Final Report

NEEDS Programmable Spoon

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Project: NEEDS Programmable Spoon (21-018)

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Executive Summary

This project concept was given by the North East Educational and Developmental Support (NEEDs), located in Tewksbury, MA. The NEEDs center provides care and support for individuals with developmental disabilities. One of the missions of the NEEDs center is to provide their clients with the means to be as independent as possible. An issue with many of their clients is that they tend to eat too quickly and forget to regularly take sips of water causing risks of choking. As a result, these individuals need to be properly guided by a qualified professional which ultimately limits their independence. To restore some independence to the users, a specially designed spoon was designed in this project to provide visual cues and haptic feedback to help guide these individuals through meals without a supervisor to hopefully restore some independence.

In this project, a handheld system was developed. This system involves three parts: a metal spoon, a plastic shell (used to attach to the spoon using magnets and harbor an internal tray), and a removable plastic tray which contains several electronic components. These components include a 9V rechargeable battery, a vibration motor, a custom printed circuit board containing a microcontroller (an Arduino Nano) which accepts feedback from a triple access accelerometer to track movement and based on the position of the spoon, send output to a Red-Green-Blue (RGB) LED which will shine through the opaque PLA plastic of the shell to provide visual feedback to the user. If the LED turns green, the user should pick up the spoon. If the LED turns blue, the user should take a drink. If the LED turns Red, the user should put the spoon down and drink. In addition to the LED turning red, a vibration motor will turn on to encourage the user to put the spoon down to chew.

This project was partially successful. While the mechanical aspects of the spoon (the magnetic locking mechanisms and the 3D printed parts) functioned as intended, the printed circuit board did not come with its parts already assembled. As a result, the final electronic configuration lacks buttons for reprogramming, a switch for turning the spoon on and off and is too big to actually fit in the spoon. In the future, these problems should be fixed and the board should only use SMT parts if possible to keep the form factor as small as possible. Figure 1 contains an image of the spoon assembled (without the internal electronics).

Figure 1: Spoon Assembled

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Introduction

People with developmental disabilities tend to eat too quickly during meals. Consequently, they are more prone to choking on their food. To prevent this from occurring, another person is required to supervise the individual's eating. As a result, the individual eating is dependent on a supervisor which limits their personal independence.

The Northeast Educational and Developmental Support Center (NEEDS Center) provides services to these individuals with programs that “combine medical monitoring, including nursing, physical occupational and speech therapies, with daily living skills training and active community involvement” [1]. To aid people who have a tough time getting through a meal safely, it would be more efficient to introduce a programmable spoon to act as a form of assistive technology as opposed to having a staff member directly watching someone. The designated user of the spoon will be an individual with high functioning autism. To add to their toolset, the NEEDS Center has requested that the spoon can vibrate to let the user know when to put down the spoon and chew, take a sip of water, and take another bite which will remove the need for a supervisor and retain the user’s independence while eating. The Northeast Educational and Developmental Support Center (NEEDS Center) provides services to these individuals with programs that “combine medical monitoring, including nursing, physical occupational and speech therapies, with daily living skills training and active community involvement” [1]. To aid people who have a tough time getting through a meal safely, it would be more efficient to introduce a programmable spoon to act as a form of assistive technology as opposed to having a staff member directly watching someone. The designated user of the spoon will be an individual with high functioning autism. To add to their toolset, the NEEDS Center has requested that the spoon can vibrate to let the user know when to start eating, chew, or take a sip of water, and take another bite which will remove the need for a supervisor and retain the user’s independence while eating. In this report, the project will be defined, the research and development processes will be reported, and the final product will be described along with an evaluation of the result of this project.

Project Definition

Company and Client

The company acting as the project sponsor for the programmable spoon is the Northeast Educational and Development Support Center (NEEDS Center). This non-profit institution was founded in 2012 to assist people who live with developmental disabilities [1]. The NEEDS center has several professionals with years of experience working with individuals who present atypical behavioral patterns. With support services offered for both children and adult groups, the goal of this organization is to enable their clients to live as independently as possible given some level of assistance. Assistance is provided in the form of education and training among other forms of individualized support.

The NEEDS Center's core philosophy is based on the principles of applied behavior analysis and positive behavior support. The location which will be making use of the programmable spoon will be the NEEDS Center in Tewksbury Massachusetts. This location is a day facility which offers residential services better suited for individuals who exhibit challenging or high-risk behavior. Across all the NEEDS locations in Massachusetts, there are 16 group residencies which each serve between two and five adults [1]. Each group residency features a spacious single-family home which is contracted with the Massachusetts Department of Developmental Disabilities (DDS). These residencies are overseen by 24/7 staffing and feature a dedicated program coordinator who will oversee planning daily activities including self-care skills, communications skills, and relationship building [1].

Professionals from the NEEDS center work with a considerable number of school systems to provide training and consultation to children and adolescents. With coordination from school staff and family members they can assist those with developmental disabilities ranging from autism spectrum disorders to attention deficit hyperactivity disorder (ADHD), and even general school adjustment to enhance their educational experience. Furthermore, there are even staff members available for providing at home therapy sessions for assisting people in a safe and familiar environment. Overall, the NEEDS center offers a plethora of options for helping those with learning disabilities so that they can live a greater quality of life.

Project Concept

According to the NEEDS center, individuals with developmental disabilities tend to eat their food too quickly and forget to periodically take sips of water to wash down the food. Consequently, these individuals are more prone to choking, which forces them to eat only when they are under the supervision of a qualified person. As a result, there is a loss of personal independence for these individuals. To restore some independence for these individuals, the NEEDS center is requesting a spoon that has built-in functions which will properly guide the user through a meal. Initially, the spoon will start on the table. To let the user, know that it is time to take a bite, a green light-emitting diode (LED) will turn on. Once the user has scooped some food and has taken a bite, the spoon will transition to red. It will vibrate to let the user know that it is time to pick up the spoon again afterwards. Additionally, a red LED should turn on which will tell the user to put the spoon do. At this stage, the green LED will turn off. The spoon should stop vibrating once it has been set on the table. At this stage, a blue LED may turn on depending on how many bites have been taken. The blue LED notifies the user to take a sip of water. The green LED will turn on once a set amount of time has passed letting the user know to take another bite. This cycle will continue until the user has finished eating. The spoon should be made from a washable and food safe material that can be used multiple times. The spoon should be programmable so that the length of the intervals between drinks and bites can be modified.

Expected Deliverables

Once completed, a fully functional spoon with the desired features will be delivered to the NEEDS center along with a user manual and spare parts. The system will include a 3D printed spoon that will hold all the components inside. The spoon will contain multiple components inside. The components are a vibration motor, LED bulbs, plastic spoon, a 9V battery, and a microcontroller that will combine all these components and program the spoon.

Benefits

The goal of the spoon will be to allow individuals with developmental disorders to regain some personal freedom while eating by eliminating the need for a qualified person to supervise them.

Problem Statement

According to the NEEDS center, persons of developmental disabilities tend to eat their food too quickly making them more prone to choking which requires them to eat only when supervised by a qualified person. It is desired to have a specially designed eating utensil which can eliminate the need for a supervisor and restore some independence to the user.

Project Objective

The objective of this project is to design, fabricate, test, and deliver a fully functioning programmable spoon to the NEEDS center by April 2022.

Research

Design

To make a model with accurate dimensions and properties given the material type and size, Computer Aided Design (CAD) is needed. There are many types of CAD that can be used to do this. Commonly used packages are Solidworks, Autodesk Inventor, Revit, AutoCAD and Creo. All these programs are used in industries ranging from aerospace to medical as noted in [2]. For this project, a three-dimensional model is required. For this, the ideal CAD program will be Solidworks. Solidworks is offered by Dassault Systems which specializes in software for a range of industrial applications. It can be used to create two- or three-dimensional sketches which can be used to create various features. Additionally, Solidworks allows files to be saved as a Standard Tessellation Language (STL) file. STL files can store the surfaces of three-dimensional models as triangles as mentioned in [3]. This format can be useful for prepping models to be machined using Computer-Aided Manufacturing software which generates G-Code as mentioned in [4]. G-Code describes sets of instructions that computer numerical control (CNC) machines can use to create objects. While other CAD packages can be used, Solidworks (Student Edition) is provided to the students at the University of Massachusetts Lowell making it free to use.

Fabrication

To create an actual physical model, a method of fabrication is needed. To create the body of the spoon and the spoon itself, the method must be able to create an intricate, irregular, and complex shape. Additionally, it should be noted that only one working model of the spoon is required to be delivered. Considering this, the best method of fabrication would be Fused Deposition Modeling (FDM) which is the most used method of 3D printing. As explained in [5], FDM utilizes predefined movements to slowly extrude molten material to create layers which fuse to make an object. This method of fabrication is especially useful for making prototypes as changes can be made quickly without needing to make molds like in injection molding or without changing tool heads with machining. Furthermore, it creates less waste than subtractive processes, is cheaper than injection molding (when creating a smaller quantity of models) and offers more design flexibility [6]. A major benefit for FDM is that G-Code is used when making models. As mentioned previously in the design section, Computer-Aided Design (CAD) can be used to make STL files and Computer Aided Manufacturing (CAM) software can create STL files and convert them into instructions (G-CODE) for the machine. This is ideal for this project as the spoon will be designed using CAD.

Despite this, FDM has its drawbacks. Unlike other methods, FDM does not create the strongest parts. FDM models tend to only be as strong as the layer that is the least bonded. Due to these layers, a 3D printed part will not be as strong as processes like injection molding where parts do not consist of layers. A major drawback of FDM is that there is often a size constraint. Many consumer level 3D printers are providing small build volumes. Consequently, parts may need to be printed in pieces separately which limits some designs.

Another method that is a candidate for creating the spoon is stereolithography. Similarly, to FDM stereolithography is an additive process that utilizes a UV laser that hits and cures photopolymer resins [7]. While doing so, a platform (usually submerged in the resin), drags the cured layer down making way for another layer to be made. This results in a very precise object which has well bonded layers.

