
<th>Reliability</th>
<th>Versatility</th>
<th>Cost</th>
<th>Total Score</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-manufactured Robotic Arm</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>$50.00</td>
</tr>
<tr>
<td>Servo as Lid w Gravity</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>$1.00</td>
</tr>
<tr>
<td>Servo as Lid Inside Container</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>14</td>
<td>$1.00</td>
</tr>
<tr>
<td>Modified Fish Feeder with DC Motor</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>15</td>
<td>$15.00</td>
</tr>
</tbody>
</table>

### 3.4 Electrical Connections

Although connecting the sensor and the food dispenser could have been completed using a simple NOT gate (inverter), the desire to add more functionalities in the future like recording video, saving data, connecting to the internet, and turning itself off when there is no food, made it sensible to use a more complex microcontroller. Complexity, price, and time to learn the system were all taken into account when choosing the best microcontroller because despite the initial prototype only requiring simple programming, the future goal was to have additional features such as internet connection etc. The scoring matrix is shown in Table 3.
Table 3: Scoring Matrix for Microcontroller

<table>
<thead>
<tr>
<th>Component: Microcontroller</th>
<th>Learning Curve</th>
<th>Capabilities</th>
<th>Cost</th>
<th>Total Score</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Will it take a long time to learn how to program the device? How easy is it to get help online through forums? Is it solderless?</td>
<td>Can it connect to the internet? Can it accommodate all of the desired needs? How easy is it to debug?</td>
<td>How much does it cost? Is it available in bulk?</td>
<td>From DigiKey or Alibaba bulk buy</td>
<td></td>
</tr>
<tr>
<td>Teensy</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>$7.00</td>
</tr>
<tr>
<td>MSP430 LaunchPad</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>$5.00</td>
</tr>
<tr>
<td>Inverter</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>11</td>
<td>$1.00</td>
</tr>
<tr>
<td>STM32 Discovery</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>$9.00</td>
</tr>
<tr>
<td>Nanode</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>$8.00</td>
</tr>
<tr>
<td>Raspberry Pi</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>11</td>
<td>$40.00</td>
</tr>
<tr>
<td>Arduino</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>13</td>
<td>$4.00</td>
</tr>
</tbody>
</table>

Although the Arduino UNO seemed like the most straightforward choice as The Pennsylvania State University offered courses on mechatronic design with Arduino, there’s multitudes of guides online to help debug, and the design team had the most experience with the Arduino, other microcontrollers were taken into account to ensure that it was the best choice. Teensy, MSP430 LaunchPad, STM32 Discovery, Nanode, and Raspberry Pi were all considered as they are similar to the Arduino and have a diverse set of functionalities.

Teensy is a USB development board, and it’s compatible with the Arduino IDE with the Teensyduino add on (PJRC). It has similar capabilities to the Arduino, and it’s priced at $7 on Digi-Key. It would be a good alternative to the Arduino for small scale production as buying a single Arduino is about 10$. Ultimately, it was not chosen as in the future the hope is to mass produce the product, in which the Arduino will cost less than $4 through bulk buys, and because the Teensy does not come with pre-soldered pins making it harder to prototype and debug (DigiKey).
MSP430 LaunchPad was also considered as a single MSP430 can cost as little as $5, although it’s lack of solderless pins and small developer community (in comparison to Arduino) made it less attractive. It also holds much less memory than Arduino, so would not be good for any potential complicated sketches in the future (Smith-Strickland).

The STM32 Discovery, Raspberry Pi, and Nanode offered a lot of functionalities, but when compared to the cost of the Arduino UNO from $5-$10, both the STM32 Discovery, Raspberry Pi, and Nanode couldn’t compare at $10, $40, and $50 respectively (Smith-Strickland), even with their additional functionalities. Both would also require additional time to learn the new IDE and language.

After comparing the aforementioned options, it was determined that either an Arduino UNO or an UNO made by a competing company with Arduino would be best for the project. A schematic diagram of the electrical connections for the concept validation is shown in Figure 11.

![Figure 11: The electrical connections for the initial concept validation](image)

In addition to choosing the best microcontroller, additional information was required to correctly set up the electrical connections. The laser was connected to digital pin 8, so it could be turned on or off if
there was no food left in the device. The photoresistor was connected to analog pin, A0, with a voltage
divider directly connected to the Arduino’s ground to keep the Arduino safe and accurately read the
voltage across the photoresistor. The DC motor was connected to PWM pin, 3, to control the speed of the
motor. A diode, transistor, and resistor setup was used to accurately and safely use the motor. The
transistor acts as a more accurate switch for the motor and keeps the Arduino safe as it pulls only a small
amount of current from the Arduino and stores it to power the motor with a much larger current. The
diode prevents electricity from flowing from the transistor back to the Arduino, which typically occurs
when the power gets turned off from a motor and can be harmful to the Arduino or the transistor, and the
resistors limit the amount of current flowing into the transistor (Monk). The complete code used for
concept validation is featured in Appendix C.