In comparison to FDM, stereolithography offers a much higher quality model. However, the material type is even more limited (must be a photopolymer resin) and is not as widely available as FDM.

Materials

While limiting material variety, Fused Deposition Modeling can produce models using commonly used materials. Three of these materials are Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG) [8]. ABS is one of the most used filaments. It is stronger than the PLA and can last longer. To print ABS, the extruder temperature should be between 230°C and 250°C and the bed temperature should be between 90°C and 95°C. The glass transition temperature (temperature where the plastic begins to deform) is about 105°C [9]. While it is used in many of today's applications (such as Legos), it is not a food safe material that can be used in eating applications. Due to this, ABS is a poor candidate for this project.

PLA is another very commonly used material. Unlike ABS, it is far easier to print, and the print quality tends to be better. The required extruder temperature (180-210°C) and bed temperature (20-45°C) is much less demanding than ABS. The downside to PLA is that it is much more brittle in comparison to ABS. Additionally, it also had a lower glass transition rate (60-65°C) which makes it far less heat resistant than ABS. An important aspect of this project is that the spoon must be washable. Ideally, the spoon should be able to be used in dishwashers. Most conventional dishwashers reach temperatures up to 60°C [10]. As a result, there is a good chance that PLA will deform if placed inside a dishwasher. This makes PLA a poor candidate for this project.

PETG is another very commonly used filament in FDM. The required extruder temperature for PETG is 220-245°C and the required bed temperature is around 70-80°C. It has a glass transition temperature of 80-82°C. Unlike ABS, PETG is more flexible and less brittle. While its glass transition temperature is lower than ABS, it is high enough to be used in conventional dishwashers without damage. Additionally, it is a plastic that is often used in food applications. This is important for this project as the spoon must be food safe. This makes PETG the best filament out of the three for this project.

Accelerometer

Undoubtedly, one of the most widely used devices found in much of today's technology is the accelerometer. This device is truly diverse in its applications and has the capacity to monitor a bevy of information such as acceleration, tilt, and vibration. While an accelerometer will be more commonly used to observe dynamic forces caused by moving the sensor or applying vibration, even static acceleration like the constant force of earth's gravity can be measured using this device. With all these measurement capabilities, it is no wonder why accelerometers are considered such a versatile piece of equipment. Industries in which accelerometers are used can widely vary from monitoring physical activity level within a fitness watch, to helping guide aircraft, or even being taken as input for a videogame [12].

To take a more in-depth look at the operation of this sensor, an accelerometer can be classified as either piezoelectric, piezoresistive, or capacitive. Firstly, a piezoelectric accelerometer utilizes what is known as the piezoelectric effect to detect motion through the change in acceleration. In brief, the piezoelectric effect is the ability for certain materials to generate electrical charges in response to having some form of mechanical stress applied to them. For this reason, piezoelectric accelerometers are mostly used for measuring vibrations or shock due to the nature of these forces [12]. Comparatively, a piezoresistive accelerometer operates by increasing its internal resistance based upon the amount of force that is applied to it. This makes it so that a piezoresistive accelerometer will typically be much less sensitive than other types however, it still sees use in scenarios like vehicle crash testing because of its properties. Thirdly, capacitive accelerometers are the most used type, and they use changes in electrical capacitance to measure acceleration. To further explain, when the sensor is moved in different directions, the distance between internal capacitor plates will vary as the device's diaphragm moves which will be used to measure acceleration [12].

For the first two accelerometer types that were mentioned, these sensors are usually larger and more clunky in comparison to capacitive alternatives. When producing capacitive accelerometers, they are typically manufactured to fit a small form factor which is why they are referred to as Micro Electromechanical Systems or MEMS [12]. The advantage of using MEMS accelerometers is that they manage to be simple in design yet easily applicable to various kinds of scenarios. This type of accelerometer has become a staple within the mobile device industry as there have been numerous implementations for this hardware in the context of smartphone use. Because of their small size, MEMS accelerometers offer low power consumption which is quite desirable for implementation in microelectronics with smaller sized power supplies. Furthermore, multiple MEMS accelerometers are often used together to perform multi-axis sensing and collect more accurate data [13].

Given how much MEMS accelerometers have developed since being introduced only a couple of decades ago, there is a wide range of available commercial options for these days. Over the years, incremental upgrades have only made them more responsive and precise with time. Because of being so compact, MEMS sensors have been comparatively expensive to develop using micro-fabrication methods in the past. However, this cost has come down as the technology has matured along with the manufacturing methods improving as well [13]. Presently there is no shortage of choices when selecting the right MEMS sensor for a specific job. For instance, the ADXL355 architecture of MEMS is a highly precise and versatile sensor option that can prove highly effective for condition monitoring and observing structural health [13]. Another standard of MEMS accelerometers used in industry is the iSensor standard created by Analog Devices which can be used for embedded compensation and signal processing. An ideal choice to be used for creating a programmable spoon would be the Adafruit Triple Axis Accelerometer Breakout (ADXL335). This model is a triple axis breakout board developed by Analog Devices which pairs with Arduino microcontrollers [13].

Microcontroller

To receive information from the sensors and output power to the other electrical components, a microcontroller is needed. A commonly used microcontroller is the ATMega328. The ATMega328 is an 8-bit chip microcontroller that has twenty-eight pins [15]. Twenty of these pins are input/output pins. Of these twenty input/output pins, fourteen are digital and six are analog. Of the fourteen digital pins, six are capable of Pulse Width Modulation (PWM). This is useful as it allows for motors and other electrical components to be controlled at varying voltages. The input voltage required to operate the ATMega328 is between 1.8-5.5 volts. The ATMega328 is a great candidate for the spoon because it is small, power efficient and provides plenty of I/O pins to receive feedback and control components.

A useful feature of the ATMega328 is that it is compatible with the Arduino IDE. In fact, the ATMega328 is used in many Arduino boards. A useful board for this project would be the Arduino Nano. The Arduino Nano is a small board that uses the ATMega328 and contains several useful features. For example, it has a Mini-b USB Connection which can be used to program the ATMega328 [16]. Additionally, it has a regulated input voltage pin that allows batteries with higher voltages (from 7-12 V) to be used. This gives the board some flexibility in terms of power source. Furthermore, the board is only 18 x 45 mm which is small enough to fit to be a suitable candidate as a control board for the spoon.

Requirements

There are multiple requirements that the system/spoon will accomplish which are all listed below:

1. The spoon will vibrate to let the user know to use the spoon.

   Many of the NEEDS center's clients have a tough time knowing when to stop, put the spoon down and chew. According to the NEEDS center, a loud buzzer would cause their client to panic. The requested alternative was to use a gentle vibration to give haptic feedback.

2. The spoon will be made tamper resistant and safe for use.

   The spoon should not have any sharp edges because it will be used by patients with high-spectrum autism. It should also be made those parts cannot be easily removed by the user.

3. The spoon will not have rapidly flashing lights (must be less than 2 Hz).

   The spoon should not have too bright LED lights because they can be blinding or irritate the user.

4. The spoon must let the user know when to take a sip of water and when to take a bite using audio or visual cues.

   Since the user is no longer holding the spoon, there must be a way to let the user know to pick up the spoon or to take a sip of water. The NEEDS center has requested that a visual or auditorial signal be used with the spoon to let their clients know when to take another bite.

5. The spoon must be able to tell when the user has taken a bite.

   The NEEDS center has requested that the spoon does not act like a timer where the user is expected to eat for a certain amount of time once the spoon has been picked up. The spoon should know when the user has taken a bite, however long it may take, so that the spoon can guide the user to the next step. There will be a range of times that will be programmed onto the spoon for the user to choose from of when to alert the user to pause between bites and drinks. These timing cues can also be made into to how many times the spoon is raised to the mouth to eat.

6. The spoon must be rechargeable.

   For the spoon to be used multiple times, the spoon should be able to be charged between meals. The spoon will use a battery that can be charged through a USB charger.

7. The charge must last through at least 10 meals.

   The spoon should have enough battery capacity to last for at least 10 meals without needing to get recharged.

8. The spoon must be washable and reusable.

   For the spoon to be used multiple times, it must be able to be washed. The NEEDS center has requested that at the very least, the head portion of the spoon should be washable. Also, the case must not be porous to prevent food from staining the case.

9. The spoon must be programmable as per the user’s convenience.

Since all their clients eat at different rates and have different preferences, the NEEDS center has requested that certain aspects such as bites between sips of water and time before the next bite be modified.

10. The spoon must have no sharp edges and must not exceed the length of a regular tablespoon (8.5 inches) by more than 2 inches.

    For the spoon to be comfortable to use, the shape of the spoon should be cylindrical, as small as possible, and comfortable to use. If the spoon looks too unlike a spoon, the clients of the NEEDS center may refuse to use it. The shape and size of this spoon will be based on an electric toothbrush. The measurements would be maximum of a 2.25 x 4.38 inches in height and width and at the very most, 9 inches in length.

Technical Details and Analysis

Design Choices

Sensor Selection

An important requirement of the spoon is that it must not rush the user to take a bite. The spoon should not vibrate while it is ready to be picked up. To do this, an Infrared (IR) Sensor could be used in conjunction with an accelerometer. In this setup, an active Infrared Sensor can be fixed near the head of the spoon and angled parallel to the spoon head so that the IR sensor can bounce IR waves off the face of the user while they are taking a bite to detect bites. Once detected, the spoon will wait until the user stops biting and their face is out of range. This would prompt the spoon to glow red, signaling to the user to put the spoon down. The accelerometer would then determine when the spoon has been put down (by checking if there is zero acceleration) and stop the spoon from vibrating.

The alternative method would be to use the accelerometer (a 3-axis accelerometer) alone. This method would use the accelerometer to track the position of the spoon. Once the user has taken a bite (determined by low to zero acceleration and then sudden downward acceleration), the spoon will change to red prompting the user to put the spoon down and chew. This method will require more complex coding. However, since only the accelerometer is used, there will be less electrical complexity.

While both approaches can get the job done, the second approach where only the accelerometer is used is the better for this project as there is less complexity, less current drawn (since an entire sensor is eliminated) and there will be no need to create a second mount. Additionally, there will be more free ports on the microcontroller.

Cues

A requirement given by the NEEDS Center is that there must be either visual or audio cues that will guide the user through their meal. Two methods to fill this requirement would be to use prerecorded audio messages to tell the user when to pick up the spoon, put it down and take a sip of water or to use light emitting diodes (LEDs) to do the same with red signaling the user to put down the spoon, green telling the user to pick up the spoon and blue telling the user to take a sip of water. A major issue with the audio method is that the Arduino Nano (the microcontroller of choice) does not have a digital to analog converter (DAC). As a result, the Nano cannot create complex sounds on its own. To play messages using the Nano, additional components such as shields, SD cards and speakers will be needed which will be added to the bulk of the spoon. In comparison, the LEDs take up less space and can be more easily configured on a printed circuit board.

The tactile cue (the vibration motor) is a feature requested by the NEEDs center. A coin vibration motor will be the ideal vibration motor due to its small form factor.

Microcontroller

To process data from the inputs (the accelerometer) and the outputs (the LEDs and the coin vibration motor) a microcontroller is needed. To accomplish this, a microcontroller with efficient components (ATMega328) would be required. The two best microcontrollers for this job would be the Adafruit Metro Mini and the Arduino Nano. Both offer a small form factor and have more than enough input/output pins for the sensors and outputs. Despite this, the Arduino Nano was determined to be the better microcontroller for this project as it comes preloaded with a bootloader which allows it to immediately connect with the Arduino Integrated Development Environment (IDE) and works more seamlessly with the Arduino Ecosystem as opposed to the Adafruit Metro Mini which requires the user to install additional software packages (specific to Adafruit) to the Arduino IDE device manager.

Electronic Configuration

Each of the aforementioned components (Arduino Nano, accelerometer, LEDs and vibration motor) need to be connected and mounted within the spoon. One approach is to individually fix each component to the inner walls of the spoon. After doing so, the components will be connected by wires which will be soldered directly to each part. The other approach is to mount all the components onto a printed circuit board (PCB) which will eliminate all the wires and reduce the number of mounts needed. To ensure that the spoon has a small form factor, and the internals are neat and organized, a PCB will be designed, fabricated, and implemented in the spoon.

Battery

The Arduino Nano has a 5-volt regulated input voltage pin and a 7-12V unregulated input voltage pin. Either of these pins can be hooked up to a battery to power the board without using the micro – USB connector. To power the Nano, a 9V battery connected to the 7-12V pin will allow for the Nano to power without being connected to a computer. The alternative option to a 9V battery would be to use a lithium polymer (LiPo) battery. While LiPo batteries have a higher capacity, they are not as common as a regular lithium battery which can be found in a store. As a result, the 9V battery is the better candidate as it is easier to find and has a small enough form factor to be used in the spoon.

Fabrication

There are several ways that the spoon can be fabricated. One such method is Stereolithography. This method utilizes lasers and resin to build layer upon layer to create objects. Another method is Fused Deposition Modeling (FDM) where molten plastic is layered onto a build surface and previous layers to create a 3-dimensional model. Of the three methods, injection molding provides the best quality. However, injection molding will be unreasonably expensive for this project as only one working spoon needs to be delivered to the NEEDS center. Furthermore, it does not allow for quick design changes. Stereolithography on the other hand also provides good quality models. The downside to Stereolithography is that most of the resin types used are toxic. Fused Deposition Modeling on the other hand is the most available of the three. Like Stereolithography, it allows for changes to be made to the design rapidly. For these reasons, Fused Deposition Modeling is the best way of manufacturing the spoon because the spoon will not need to be very accurate dimensionally nor will the spoon experience a ton of mechanical stress. Additionally, many of the filaments used with FDM are food safe.

Material

Table 1: Below is a table of the different temperatures that the material used for the spoon can withstand. (Material Matrix)

	Acrylonitrile Butadiene Styrene (ABS)	Polylactic Acid (PLA)	Polyethylene Terephthalate Glycol (PETG)
Nozzle Temperature	230-250℃	180-210℃	220-245℃
Bed Temperature	90-95℃	60-65℃	70-80℃
Glass Transition Temperature	105℃	60℃	80-82℃
Food Safe	No	Yes	Yes
Physical Properties	Ductile	Brittle	Flexible

The material used to make the spoon must be food safe, durable, and ideally have a high enough heat resistance to be used in a dishwasher or be washed with hot water without deforming. *Table 1* shows the characteristics of three popular filaments used with Fused Deposition Modeling. Immediately, Acrylonitrile Butadiene Styrene (ABS) can be eliminated as it is not a food safe filament. Both the remaining filaments Polylactic Acid (PLA) and Polyethylene Terephthalate Glycol (PETG) are food safe. Between the two, PLA is more brittle and has a lower glass transition temperature which makes it prone to deforming when getting washed. PETG on the other hand has a higher glass transition temperature (at 70-80°C) which is above the operating temperatures of most conventional dishwashers. PETG would be the best material to use if the use of dishwashers is required. Otherwise, PLA makes more stiff parts which may be more useful in the context of this project.

Spoon Design

Using PETG/PLA and FDM, a spoon must be modelled and designed to enclose all the electrical components and interact with the user. Two design options were to use a unibody system like a remote where the entire spoon is one piece and the electronics, battery and USB connections will be installed through an opening. This opening will be covered using a panel. The alternative would be to create a modular system that can be taken apart easily, washed, and reassembled for the next use. To adhere to the requirement that the spoon must be washable, the modular method offers a better approach. The modular method allows for individual pieces to be washed separately. Additionally, a unibody approach with a fixed panel may potentially lead to leaks if the panel is not fixed into place accurately. A third option is to use a modular system in conjunction with a premade spoon. The spoon may be attached using strong magnets which eliminates the need to take food safety into account as the pre-made spoon must have already passed food safety standards. Additionally, attaching a premade spoon allows for the user to easily clean the spoon itself while rinsing all other non-metal components if needed.

Chosen Solution

The chosen design utilizes a 3-piece system which consists of a pre-made metal spoon, a plastic shell, and an insertable tray which contains the electronics needed to operate the spoon.

The shell and tray are made from PLA and are fabricated using Fused Deposition Modeling. The spoon will be mounted onto the shell using four embedded neodymium magnets. The shell will also have 2 internally embedded neodymium magnets which will come in contact with the neodymium magnets mounted on the underside of the tray which allows for the insertable tray to be locked into place. In terms of internal components, the spoon will utilize an accelerometer to determine the location and stage of the spoon while a red-green-blue LED will signal to the user when to put down the spoon (red), pick it up (green) and take a sip of water (blue). Furthermore, a vibration motor will provide haptic feedback to encourage the user to put down the spoon when needed. All these components will be controlled by an Arduino Nano which will be mounted on a Printed Circuit Board (PCB). The alternative solution to this would be to use the ATMEGA328 chip (the same chip that is used on an Arduino Nano) on a board that uses only surface mounted parts which will drastically reduce space and cost.

This design differs drastically from the initial design in numerous ways. First, this design uses PLA instead of PETG. While PETG is the stronger material, it tends to be more flexible. For this project, stiffness and sturdiness is more important than flexibility which leads to the choice of material being PLA. Second, this design utilizes a premade spoon to ensure that the system is food safe. The previous design utilized a fully 3D printed spoon which may lead to harmful bacteria growth within the crevices in the plastic caused by the process of Fused Deposition Modeling. A smooth metal premade spoon ensures that there will be no such buildup of bacteria. Third, the parts fit together using magnets. The previous design utilized interference fits which required tight tolerances. The current design allows for more lax tolerances.

Design and Analysis

The final design utilizes a 3-piece system which consists of a pre-made metal spoon, a hollow shell and an insertable tray. This design allows for the pre-made spoon to be removed with ease for cleaning. Additionally, the tray can be removed to allow for the cleaning of the main body.

The tray is one of the two original parts designed by the team. It is made from opaque PLA and fabricated using 3D printing. It is designed to hold the internal electrical components of the tray (battery, vibration motor and PCB). The tray portion itself is approximately 14.25 cm long and 2.65 cm wide as seen in Figure C2 (Appendix C). Located at the bottom of the tray are 2 neodymium magnets embedded into the plastic using super glue. These two magnets act as contacts to stick to the 2 magnets embedded in the plastic inside of the shell.