3.5 Structure

The final design for concept validation involved two compartments, one situated below
water which housed a funnel and the sensing component and another situated above water which
held the Arduino and food dispenser. The structure was also meant to be balanced at the surface
of the water, so it could be attached to the side of the tank using removable adhesive. Figure 12
shows an image of the device and an image of the device inside of the zebrafish tank.
The bottom half of the design which housed the laser, photoresistor, and funnel involved modeling clay, glue, breadboards, and a small plastic container. The design was chosen as all of the objects were easily accessible and inexpensive. To allow the fish to enter the funnel while keeping the laser and photoresistor out of the water, the funnel was inserted in the bottom compartment. An exacto knife was used to cut holes in the bottom and top of the plastic container, so the funnel would be open at the top and bottom. Glue was used to seal the holes once the funnel was inserted. The bottom structure is shown in Figure 13.
To properly position the photoresistor and laser, clay was used to house small breadboards. The clay was also used to weigh the device so the bottom compartment would submerge into the water.

Small breadboards allowed easy debugging while putting the structure together. While building the structure, the laser often came unplugged from the breadboard, so pin headers were soldered to the leads of the laser to make the ends a better fitting size for the breadboards.

The top half of the design was so the device could be inserted into the tank in a one-step process (instead of separating the food dispenser and the funnel). Essentially, it is a separate plastic container, which houses the Arduino and food dispenser around the opening of the funnel. Separating the top half from the bottom allowed for less damage in the case that the bottom container leaked and made it easier to debug the device as the motor and Arduino were easily accessible from the top. The top compartment was also bigger than the bottom compartment, which gave the device additional surface area on the top half to stay above water. An image of the top half is shown in Figure 14.

![Image of the top compartment of the device used for concept validation](image.png)

**Figure 14:** The top compartment of the device used for concept validation
The motor needed to be placed far enough above from the water to avoid hitting the fish when the compartment door opened, which is why it’s at the top of the container.
Chapter 4

Concept Validation and Improvements

The device was tested at The Pennsylvania State University’s Biology Lab to see how the fish interacted with the setup, if the sensor could consistently detect the fish, and if the complete system worked in unison. Image of the device in the tank are shown in Figure 15.

4.1 Design for Validation

As described before the design used for concept validation involved a photoresistor, laser, DC motor, food container, Arduino, clay, and a two compartment structure. An image of the bottom half of the device is shown in Figure 16.
The photoresistor on one side of a transparent funnel picks up light from a red laser on the opposing side of the funnel. When a fish enters the funnel, it blocks the laser from reaching the photoresistor. During steady state, an Arduino UNO monitors readings from the photoresistor, and when a fish triggers the sensor, the Arduino sends a signal to a small DC motor to release food into the tank. The Arduino, motor, food container, and breadboard are featured in Figure 17.
After food is released in the tank, the code pauses for 15 seconds to allow time for the fish to eat the food before another fish can trigger the release of more food. The complete code is featured in Appendix C, and a flow chart of events is shown in Figure 18.
Steady state for the device means that the photoresistors and lasers are active and the Arduino is constantly looping to see if the photoresistor and laser connection gets interrupted (triggered). During steady state the motor and food dispenser do not move. The future state design involves battery monitoring, wireless data storage, and an additional sensor on the motor to determine a full rotation, to list a few.

4.2 Implementation

The device was left in the tank for 10 minutes and the food dispenser was filled with dried brine shrimp, a common food for zebrafish. This was the first time the zebrafish were fed brine shrimp as their typical diet consists of flake. Brine shrimp were used for this experiment because unlike flake, a majority of dried brine shrimp will stay at the top of the water when released into the tank instead of sink. This means that to eat, the zebrafish were forced to enter the device.

Within the first 465 seconds (7 minutes, 45 seconds) of insertion, the device was triggered and food was released 19 times. On average, 16 of 24 total fish surrounded the device (67.54%) at all times. Even seconds before the device was inserted, fish began to move to the area of insertion as they saw the device hovering over the tank. Figure 19 shows the percent of fish surrounded the device from seconds before insertion to 422 seconds later along with markers for each device trigger with relation to time. Figure 20 shows what was considered “Near Device” in the recorded video of the insertion. The area is about 20% of the tank starting at the right wall. Before the device was moved towards the tank, 0 fish were in this portion of the tank. Counting stopped as around 422 seconds after insertion, non-related movement outside of the tank became an additional variable.
The first fish entered the device 49 seconds after insertion. Each trigger and food release was due to a fish crossing through the photoresistor and laser setup, as expected. Food releases were relatively consistent and so was the amount of fish near the device.