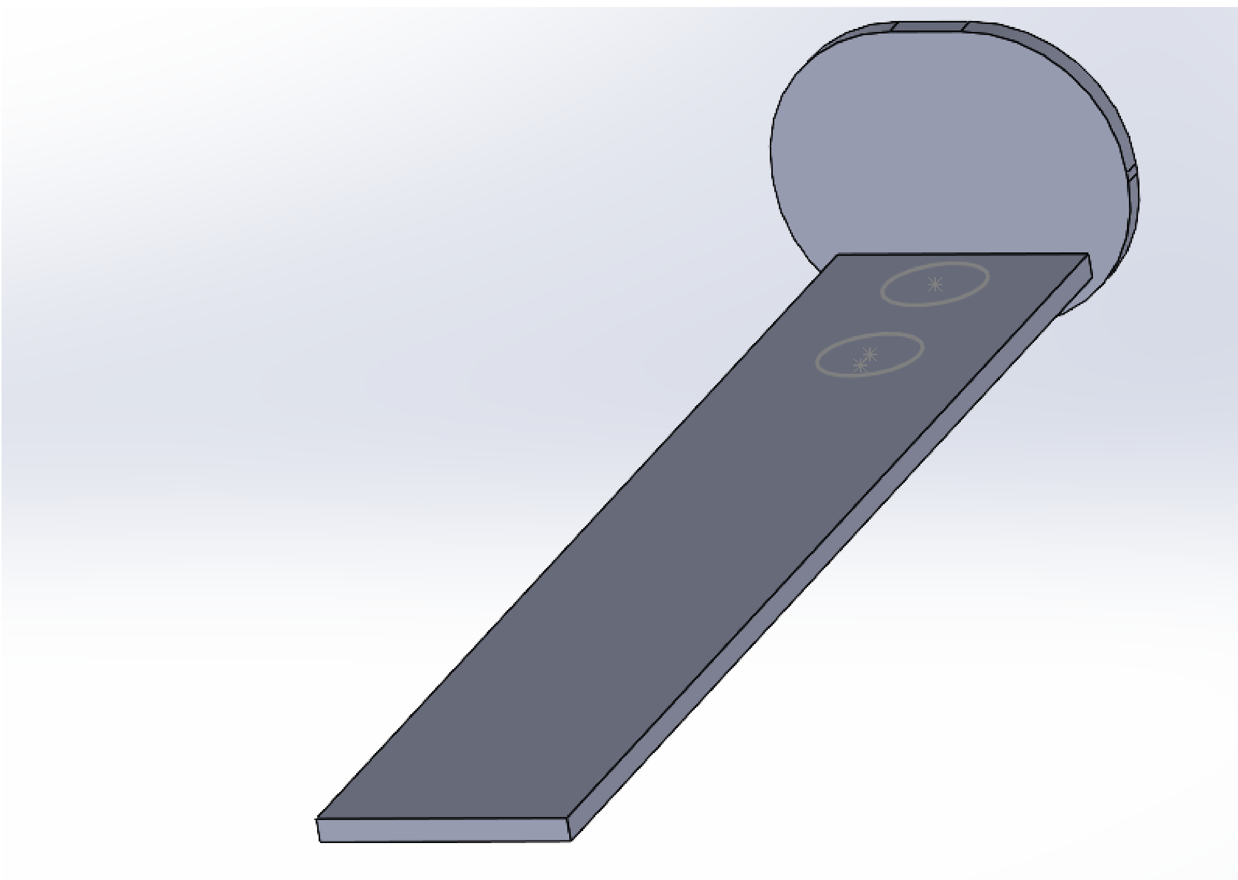

Figure 1: Tray

The second original part is the shell. Like the tray, it is made of opaque PLA which allows for light to pass through while hiding the internal components. The shell is also fabricated using 3D printing. On the bottom of the shell are 4 magnets which are embedded within a spoon shaped groove. Like the other magnets, they are embedded using super glue. These magnets allow for a metal spoon to be attached for operation and removed for cleaning. Located inside of the spoon are two magnets which are positioned to match with the two magnets on the underside of the tray. This allows for the tray to stay secured to the shell during operation and removed when needed for cleaning. The shell is 14.25 cm long and 3.75 cm wide (as shown in figure C1 located in Appendix C). It has rounded edges which makes it more comfortable to handle.

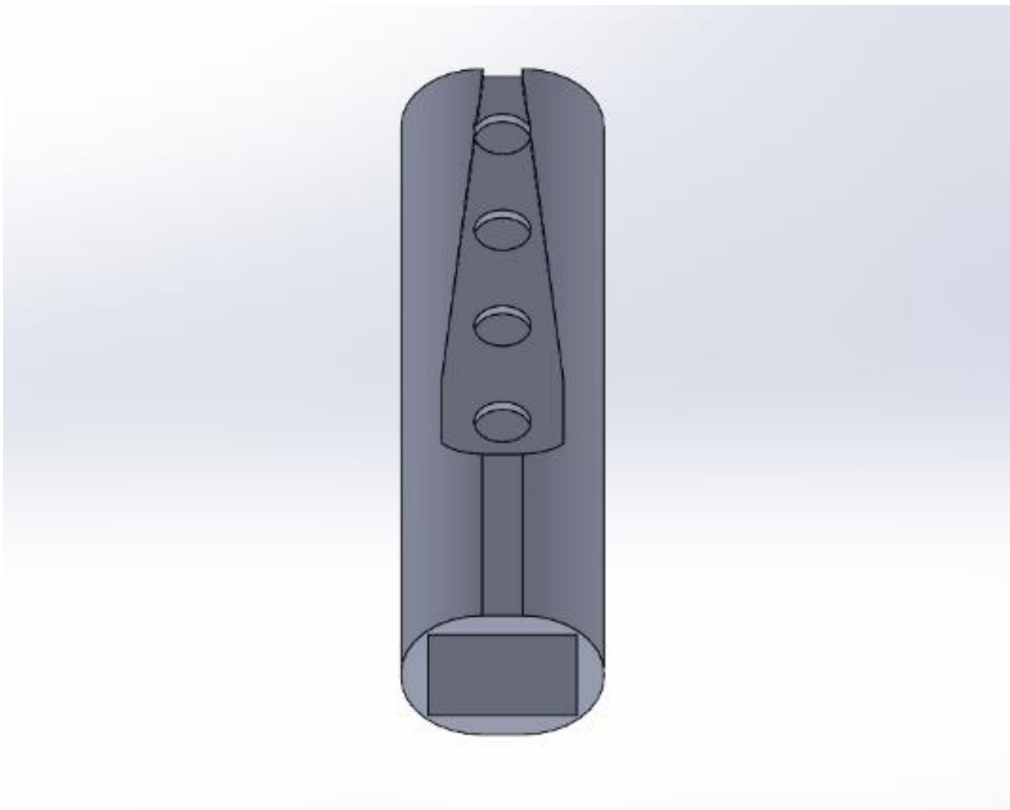

Figure 2: Shell

The tray, shell and magnets assemble as shown in figure 3 (see figure C3 in Appendix C to see a drawing of the assembly). As mentioned before, the magnets are permanently embedded using super glue while the tray can simply be inserted and extracted from the shell when needed.

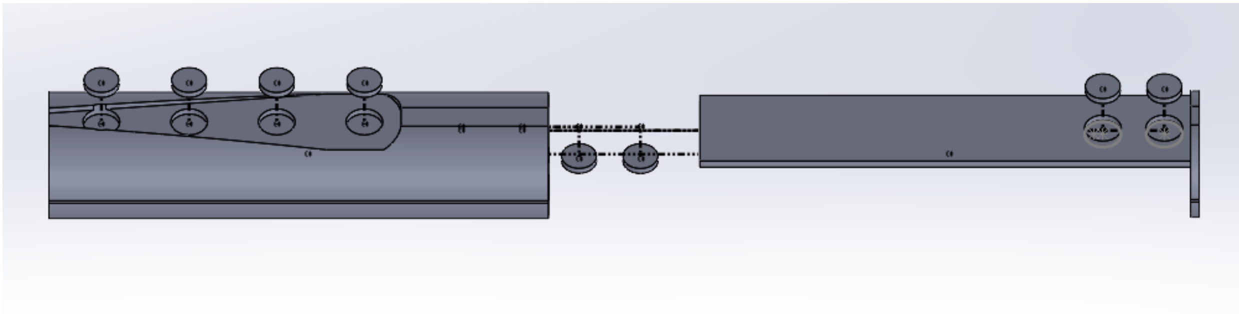

Figure 3: Assembly

The third major part of the spoon is the pre-made metal spoon. This spoon simply attaches to the 3 magnetic contacts located on the spoon shaped groove of the shell. The use of a metal spoon ensures that the portion of the spoon which will be in contact with food is entirely food safe. Additionally, it allows for easy cleaning. The fully assembled spoon can be seen in Figure 4.

Figure 4: Fully Assembled Spoon

To guide the user, the spoon goes through a multistage process. If the user powers the spoon on, the spoon will glow green indicating to the user to turn the spoon on. If the spoon is picked up and a bite has been taken, the spoon will vibrate and turn red which will indicate to the user that it is time to put down the spoon and chew. In some cases, after the user has taken a bite, the spoon will glow blue. This will indicate to the user that it is time to put a spoon down and take a sip of water. The frequency of this process (between the number of bites) will be set by the user using a button. Once the spoon has been put down, a user determine number of seconds (set using a button) will elapse until the spoon once again turns green prompting the user to take another bite and restart the cycle until the meal has been completed.

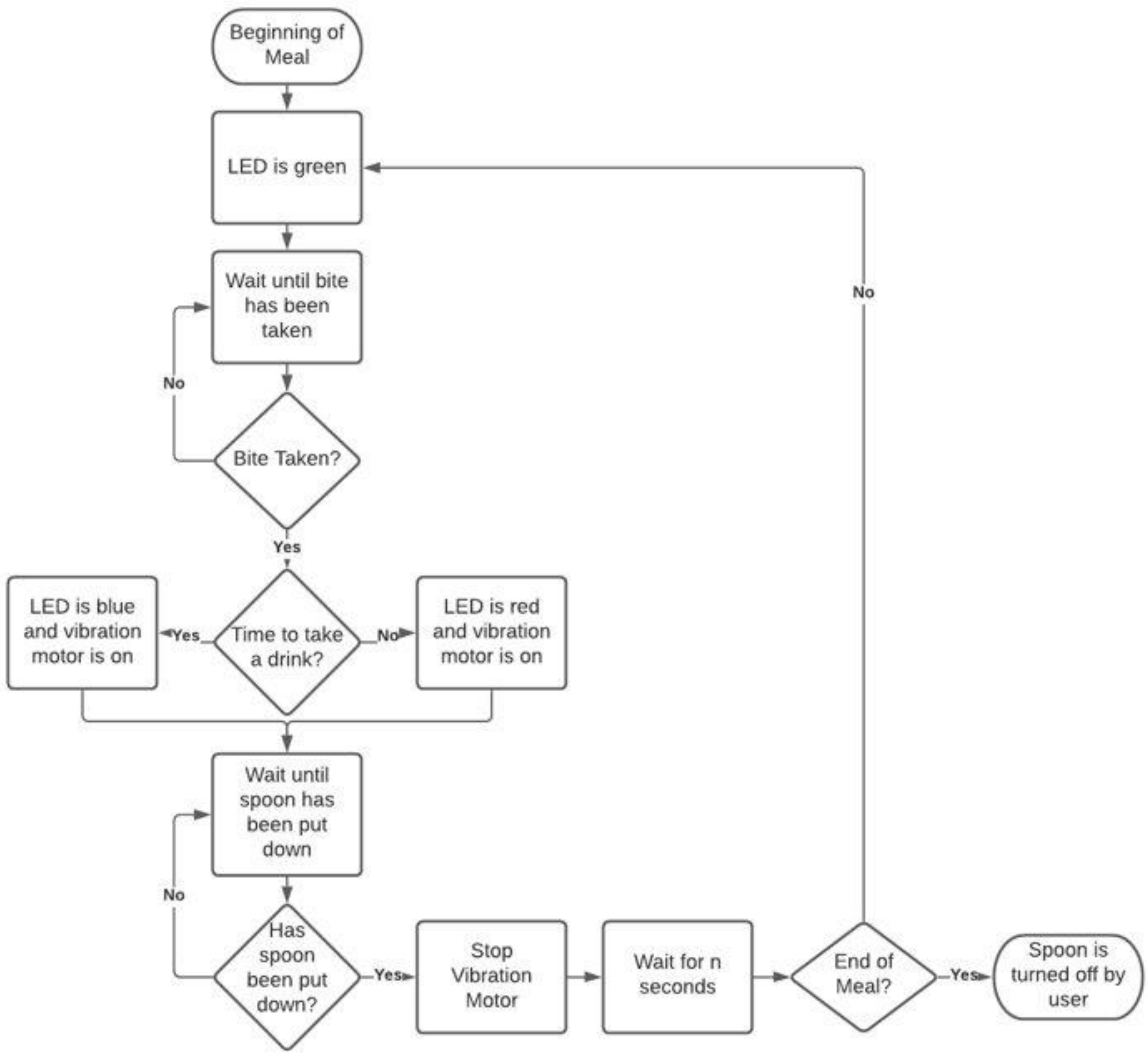

Figure 5: Processes

To make the processes work an accelerometer is needed to track movement, a vibration motor is needed to provide haptic feedback and a red-green-blue (RGB) LED is needed to make the spoon glow. To control these components, an Arduino Nano will be used. The Nano will read input from the accelerometer using input pins. The Nano will control the vibration motor and RGB LED using a Pulse Width Modulation (PWM) digital output pin. This design can be seen in Figure 6.

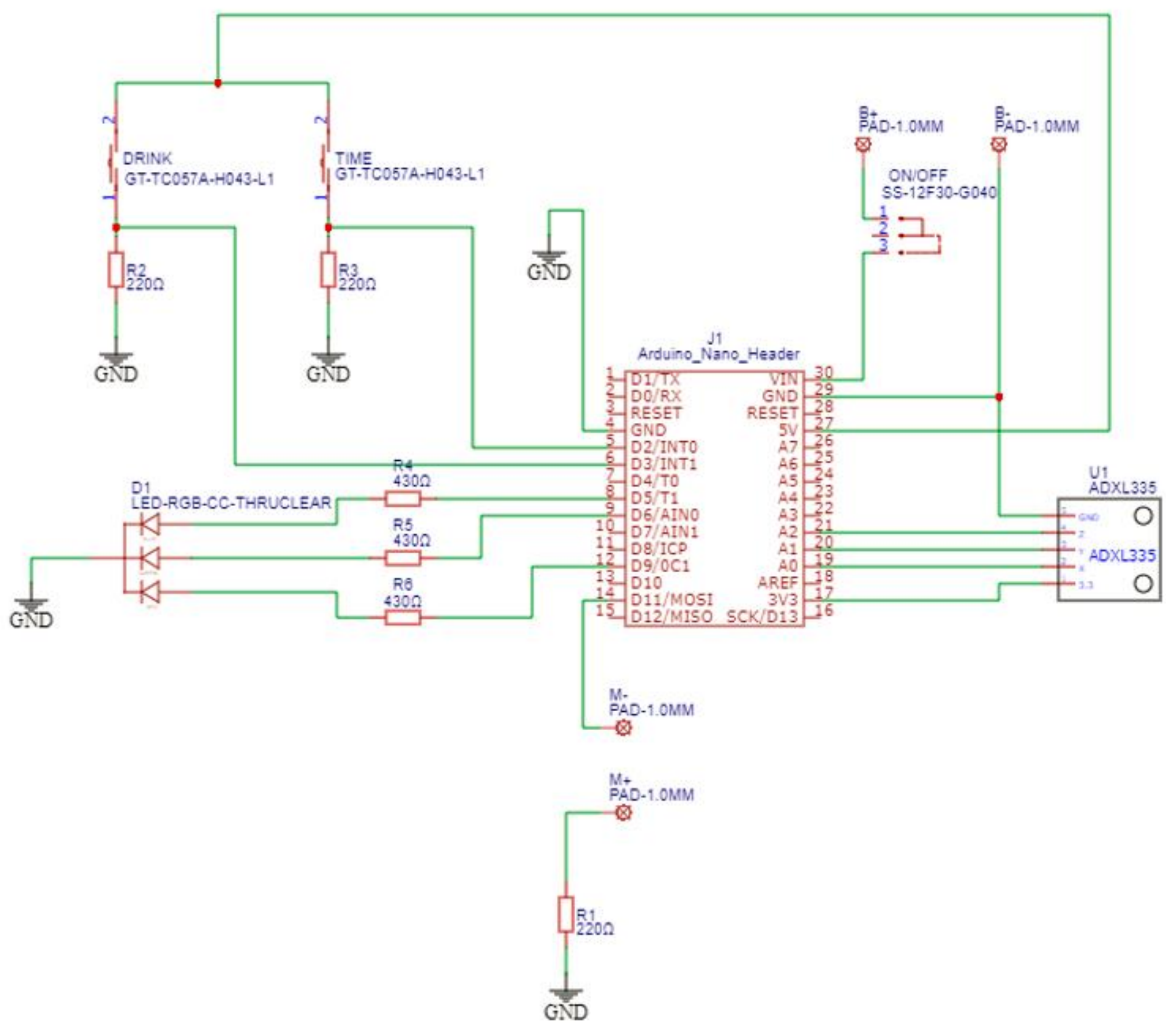

Figure 6: Electrical Schematic of the Spoon

Additionally, there are several current limiting resistors which ensure that the current drawn does not exceed the 40-mA limit of the Arduino Nano input/output ports. The LED utilizes 3 430 Ω resistors while the vibration motor and buttons utilize a 220 Ω resistor. The calculations for each of the resistor values can be found in Figure D1 and D2 (Appendix D). There are also 4 solder pads. Pad M+ and M- are for the vibration motor leads while Pad B+ and B- are for the battery snap leads. The momentary button named DRINK controls the number of bites between each sip (increments + 1 second after each press until a set amount). The TIME button increases the time between each RGB LED turning red to green (time between chewing and the next bite). A single pole double throw switch is used to make and break the connection with the battery which acts like an On/Off switch. The Bill of Materials for this schematic can be found at Figure C6 (located in Appendix C). This design is implemented on a PCB board file where all the nets are routed to form a Printed Circuit board. This can be seen in Figure 7.

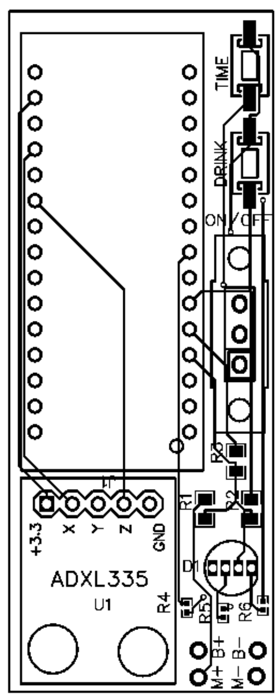

Figure 7: Printed Circuit Board

It should be noted that the accelerometer used is an ADXL335 accelerometer which comes mounted on a breakout board (no ADXL335 standalone chips were in stock at this time). The breakout board is mounted onto the PCB using header pins. The Arduino Nano used is also mounted using header pins. The RGB LED along with the ADXL335, Arduino Nano and On/Off switch all utilize Through Hole Technology (THT) while the other components (resistors and momentary switches) utilize Surface Mounted Technology (SMT). The use of SMT parts allows for some space to be saved as they tend to be smaller. However, due to limitations in stock and availability, this board utilizes both THT and SMT parts.

Once fabricated, the battery (a 9V battery with a USB-C recharger) will be mounted on the tray. This battery will be attached to the PCB using a snap which will be soldered (at the designated pads) onto the PCB. The vibration motor will also be soldered onto the PCB at its designated pads and be mounted directly onto the tray. The PCB will be mounted directly onto the tray using double sided adhesives.

Disclosure of Non-Original Design Content

All designs aside from the Arduino Nano (developed by Arduino) and electrical components are original.

Project Evaluation

Original Plan

Overall, the concept and idea for the project was established successfully with a few tweaks and blockers that came along the way. The project plan was to establish a spoon system with the different mode changes for the time intervals between bites and the different states. So, to reinstate our plan, we wanted to establish a spoon system that can make the user independent instead of having a nurse or a caretaker overwatching the patient. We wanted to develop a system in which a green glow will notify the user that the spoon is in the ready state and is powered on. Once the spoon glows green, the user can go ahead and take a bite and then during the bite the spoon will glow red, notifying the user to place the spoon down and chew and swallow within the time interval. Once the system has been set on the table, the spoon will stop vibrating and will keep glowing red until the timer has been complete. After about three bites, the spoon should turn blue after the red glow to notify the user to take a sip of water instead of taking another bite. There is a button which will allow you to change the modes between the different number of bites. The spoon will then glow green again after the set amount of time, letting the user know to take another bite. This cycle should keep continuing until the user has finished eating. The spoon then can be powered off and stored as well. The spoon should be made from a washable and food safe material that can be used multiple times. The spoon can be made programmable as well with the length of the intervals between the drinks and bites. These changes can be modified from the code. The button will allow the user to change the number of bites before taking a sip of water.