The device was entered 42 times over the span of 465 seconds. The average time between fish entrances was 10.35 seconds with a standard deviation of 9.94 seconds. This
average does not take into account the time for the first trigger, as the fish were still determining how to interact with the device. Also, not every entrance triggered the device as the code pauses 15 seconds after every food release to allow time for the food to be eaten. It was also common for fish to come close to the opening of the funnel, as if they were going to enter, then swim away without fully entering. This occurred 47 times within the span of 465 seconds. A timeline of near entrances and entrances is shown in Figure 21.

Within the span of 465 seconds from insertion into the tank for the first time, the zebrafish consistently inspected and entered the device. Within the first 135 seconds after the initial trigger (2 minutes and 15 seconds), the fish entered the device 13 times. Within the next 135 seconds, the fish entered the device an additional 14 times, and within the 135 seconds after that, fish entered the device an additional 12 times. The consistent inspection within the first few minutes
of insertion into the tank for the first time alludes to the zebrafish being more curious than fearful. It also alludes to their group-like mentality, as once the initial fish entered the device, additional fish consistently followed. There was not more than three fish in the device at the same time. The large amount of near entrances may allude to some fish being too nervous to fully enter the device, their curiosity to see what’s inside the device, or their desire to get food but denial as the container already had a fish inside.

The fish triggered the sensor and food was released. To help ease any potential debugging, the Arduino’s Serial monitor showed readings from the photoresistor and wrote “Food Released” when triggered. All aspects of the device worked as expected, the only initial issue was that the device would not stay submerged in the water with only the force of tape to secure it to the side of the tank. The device had to be held for the period of the initial test. Because of this, it was not feasible to leave the device in the tank for an extended period. A full checklist of procedures is featured in Appendix D. The rest of this section outlines the fish behavioral activity for the first 8 minutes of the device being submerged in the tank, and the following section, outlines suggested improvements to make the device more long lasting.

4.3 Issues and Improvements

Although there were not any issues within the first 8 minutes of insertion, after about 8 minutes the device began to have several mechatronic flaws, which lead to the device being taken out of the tank after about 10 minutes in the water. These flaws and the improvements for them are outlined in this section.
4.3.1 Sensing Opportunities

The photoresistor and laser worked well detecting fish entering the device; although, a future improvement would be that additional sensors be built into the system. These additional sensors would ensure that a zebrafish cannot enter the funnel without hitting a laser, and they would be able to determine the direction that the zebrafish moves - in or out. It is also suggested that the wires get placed neatly and securely as after about 10 minutes in the tank, the photoresistor had skewed readings and would no longer reach zero even when the laser was blocked. This may be due to a ground connection becoming loose, wires touching each other, or water entering the container.

It is also suggested that if the food container is out of food or if there is an issue in the circuit, the laser gets turned off, so the zebrafish can associate the laser with the potential for food.

4.3.2 Food Dispensing Opportunities

Although the food dispenser properly dispensed food during the first 10 minutes, shortly after it became unreliable and required additional voltage to complete a full rotation. This may be due to the transistor in the circuit and the motor being triggered frequently within the first 10 minutes. It is suggested to implement a small button, which gets pushed after the food container completes a full rotation. This button notifies the Arduino that the container has completed a full rotation and tells the Arduino to stop sending voltage to the motor. Therefore, the motor will stop spinning after one rotation, and it does not rely on speed and time to determine the completion of a full cycle. This is how the Resun’s timed fish dispenser works; it is suggested to just use the small DC motor setup from Resun. Originally, it was not used because the motor moved much slower than the selected DC motor and it was assumed they would both be reliable.

The food dispenser was also set to only rotate once in a 15 second time interval; it’s suggested that this time interval gets increased to at least 30 seconds. This would allow the dispensed food to get
eaten before dispensing more food. 15 seconds proved to be too short for the zebrafish to eat all of the food, especially because brine shrimp tends to float on the water instead of drop down into the tank, which meant that only the fish in the funnel could eat the food. Within the first few minutes of the experiment, the funnel became crowded with food as fish swam in and out triggering the release of food each time.

4.3.3 Electrical Opportunities

As most of the large-scale prototyping is completed, it is suggested that all of the electrical connections get soldered to ensure that none of the wires get bumped out of place. It is also suggested that the wires are trimmed to needed length, so they do not get in the way of dispensing food. Additional changes may need implemented to accommodate for the suggested additional sensors.

It is also important to implement a better data tracking system for the long-term prototype. The previous device printed to the Serial Monitor every time food was released, but the Serial Monitor deletes its information every time that it is closed. It is suggested that the Arduino’s internal memory gets incorporated as a storing device for the number of times the device is triggered. This information can also be used to calculate how many rotations are left before completely running out of food.