Executed Plan

In execution, the spoon system we had designed was not fully realized due to a misunderstanding with the stockroom. Due to clarity issues in the order form, only the bare PCB was delivered. The PCB lacked the SMT resistors and buttons which it was originally intended to have, thus it could not be fully assembled while meeting the size requirements necessary for the design to fit in our 3D printed shell. Consequently, the spoon did not meet all the goals that were initially set. However, a larger build of the custom-made PCB was still put together to demonstrate that the mechanical components of the design were working along with the code used to operate the spoon. This board is still capable of providing feedback to the product user by cycling through different states of eating a meal via the use of the RGB led and vibration motor. Moreover, it still signals when to pick up a bite of food, when to pause to chew, and when to take a drink during a meal. One failure of this of the resultant board is that it is made without buttons so it is not user programmable. Without the button input, it operates using a pre-determined delay put in place to have the user take a drink as well as a static interval of time between bites. Additionally, the operation of the board assumes that there will be two bites taken before taking a drink each time. With the appropriate SMT components it would have been possible to keep the PCB at the right size for it to be inserted into the shell and take user input for the spoon to be customizable. While we had created a design that was proved to have worked, the objective of the project was not fully accomplished. Figure 8 shows the entire disassembled system of the spoon.

Figure 8: Disassembled System

Satisfaction of Project Requirements

1. The spoon will vibrate to let the user know to use the spoon.

   The spoon LED turns red which indicates to the user that it is time to put the spoon down. It also glows blue to indicate it is time to take a drink
   This requirement has been met.

2. The spoon will be made tamper resistant and safe for use.

   The tray is hard to remove as there are no handles or gripping areas to grab the tray. Removing the tray requires focused effort and dexterity as the end of the tray is very thin and flush to the shell. This keeps the internal components out of reach for clients that may want to try to open the spoon up. As a result, while the spoon is not completely tampered proof, it is tampered resistant. It is also safe to use as a premade metal spoon is used which makes the part that is in contact with food safe to use. This requirement has been met.

3. The spoon will not have rapidly flashing lights (must be less than 2 Hz).

   The LEDs are set not to flash at all. This requirement has been met.

4. The spoon must let the user know when to take a sip of water and when to take a bite using audio or visual cues.

   The spoon LED turns blue when it is time for a drink. It used a vibration motor when its ready to use. The RGB LED turns green to indicate to the user to take a bite. The RGB LED turns blue to tell the user when to take a drink of water. These processes are visual cues. This requirement has been met.

5. The spoon must be able to tell when the user has taken a bite.

   We were unsuccessful in using the accelerometer to check when exactly the user takes a bite. To compensate for this, we have utilized a delay to give the user some time to take a bite. This is not ideal as it will rush the user. As a result, this requirement has not been met.

6. The spoon must be rechargeable.

   The spoon utilizes a 9V battery that can be recharged with a USB-C cable. This requirement has been met.

7. The charge must last through at least 10 meals.

   We were unable to test this requirement. This requirement was not met.

8. The spoon must be washable and reusable.

   The metal spoon part itself is a standard spoon that can be rewashed. The tray of the spoon can be removed, and the shell (which is made from PLA) can be washed and rinsed with soap and cold water. This requirement has been met.

9. The spoon must be programmable as per the user's convenience.

   The PCB that we ordered did not come with the needed SMT parts (which includes the buttons which were to be the method of reprogramming the spoon). As a result, the spoon cannot be reprogrammed unless it is through the Arduino Nano's programming port using the Arduino IDE. This requirement has not been met.

10. The spoon must have no sharp edges and must not exceed the length of a regular tablespoon (8.5 inches) by more than 2 inches.

The spoon has filleted edges which make it easy and comfortable to grip. The overall length of the spoon (with the shell and tray installed) is approximately 9.5 inches which follows the requirement. This requirement has been met.

Budget

Table 1: Project Cost Estimate

Item	Cost Per Unit	Count	Total
Custom Printed Circuit Board	**$5.25**	**5**	**$26.25**
SMT Service	**$23.54**	**0 (Not Placed)**	**0**
9V Battery	**$16.99**	**1**	**$16.99**
Arduino Nano	**$21.80**	**3**	**$65.4**
ADXL335 Accelerometer	**$14.95**	**3**	**$44.85**
Vibration Motor	**$5.99**	**1 (3 in 1 pack)**	**$5.99**
PLA Reel	**$22.99**	**1**	**$22.99**
Total			**$181.47**

The allotted budget for Assistive Technology projects is approximately $500.00. For this project, we utilized a PCB maker to make a board. Additionally, a request for an SMT Assembly service from JLC PCB (to have the manufacturer mount the PCB with surface mounted parts based on a library of components that they have). This request was not fulfilled. Several other items ranging from a 9V battery to a PLA reel were needed bringing the total cost of all the components to $181.47 (without shipping) which is $318.53 underbudget.

Project Reflection

Challenges and Critical Issues

Overall, the project went very well but like many other things in the world, there were many obstacles and issues that came along the way. One of the key issues that occurred was the code. It was difficult to structure it how it was accustomed to work. It was easy to set the time intervals for the LEDs to change between the colors but once adding on the accelerometer, it became a bit difficult to get the correct values for the different axis. The accelerometer kept giving off inaccurate values when it was placed in various positions. There had to be a function that would calculate accurate values that would allow defined values for the state changed between when the spoon is rested on the table and when the spoon is lifted for a bite. Other than that, it was tough coding the button in so it will allow to change the modes between the number of bites. Other than that, the code was quite simple, but it took about 2-3 weeks troubleshooting these issues.

We also had challenges regarding food safety. Our initial design did not utilize a separate metal spoon. Rather, the portion that was to come in contact with food was to be 3D printed. This caused many issues with food safety as 3D printers tend to have brass nozzles which leak microscopic amounts of lead onto the spoon. Additionally, due to the layering process of 3D printing, there are tons of microscopic cracks and crevices which over time may harbor harmful bacteria from food and saliva which may cause illness to the user. This issue was solved by using a pre-manufactured metal spoon and magnets to attach the spoon and the shell together. Since the actual spoon part is now food safe, we switched from using PETG to PLA as PLA was far more rigid and had a cleaner finish.

Another major challenge was learning how to use circuit manufacturing CAD. For this project, we used Autodesk Eagle and eventually EasyEDA. Initially, we used Autodesk Eagle to Design the PCB as it was available for free and could generate Gerber files. However, since we opted to use a SMT assembly service, we needed to be compliant with our PCB maker (JLC PCB).

Since JLC PCB has their own library of parts, we switched to EasyEDA which is a web-based circuit designer which is optimized for JLC PCB customers. As a result, we needed to copy everything we had from the Autodesk Eagle circuit and remake it in EasyEDA with parts that are in stock. A major issue with this is that many of the parts we needed were out of stock. For instance, the ADXL335 triple axis accelerometer was not in stock along with some of the needed capacitors to filter output. As a result, we needed to use an accelerometer with a breakout board. To mount directly onto the PCB with header pins which increased the form factor. Additionally, not all the parts that were needed could be found with surface mount technology (SMT). The single throw double throw switch only came in through hole tech (THT). As a result, the PCB is a combination of THT and SMT parts which is not ideal in terms of form factor.

Safety and Hazards

In this project there were 2 main hazards with the first being the use of a 3D printer. Most 3D printers do not have an emergency stop button. This is true for the 3D printer used in this project: a Prusa Mini+. The lack of an emergency stop may cause the user to get their hands caught in the pulleys of the 3D printer or get their hand burned on the nozzle or heat bed. This is easily avoided by following proper procedures and turning off the 3D printer before removing parts or cleaning the machinery. The second major hazard is soldering which is needed to attach components onto the board. Improper use of soldering tools may cause burns (from both the soldering and the molten solder) and inhalation of toxic fumes (caused by melting the solder using the soldering iron). This can be avoided by properly ventilating the area, wearing goggles, and exercising the proper procedures for soldering.

Customer Perspective

One of the biggest benefits of this project to the NEEDs Center and their clients is that it restores independence to the user. Many individuals with developmental disabilities are unable to properly pace themselves while eating which demands a more capable individual to manually guide them during meals. A spoon with guiding and feedback capabilities allows for user to eat without supervision and on their own time therefore restoring some independence. A secondary benefit would be to free up a supervisor. In the context of the NEEDs center, the workers will be able to leave their clients alone which may allow them to tend to their other clients, therefore allowing more people to get the care they need.

In terms of end hazards to the user, there may be a potential buildup in bacteria on the spoon handle. Since 3D printed parts have microscopic crevices, they tend to grow bacteria over time. Although the spoon is metal, the transfer and buildup of bacteria on the outside of the shell may potentially cause sickness if the spoon is not washed frequently.

Standards Utilized

1. ANSI C18.3M: Safety standard for portable lithium primary cells and batteries

   Since the spoon will be powered by a battery when not connected to a computer, safety standards need to be met. The ANSI C18.3M standard provides a safety standard for testing batteries [26]. This is done by the battery manufacturer.

2. ISO 128 – Technical drawings — General principles of presentation
   This project utilizes several types of Computer Aided Design (CAD) software to develop the spoon. To ensure the product and its properties are well documented, the ISO 128 - Technical drawings standard should be adopted. This standard shows the drawing conventions for mechanical designs which include methods of creating lines and dimensions [27]. Since the spoon project utilizes parts designed by Solidworks, the resulting drawings must follow these standards.

3. IPC J-STD-001G – Standards for Soldering

Since this project will use a custom PCB with items that will need to be assembled and soldered, a soldering standard must be considered. The IPC J-STD-001G provides information on materials specifications and soldering [28]. This standard will be used to ensure that all components on the PCB are assembled correctly.

Environmental Considerations and Impact

Since the spoon uses non-biodegradable parts (PLA, Battery, Vibration Motor, PCB and Neodymium magnets), there is a negative environmental impact as the spoon cannot be easily disposed of. PLA can potentially be remelted and repurposed. Additionally, since PLA is often extracted from raw materials such as corn, there is an impact in the agricultural industry with raw items going towards making plastic. Similarly, to PLA, the printed circuit boards are not easy to dispose of. However, they can be dismantled to harvest components.

While the spoon is operating, there is no environmental impact as the spoon does not release fumes or directly damage the environment in any way.

Societal, Social and Economic Impact and Considerations

This project allows for persons with special needs to eat without minimal to no supervision therefore restoring independence. While this spoon is currently geared towards individuals with developmental disabilities, it may potentially be implemented in a way that it helps people suffering from other issues. For example, it may be used in weight loss applications. Many non-special needs individuals tend to overeat as they tend to eat far too quickly and not chew. As a result, this spoon can potentially benefit people trying to lose weight and improve eating habits.

Ethical Considerations

For this project, our team needed to exercise caution in the materials used as our method of fabrication is not food safe. If we used our old design, our project would not be food safe which may cause illness to the NEED's center's clients. To ensure that this does not happen, we have changed the design so that it is food safe.

Intellectual Property Considerations

All designs aside from the Arduino Nano, and individual parts (such as resistors, vibration motors etc.) are original parts developed by the team. The use of the Arduino Nano falls under the creative commons license (Attribution 2.0 Generic (CC By 2.0)) which allows for the component in question to be shared or adapted [23].

Teamwork

Our group was thorough and efficient with delegating tasks regularly while developing our project. We would play to each other's strengths and provide help when necessary to make sure we were on track. In term so workload, 2 team members worked 3D modeling and fabricating the spoon while 2 other team members worked on the circuitry and programming.

Technical Communication Skills

On the team level, we have committed to meeting in person to work on the project once a week from 10 AM to 1 PM on Tuesdays. Additionally, we committed to meeting with our advisor once a week at 10 AM on Wednesdays to report our progress.

Multidisciplinary Issues

Our team consisted of 2 Computer Engineering majors, 1 Electrical Engineering major and 1 Biomedical Engineering major. Due to overlapping knowledge, the team worked together well.

Future Direction

Aside from solving the issues that prevented the spoon from functioning, a future improvement could be designing a fully surface mounted PCB. Additionally, a microprocessor microchip can be used in place of an Arduino Nano. While an Arduino Nano has many features, most of them are unneeded in the context of this project (such as pullup resistors and other unused pins). To make a simpler, more efficient and production ready board, the microcontroller used in the Arduino Nano (ATMEGA328) can be used on its own to create a special purpose board. Figure C6 in Appendix C shows what a fully SMT PCB without breakout boards or premade components such as an Arduino Nano would look like. This is a direction that should be taken if this board is to be manufactured in large quantities.

Another potential direction is to make the microcontroller wireless and create a graphical user interface application for the use for programming. This may, however, cause issues with battery life and cost.

Project Completion Plan

Gantt charts and RACI Matrices are used for project planning and assigning responsibilities. RACI stands for (Responsible, Accountable, Consulted, and Informed). In a RACI

Matrix, each cell is filled with one of these letters to designate responsibility. For this project, both a Gantt Chart (Figure A1 in Appendix A) and a RACI chart were made. According to the schedule set in the Gantt chart, we got really far behind. Due to design changes, modeling the parts took half the semester and the PCB order, and the debugging process took until the end of the semester. The RACI chart on other hand remains largely the same with the roles being accurate.

Summary

The NEEDs Center established a need for a programmable spoon to assist individuals with disabilities to pace themselves while consuming a meal. The project was designed for high-functioning autistic individuals who usually require cues from healthcare workers on when to chew, swallow, and take a drink of water while eating. The risk for choking or aspiration during meals is high for these individuals due to them eating too fast or not taking a drink. The programmable spoon was designed to provide its user with vibrational and visual cues on when it is safe to take a bite of food. The vibrational cues were tied in with sensors to determine when its user can take a bite of food without risk. With this, the team needed to keep in mind the proper size and components that would work to design this spoon. The spoon needed many different components, such as the following: Arduino Nano, Axis Accelerometer, switches, battery, RGB LED, and a Vibration Motor. The component’s sizes had to be small to fit inside the housing of the spoon. The housing was designed to fit in its user's hand comfortably. In addition, the team ensured that the spoon is food safe by utilizing a metal spoon attachment which would come in contact with the food as opposed to a 3D printed version. Fused Deposition Modeling was used for fabricating the spoon's housing in the team's desired material. The team also utilized the use of magnets to fasten the housing closed and to keep the head of the spoon attached to the body. In addition, the team chose to use a rechargeable battery to power the spoon for simplicity.

Through this, the team met most design requirements for this project. The spoon can remind the user when to put it down by a vibration when the LED turns red. The user is prompted to take another bite when the LED s green. Additionally, the user is prompted to take a sip of water when the LED is blue. The design also does not have rapidly flashing lights to distract the individual from eating. Furthermore, the team was able to make the spoon tamper resistant, rechargeable, and reusable. Due to various complications, the team struggled with hitting all requirements established. Unfortunately, we could not accomplish the requirement for the spoon to be reprogrammable, as well as detecting when the user has taken a bite. We were also unable to test the battery life of the spoon through 10 meals. In the future, the team would work towards correcting these failures and do additional tests to evaluate the batteries' lifespan.

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spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUExWUkxN01ZRFExMDE5JmVuY3J5cHRlZElkPUExMDQ0OTYwMUs5UExKRTBZMDE. [Accessed 29 11 2021].

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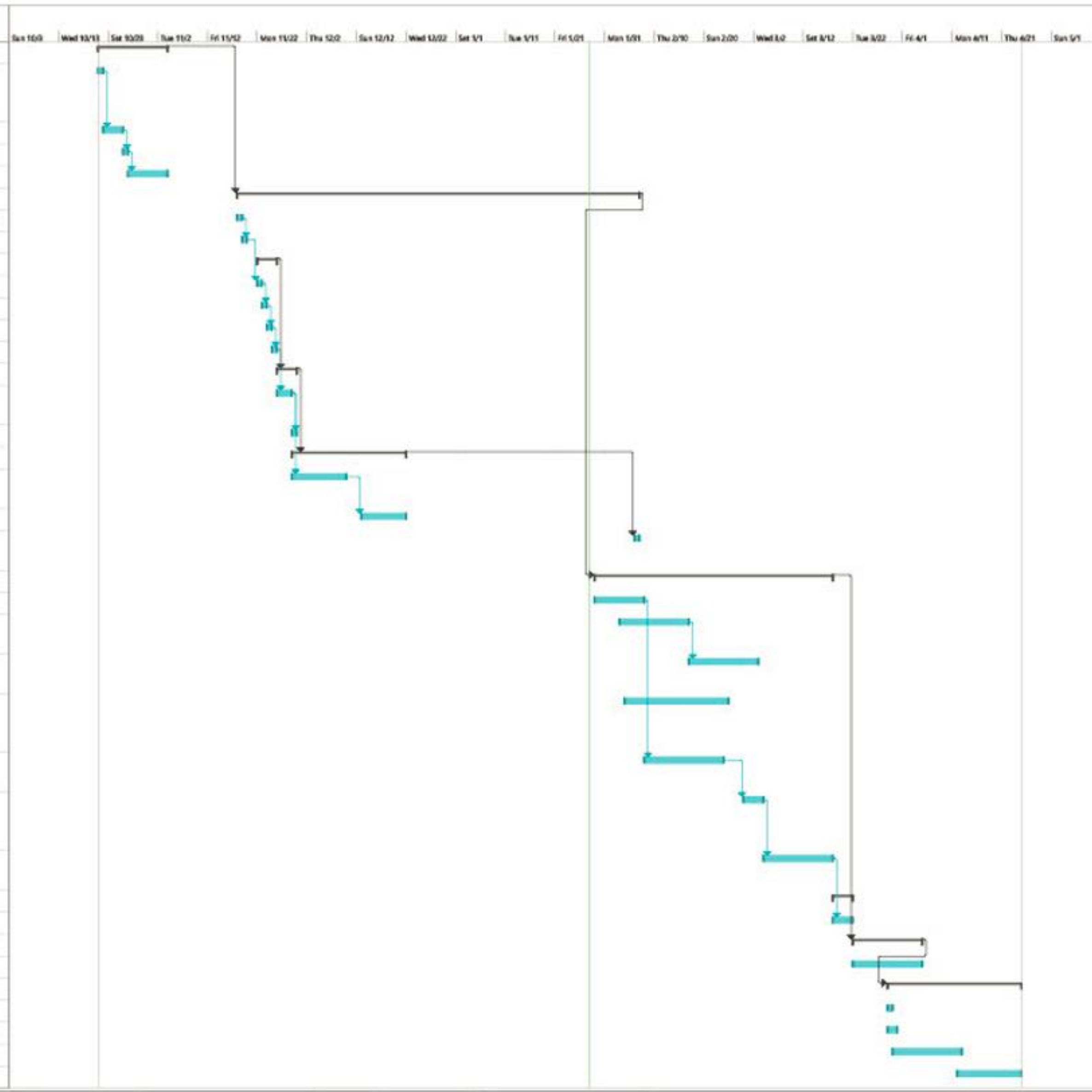
Appendix A