4.3.4 Structural Opportunities

One of the largest areas of opportunity is in improving the structure of the device for the following reasons:

1. the device did not stay submerged in the water without human force
2. after 10 minutes being submerged in the water, the lower container had droplets of water inside the electrical sensing area
3. food from the food dispenser often missed the funnel and landed around the Arduino and breadboard in the upper compartment
4. the food dispenser was not properly attached and began to fall after 10 minutes of being submerged in the tank

To solve these issues in the prototype, it is suggested that the food dispensing and Arduino components be kept at the top of the tank while the sensors get fully submerged and completely surrounded by clay. The clay will help prevent the water from reaching the photoresistor and laser, and it will remove the entire bottom compartment, which is what kept the device buoyant. This was chosen instead of just adding weight to the bottom compartment because a quick buoyancy calculation shows that with the volume of the smaller compartment it would take around 60 pounds to keep the entire compartment submerged. This amount of weight would not be easily achieved in the area given in the lower compartment. The complete calculation is shown in Appendix E. The clay and funnel device will be secured to the side of the tank using a large hook. Depending on the amount of required clay, the hook could be created by several pipe cleaners, as they are adjustable or by a plastic hook superglued to the funnel.

The motor supplied with Resun’s timed fish feeding device has its own attachment device, which can be screwed onto the top of the tank. A small shelf can be placed at the top of the tank to hold the Arduino and any desired battery packs (if the USB cable is not being used). The funnel would also be increased in the large opening end, so the fish have more room to swim and to make it easier for the food to enter the funnel. An outline of the structure is shown in Figure 22.
4.4 Design for Production

Although it is suggested to conduct additional long term testing before moving to manufacturing and marketing the device, a laid out design is offered for future use. An image of the device is shown in Figure 23.
The device shall work the same as the previously mentioned prototype with photoresistors and lasers as sensors, a small DC motor to release food, and an Arduino to connect the system together. The primary difference between the prototype and the large-scale manufactured device is the structural design. The manufacturable device includes several custom plastic parts. A full layout of the parts are shown in Figure 24. The primary goals of the design were to make the device cost efficient and easy to assemble.

A set of six custom stands were designed for the photoresistors and lasers. These standards allow the easy placement and alignment of the photoresistors and lasers. They come in three different heights to help determine if the fish are entering or leaving the compartment and to ensure that a fish cannot enter without triggering at least two of the sensors. Each stand is designed so the laser and photoresistors can be inserted from the back and snapped into place. The stands for the photoresistors also have two notches in the back to help prevent the photoresistors leads from touching. Keeping each stand separate allows for easy alterations in the future such as adding more sensors per device or switching to alternate sensors.
Their simple design also makes it fast and relatively simple to produce a large quantity. Images of the stands are in Figure 25.

![Image](image_url)

**Figure 25: Custom photoresistor and laser stands to hold the devices and ease assembly**

The sensors along with a small breadboard get glued into a plastic cylindrical compartment. This compartment is removable from the entire device to allow for potentially expanding the sensing capabilities of the device in the future and replacing any sensing components that become damaged over time. The bottom of the compartment has indents to help align the photoresistor and laser stands during assembly, and the entire compartment has a screw on lid. The inner diameter is threaded while the outer diameter will be closed with sealant during assembly to prevent water from entering during use. Additional inserts may be included to help keep the device submerged. Images of the sensing compartment are shown in Figure 26.
A circular tray was designed to help hold the device underwater. The tray will be filled with colored weighted objects such as aquarium rocks to give additional weight to the device. These objects can be outsourced, which makes it cheaper than manufacturing a single heavy object or the objects can be determined by the customer if they want to change out the objects over time to add variability in the tank environment. The tray is featured in Figure 27.
The tray and sensing compartment lid snap onto a custom funnel. The snapping allows for quick assembly. Images of the funnel are shown in Figure 28.

![Isometric View and Right View of Funnel](image)

**Isometric View**

**Right View**

Figure 28: Isometric and right views of the device’s funnel

The motor and food storage container are similar to the system used in the prototype. A small DC motor shall be attached to a larger version of the food storage container used in ReSun’s timed fish device (SportsMax). The increase in size allows for a larger amount of food to be kept in the device.

The DC motor shall be glued to a custom holder for the device. This holder secures the Arduino in an enclosed compartment that snaps closed and uses a plastic injection molded joint. The compartment has several openings to allow electrical connections to leave the Arduino. The holder attaches to the funnel through two hooks. The holder was designed to sit on aquarium walls and can accommodate for about a 1-inch ledge on the top of fish tanks. The holder also has space next to the Arduino to place a battery pack. Images of the holder are shown in Figure 29.
4.5 Future Steps

The aforementioned improvements to the prototype shall be implemented to complete additional long-term testing. The device should be left in the tank for the complete lifespan of several zebrafish to fully analyze behavioral and psychological benefits before mass production and implementation.

Long term implementation could to prove or disprove expected physical and psychological effects of the device on zebrafish such as whether or not the zebrafish will overeat, whether or not the zebrafish will continue to be intrigued after the device is no longer a novel object, does the device increase growth or stress, and if the zebrafish who did not initially interact with the device will eventually learn to use it. This data is important before marketing a fully manufacturable device.

Once the device proves to be reliable and not harmful to the zebrafish, steps shall be taken to implement and produce the large-scale manufacturable device. A marketing plan needs to be drawn and additional customers analyzed to determine successful implementation.
Chapter 5 Conclusion

To summarize, the steps to create a self-feeding zebrafish device were laid out from concept generation to manufacturing, and the concept was validated with zebrafish at The Pennsylvania State University. The device uses a photoresistor and laser that sense fish movement through a funnel, and when the sensors are triggered by the zebrafish entering the device they send a signal to a DC motor that releases food into the tank. An Arduino UNO is connected in the system to track data and allow the system to communicate. Additional sensing, food dispensing, and computing methods were taken into account, but the photoresistor, DC motor, and Arduino were determined to be the best choice due to their cost efficiency and ease to obtain.

Although the device was only tested for 10 minutes with zebrafish due to failures in the wiring and sealants, the initial test proved that within seconds of inserting the device into the water, zebrafish will interact with the device and trigger food to be dispensed. Over a span of 7 minutes and 45 seconds, the device was triggered 19 times, and on average, 67% of the fish in the tank were constantly inspecting and interacting with the device. After the initial trigger, which occurred 49 seconds after insertion, interaction and triggers were relatively constant throughout the entire experiment. On average, a fish entered the device once every 10.35 seconds after the initial trigger.

Because the device did not prove to be long-lasting, additional improvements were laid out to achieve a longer lasting experiment (several months) to ensure that the zebrafish do not over eat or become ill from a lack of food and to test any psychological and psychological benefits. This device would also prove that caretakers could leave the fish for extended periods with the device and the fish would survive without daily in-person feedings.
Finally, the design for a mass-marketable device was laid out for global implementation, pending positive long-term results.
Appendix A

Previous Prototypes

This section outlines previous prototypes in more detail.

The initial sensor involved a small paddle that when nudged would trigger the release of food. An image of the CADD model is shown in Figure A-1.

Figure A-1: Initial Sensor Tested, Paddle

When the paddle was nudged, it completed a circuit at the top of the device to tell the Arduino and servo to release food into the tank. The paddle often triggered the device during any change in water level when placed too close to the circuit, and it often wouldn’t complete the circuit when nudged by the fish. The paddle is in conjunction with a custom designed holder shown in Figure A-1. A small servo is inside of the holder which pushes food through a hole in the bottom of the container. The paddle was secured in the holder with gravity and a ring which kept the rod
from falling through the holder. The paddle was attached to the rod after the rod’s insertion by using a large clip, which is not featured in the image.

The following sensor which was tested was JSN-SR04T and is shown in Figure A-2.

![Figure A-2: Sensor tested but could not detect fish underwater (PotentialLabs)](image)

The code used to test JSN-SR04T is shown in Figure A-3. The code is from Arduino’s website and was created by Tim Eckel.

```cpp
// this sketch is to use the underwater sensor JSN-SR04T - 2.0
// tries using NewPing library to make more accurate
// although waterproof, it also does not go through water
// code from https://playground.arduino.cc/Code/NewPing
// Author: Tim Eckel, tim@leethost.com

#include <NewPing.h>

#define TRIGGER_PIN 12
#define ECHO_PIN 11
#define MAX_DISTANCE 200

NewPing sonar(TRIGGER_PIN, ECHO_PIN, MAX_DISTANCE);

void setup() {
    Serial.begin(9600);
}

void loop() {
    delay(600);
    Serial.print("Ping: ");
    Serial.print(sonar.ping_cm());
    Serial.println("cm");
}
```

![Figure A-3: Arduino code to power JSN-SR04T](image)
The code used the NewPing Library for Arduino to simulate more accurate results than manually timing the sound releases and echo reads, but even so, the sensor proved to not measure objects under water.

Finally it was determined to use a photoresistor and laser to sense the fish entering the device. The schematic diagram and code to test the setup are in Figures A-4 and A-5, respectively.

![Schematic diagram of photoresistor and laser used to test sensing method.](image)

Figure A-4: Schematic diagram of photoresistor and laser used to test sensing method.
Because the photoresistor and laser were not waterproof, the laser and photoresistor were set up around a small transparent plastic container to see if the setup worked through water.
Appendix B

Photoresistor Datasheet

GM55 Series Datasheet

Photoconductive resistance is a kind of semiconductor resistor, conductivity with light changes. Using the characteristics of different shapes and made by light area of photoconductive resistance. Photoconductive resistance is widely applied in toys, lamps and lanterns, camera, etc.

Structure diagram(unit: mm)

Properties and characteristics

- Epoxy encapsulated
- Small size
- Reliable performance
- Quick response
- High sensitivity
- Good characteristic of spectrum

Type and specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Type</th>
<th>Max Voltage (VDC)</th>
<th>Power Dissipation (mw)</th>
<th>Ambient Temperature Range (°C)</th>
<th>Spectral Response peak(nm)</th>
<th>Light Resistance (10Lux) (kΩ)</th>
<th>Dark Resistance (MΩ)</th>
<th>1/V100mA Increase</th>
<th>1/V100mA Decrease</th>
<th>Response time (ms)</th>
<th>Illuminance resistance Characterist</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM5516</td>
<td>150</td>
<td>90</td>
<td>-30--70</td>
<td>540</td>
<td>5-10</td>
<td>0.5</td>
<td>0.5</td>
<td>30</td>
<td>30</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GM5528</td>
<td>150</td>
<td>100</td>
<td>-30--70</td>
<td>540</td>
<td>10-20</td>
<td>1</td>
<td>0.6</td>
<td>20</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GM5537-1</td>
<td>150</td>
<td>100</td>
<td>-30--70</td>
<td>540</td>
<td>20-30</td>
<td>2</td>
<td>0.6</td>
<td>20</td>
<td>30</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GM5537-2</td>
<td>150</td>
<td>100</td>
<td>-30--70</td>
<td>540</td>
<td>30-50</td>
<td>3</td>
<td>0.7</td>
<td>20</td>
<td>30</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>GM5539</td>
<td>150</td>
<td>100</td>
<td>-30--70</td>
<td>540</td>
<td>50-100</td>
<td>5</td>
<td>0.8</td>
<td>20</td>
<td>30</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>GM5549</td>
<td>150</td>
<td>100</td>
<td>-30--70</td>
<td>540</td>
<td>100-200</td>
<td>10</td>
<td>0.9</td>
<td>20</td>
<td>30</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Measuring Conditions

1. Light Resistance: measured at 10 lux with standard light A (2854K color temperature) and 2h pre-illumination at 400-600 lux prior to testing.

2. Dark Resistance: measured 10 seconds after pulsed 10 lux.

3. Gamma Characteristic: between 10 lux and 100 lux and given by

   \[ T = \frac{\log(R_{10}/R_{100})}{\log(100/10)} = \frac{\log(R_{10}/R_{100})}{\log(100/10)} \]

   R10, R100 cell resistance at 10 lux and 100 lux. The error of T is +0.1.

4. Pmax: Max. power dissipation at ambient temperature of 25°C.

5. Vmax: Max. voltage in darkness that may be applied to the cell continuously.

Main characteristic curve

- Temperature characteristic curve
- Spectral response characteristic curve
Appendix C

Prototype Arduino Code

//Code to power prototype self-fishing device
//May 2018 by Emily Burke
//Arduino powers DC motor, laser and photoresistor
//DC motor releases food when fish breaks laser's line of sight
//Sensing stops for 15 seconds after food dispense
//10k Ohm voltage divide for the photoresistor

//TO DO FUTURE
//want to add a button to turn it on and off manually
//want to add trigger for full rotation of motor
//want to add code to turn off if food is out
//want to determine if the fish are entering or leaving
//this code is for concept validation

//VARIABLES
//to release food
int motorpin = 3; //tells the motor to run
int Value1; //value that the photoresistor sends through - in the dark = 0
int LaserPow = 8; //turns first triggered laser on
int PhotoRead1 = A0; //reads first triggered laser
//to track data
int TurnCount=0; //turns off light if there is no more food

void setup() {
// put your setup code here, to run once:
pinMode(PhotoRead1,INPUT); //photoresistor
pinMode(motorpin,OUTPUT); //motor
pinMode(LaserPow,OUTPUT); //laser
Serial.begin(9600); //turns on screen
digitalWrite(LaserPow,HIGH); //turn laser 1 on
}

void loop() {
// put your main code here, to run repeatedly:
Value1=analogRead(A0); //check photoresistor
Serial.print(Value1); //write value of photoresistor

if (Value1<30) { //fish blocking laser
Serial.println("release food"); //write release food
analogWrite(motorpin,100); //turn on motor to lowest speed
delay(1400); //let spin for timed 1 cycle - should fix this to a switch}
analogWrite(motorpin,0);  //turn off motor
delay(15000);  //let the fish eat food for a while, so pause code
}

//continue to read sensor
//add logic to stop if no more food
//add logic to turn off device if desired
## Appendix D

### Concept Validation Checklist

<table>
<thead>
<tr>
<th>Test</th>
<th>Achieved?</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before inserting in tank (4/26/18)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tested in plastic bowl with water and used finger as fish.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Does the laser turn on?</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>2. Does the photoresistor read the laser correctly?</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>3. Does the motor turn when the sensor is triggered?</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>4 . Does it dispense food?</td>
<td>YES</td>
<td>Requires consistent rotations</td>
</tr>
<tr>
<td>5. Does it print to the Serial Monitor?</td>
<td>YES</td>
<td>Record Serial Monitor before restarting to not lose data</td>
</tr>
<tr>
<td>6. Does the structure hold everything?</td>
<td>YES</td>
<td>Fragile</td>
</tr>
<tr>
<td>7. Can it be powered by the USB cord?</td>
<td>YES</td>
<td>Suggested for first concept validation - easier to debug</td>
</tr>
<tr>
<td>Suggestions for improvement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add sensor for 1 full rotation of food compartment.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make structure more stable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add data storage instead of Serial Monitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initially after inserting in tank (May 2018)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does the above work? (1-7)</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>8. Does the water push the structure upward?</td>
<td>YES</td>
<td>Needed held down during testing</td>
</tr>
<tr>
<td>9. Is the sensor compartment still dry?</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>10. Does the structure connect to the tank?</td>
<td>NO</td>
<td>The water pushes the device upwards with more force than a single piece of tape can hold down. Quick mitigation was to have a person hold the device in the tank.</td>
</tr>
<tr>
<td>Suggestions for improvement</td>
<td>Make the device heavier to overcome the buoyant force, and find a stronger attachment method to the tank.</td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>10 minutes after inserting in tank</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Are 1-7 still satisfied?</strong></td>
<td><strong>NO</strong></td>
<td></td>
</tr>
<tr>
<td><strong>1. Does the laser turn on?</strong></td>
<td><strong>YES</strong></td>
<td></td>
</tr>
<tr>
<td><strong>2. Does the photoresistor read the laser correctly?</strong></td>
<td><strong>NO</strong> (At about minute 9) Values are all increased by 60. Stops reaching below 30 to trigger the food release.</td>
<td></td>
</tr>
<tr>
<td><strong>3. Does the motor turn when the sensor is triggered?</strong></td>
<td><strong>YES</strong> (At about minute 9) Much slower, so does not complete one full rotation of food container in the allotted time.</td>
<td></td>
</tr>
<tr>
<td><strong>4. Does it dispense food?</strong></td>
<td><strong>NO</strong> (At about minute 9) Depends where in the full rotation the motor stopped turning.</td>
<td></td>
</tr>
<tr>
<td><strong>5. Does it print to the Serial Monitor?</strong></td>
<td><strong>YES</strong></td>
<td></td>
</tr>
<tr>
<td><strong>6. Does the structure hold everything?</strong></td>
<td><strong>YES</strong> Yes, but motor’s connection to the structure became tilted. Lots of food not making it to the funnel (wasted)</td>
<td></td>
</tr>
<tr>
<td><strong>7. Can it be powered by the USB cord?</strong></td>
<td><strong>YES</strong></td>
<td></td>
</tr>
<tr>
<td><strong>8. Does the water push the structure upward?</strong></td>
<td><strong>YES</strong> Needed held down during testing</td>
<td></td>
</tr>
<tr>
<td><strong>9. Is the sensor compartment still dry?</strong></td>
<td><strong>NO</strong> About 6 droplets of water inside the sensing compartment.</td>
<td></td>
</tr>
<tr>
<td><strong>10. Does the structure connect to the tank?</strong></td>
<td><strong>NO</strong> The water pushes the device upwards with more force than a single piece of tape can hold down. Quick mitigation was to have a person hold the device in the tank.</td>
<td></td>
</tr>
<tr>
<td><strong>11. Do the fish come near the device?</strong></td>
<td><strong>YES</strong></td>
<td></td>
</tr>
<tr>
<td><strong>12. Have more than 50% of the fish interacted with the device?</strong></td>
<td><strong>YES</strong> On average 67% of the fish are swimming near the device inspecting it throughout the entire 10 minutes.</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Notes</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>13. Do the fish trigger the device?</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>14. Do the fish eat the food in the device?</td>
<td>YES</td>
<td>Still a lot of food floating in the device (wasted)</td>
</tr>
<tr>
<td>15. Can the fish leave the device?</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

**After 1 week**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are 1-16 still satisfied?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Do all fish appear healthy (not overeating or undereating)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18. Do all fish appear to react to visual stimuli? (not blinded from laser light)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Have all of the fish triggered the device?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**After 1 month**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are 1-19 still satisfied?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20. Are there any physiological differences compared to a control group?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Are there any differences in stress levels compared to a control group?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22. Are there significant differences between the growth of some zebrafish in the tank compared to others?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**After 2 months**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are 1-22 still satisfied?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Future Behavioral Questions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When offered 2 food options, which do the fish prefer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When offered hand released food, do the fish still trigger the device?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do fish interact differently with the device when offered a food that sinks into the tank? (only requires 1 fish to trigger and enter the device to feed other fish outside of the device)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix E

Force Calculations

\[ F_{\text{buoy}} = \rho g V \]
\[ g = 9.81 \text{ m/s}^2 \]
\[ \rho = 1000 \text{ kg/m}^3 \]
\[ F \rightarrow N \]
\[ V \rightarrow (\text{m}^3) \]

volume of container = 500 mL
want same submerged → 400 mL
1 m³ = 1000 L
400 mL = 0.4 L = 0.0004 m³

volume of funnel (estimated cylinder)
\[ d = 4\text{ cm} \Rightarrow \frac{d^2 \pi}{4} \text{ cm} = \pi = 0.0200 \text{ m} \]
\[ L = 7.5 \text{ cm} = 0.075 \text{ m} \]
\[ V_{\text{cylinder}} = \pi r^2 L \]
\[ = 3.14 \times (0.0200)^2 \times (0.075) = 0.0003058 \text{ m}^3 \]
\[ V_{\text{displaced}} = 0.0003058 \text{ m}^3 \]

\[ F_{\text{buoy}} = 9.81 \times 1000 \times 0.0003058 = 2.99 \text{ N} \]

\[ F_g \text{ needed} = F_b = 2.99 \text{ N} \]

\[ F_g = mg = m \times (9.81) \]
\[ m = \frac{2.99}{9.81} = 0.309 \text{ kg} = 63 \text{ pounds} \]
Appendix F

Toolset

This is a general list of the tools available during the research process. The total budget for concept generation, prototyping, and concept validation was $300 provided by The Pennsylvania State University Schreyer Honors College.

Tools:

- Soldering iron
- Wire Strippers
- Wire Cutters
- Exacto Knife
- Scissors
- Hot glue gun
- Permanent Markers

*Additional tools could have been purchased from common stores such as Walmart, Amazon, Ebay and Target.
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www.sciencedaily.com/terms/danio_rerio.htm
Emily C. Burke

EDUCATION

The Pennsylvania State University, University Park, PA
Schreyer Honors College & Paterno Fellows Program
Graduated: May 2018
College of Engineering: Mechanical Engineering B.S
College of Liberal Arts: Comparative Literature B.A
Minor: English

ENGINEERING EXPERIENCE

Ingersoll Rand Furnace Engineering Co-Op
Interacted with multiple aspects of the company to determine cost saving improvements with a projected savings of $400,000+ as a Value Added Value Engineering Engineer.
Calculated and designed a test setup to simulate water damage inside indoor furnaces due to humidity.
Summer-Fall 2017

TE Connectivity Operational Excellence Intern
Created a dynamic communication system to increase accountability in manufacturing facilities
Optimized a machine build process using Lean and 6 Sigma principles
Summer 2016

Lutron Electronics Engineering/Supply Chain Co-Op
Designed a unique product for international markets to ease lighting installations
Developed automated analysis tools for supply chain using Visual Basic Applications
Communicated with team members in multiple countries around the world
Summer 2014; Winter 2014; Summer 2015

Lead Organizer of the Tech for Tyler Hackathon: Organized a 2 day innovation competition bringing together participants from Texas and nearby states to create technology based ideas and prototypes.
2017

Department of State Virtual Intern: Automated systems for the Department of State’s Near Eastern Affairs and Central Asian Affairs Executive Office through the Virtual Student Foreign Service Internship
2017

Lead Facilitator for the NHS Navigation Hackathon: Collaborated with healthcare professionals in the UK to develop a digital solution which could help refugees understand the UK’s National Health Service
2016

Global Innovation Challenge (1st): Worked remotely with students in The United Kingdom and Croatia to create an innovative solution regarding sustainability
2015

Engineering Mentor: Lead incoming freshmen during Engineering Orientation Network
2015

LEADERSHIP

Resident Assistant: Mentored and held responsible for a floor of undergraduates in the residence halls
Central Asian Affairs Executive Office through the Virtual Student Foreign Service Internship
2016-17

Orientation Leader: Mentored international students during International Student Orientation
2014-16

Alumni Liaison: Executive Member of Gamma Sigma Sigma community service sorority
2014

Head Coordinator: Organized “The Penn State Freedom Tour: What’s Next?” to stop racism on campus
2014

Midshipman: Promoted to Fire Team Leader in the Penn State’s Naval ROTC Program
2013-14

HONORS & AWARDS

Academic Excellence Scholarship
2013-17

Ranked 7th in Penn State’s NROTC 1st year program
2014

TECHNICAL SKILLS

SolidWorks--------Creo Parametrics-------------Visual Basic Applications----------Android Studio