Figures A1 (Gantt Chart) and A2(RACI Chart) can be found below

ID		Heirarchal Number (Text1)	Task Name	Duration	Start	Finish	Predecessors
1		1	Project Research	10 days	Thu 10/21/2	Wed 11/3/21	
2		1.1	Get Project Details From Industry Sponsor	1 day	Thu 10/21/21	Thu 10/21/21	
3		1.2	Brainstorm	2 days	Fri 10/22/21	Mon 10/25/2	2
4		1.3	Contact Project Ad	1 day	Tue 10/26/2	Tue 10/26/21	3
5		1.4	Preliminary Report	6 days	Wed 10/27/2	Wed 11/3/21	4
6		2	Project Design	57 days?	Thu 11/18/2	Sun 2/6/22	1
7		2.1	Meeting with Advi	1 day	Thu 11/18/2	Thu 11/18/2	
8		2.2	Decide on a design	1 day?	Fri 11/19/21	Fri 11/19/21	7
9		2.3	Midterm Report	4 days	Mon 11/22/	Thu 11/25/2	
10		2.3.1	Block Diagrams	1 day	Mon 11/22/	Mon 11/22/2	8
11		2.3.2	Circuit Diagrams	1 day	Tue 11/23/2	Tue 11/23/2	10
12		2.3.3	3D Model	1 day	Wed 11/24/	Wed 11/24/2	11
13		2.3.4	Figures	1 day	Thu 11/25/2	Thu 11/25/2	12
14		2.4	Final Presentation	2 days	Fri 11/26/21	Mon 11/29/	9
15		2.4.1	Final Presentation Powerpoint	2 days	Fri 11/26/21	Sun 11/28/21	13
16		2.4.2	Presentation Da	1 day	Mon 11/29/	Mon 11/29/2	15
17		2.5	Final Report	17 days	Mon 11/29/	Tue 12/21/2	14
18		2.5.1	Printed Circuit Board Drafts	9 days	Mon 11/29/21	Thu 12/9/21	15
19		2.5.2	New Sections	7 days	Mon 12/13/	Tue 12/21/2	18
20		2.5.3	Homework 1: Final Schematics & BOM	1 day	Sun 2/6/22	Sun 2/6/22	17
21		3	Fabrication	34 days	Sat 1/29/22	Thu 3/17/22	6
22		3.1	Order Parts	7 days	Sat 1/29/22	Mon 2/7/22	
23		3.2	3D Print Outer Body of Spoon	10 days	Thu 2/3/22	Wed 2/16/22	
24		3.3	3D Print Inner Body of Spoon	10 days	Thu 2/17/22	Wed 3/2/22	23
25		3.4	Develop Graphical User Interface for Spoon	15 days	Fri 2/4/22	Thu 2/24/22	
26		3.5	Breadboard parts and Develop Program	12 days	Tue 2/8/22	Wed 2/23/22	22
27		3.6	Develop a Final Draft of Printed Circuit Board	4 days	Mon 2/28/22	Thu 3/3/22	26
28		3.7	Order Printed Circuit Board	10 days	Fri 3/4/22	Thu 3/17/22	27
29		4	Assembly	2 days	Fri 3/18/22	Mon 3/21/2	
30		4.1	Soldering	2 days	Fri 3/18/22	Mon 3/21/22	28
31		5	Testing	10 days	Tue 3/22/22	Mon 4/4/22	21
32		5.1	Debugging	10 days	Tue 3/22/22	Mon 4/4/22	
33		6	Documentation	19 days	Tue 3/29/22	Sun 4/24/22	31
34		6.1	User Manual	1 day	Tue 3/29/22	Tue 3/29/22	
35		6.2	Poster	2 days	Tue 3/29/22	Wed 3/30/2	
36		6.3	Final Report	10 days	Wed 3/30/2	Tue 4/12/22	
37		9.4	Final Presentation	10 days	Tue 4/12/22	Sun 4/24/22	



Project: Project1
Date: Fri 1/28/22

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Project1

ID	Heirarch Number (Text1) (Text1)	Task Name	Haris Waqar	Pratush Kc	Emmanuel Segura	Eliza Slocum	Ryan McPherson (Advisor)	Karyn L Karey (Industry Contact)	John Palma (Instructor)
1	**1**	**Project Research**	**R**	**R**	**R**	**R**	**C**	**I**	**I**
2	1.1	Get Project Details From Inc	R/A	R	R	R		C	I
3	1.2	Brainstorm	R	R/A	R	R			
4	1.3	Contact Project Advisor	R/A	R	R	R	C		
5	1.4	Preliminary Report	R	R/A	R	R	I		I
6	**2**	**Project Design**	**R**	**R**	**R**	**R**	**C**	**I**	**I**
7	2.1	Meeting with Advisor	R/A	R	R	R	C		
8	2.2	Decide on a design	R	R/A	R	R	C	I	I
9	**2.3**	**Midterm Report**	**R**	**R**	**R**	**R**	**I**		**I**
10	2.3.1	Block Diagrams	R	R	R/A	I	C		I
11	2.3.2	Circuit Diagrams	R	R	R/A	I	C		I
12	2.3.3	3D Model	R	R/A	R	I	C		I
13	2.3.4	Figures	R	R/A	R	I	C		I
14	**2.4**	**Final Presentation**	**R**	**R**	**R**	**R/A**	**I**		**I**
15	2.4.1	Final Presentation Power	R	R	R	R/A	I		I
16	2.4.2	Presentation Day	R	R	R	R/A	I		I
17	**2.5**	**Final Report**	**R**	**R**	**R**	**R**	**I**	**I**	**I**
18	2.5.1	Printed Circuit Board Dra	R	R	R/A	I	I		
19	2.5.2	New Sections	R	R	R	R/A	I		I
20	2.5.3	Homework 1: Final Schemat	R	R/A	R	R	I		I
21	**3**	**Fabrication**	**R**	**R**	**R**	**R**	**C**		**R**
22	3.1	Order Parts	R/A	R	R	R	C		I
23	3.2	3D Print Outer Body of Spoo	R	R/A	R	R	I		I
24	3.3	3D Print Inner Body of Spoo	R	R/A	R	R	I		I
25	3.4	Develop Graphical User Inte	I	R/A	I	I	I		I
26	3.5	Breadboard parts and Devel	R/A	I	R	I	I		I
27	3.6	Develop a Final Draft of Prir	R	I	R/A	I	I		I
28	3.7	Order Printed Circuit Board	I	I	R/A	I	I		I
29	**4**	**Assembly**	**R/A**	**I**	**R**	**I**	**I**		**I**
30	4.1	Soldering	R/A	I	R	I	I		I
31	**5**	**Testing**	**R/A**	**R**	**R**	**R**	**I**		**I**
32	5.1	Debugging	R/A	R	R	R	I		I
33	**6**	**Documentation**	**R**	**R**	**R**	**R/A**	**I**	**I**	**I**
34	6.1	User Manual	R	R	R	R/A	I	I	I
35	6.2	Poster	R	R	R	R/A	I	I	I
36	6.3	Final Report	R	R	R	R/A	I	I	I
37	6.4	Final Presentation	R	R	R	R/A	I	I	I

Appendix B

Appendix: User's Manual / Project Handoff

User Guide Manual

University of Massachusetts Lowell

NEEDs Programmable Spoon

Capstone II – Spring 2022

Table of Contents

Contents

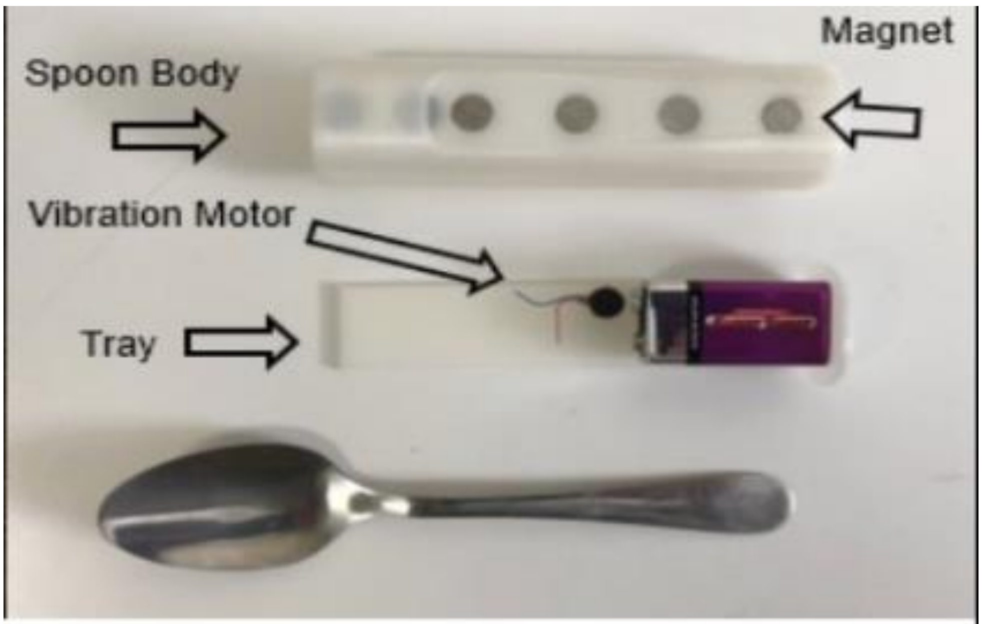
User Precautions

- Before cleaning the spoon system, please turn off the power by unplugging it from the battery
- Use a dust brush when clearing off dust from the circuit board on the tray
- Make sure the plastic capsule is wiped with a sanitized wipe instead of washed in a dishwasher
- Do not let the circuit tray get wet or damp
- If any of the parts get damaged, please reach out to the ECE department at UML for any replacement parts

Parts Description

The spoon interface of the whole spoon capsule system is water resistant but cannot be washed under a sink but rather should be wiped with a damp towel or wet wipe. The system can be turned on by a toggle switch if the tray is pulled out of the spoon body capsule. The tray is installed in by sliding into the capsule and is held in the capsule through magnets. The system can be attached to the spoon using magnets as well on a stainless steal spoon.

Control Interface



The spoon system keeps track of the number of bites and is able to inform the user accordingly of when to stop taking a bite and taking a sip of water. The spoon system can be operated by pulling out the tray from the plastic capsule. The switch is toggled to the "On" position, the spoon system should glow green and should be in the ready position. Once the spoon is lifted it should glow red and the spoon should vibrate as well. After three lifts of the spoon, the spoon should glow blue. Once the spoon is back to the green glow, it should be reset to taking another three bites before it glows blue. There is a button as well which allows to change the number of bites before the spoon glows blue or in the real case to take a sip of water.

Operation Instructions

Operating the spoon system takes some simple few steps:

1.) First step is to pull out the tray from the spoon capsule.
2.) Second step is to flip the toggle switch to the “on” position.
3.) Third step is to just insert the tray back in making sure the battery is plugged in.
4.) The tray should be placed in correctly so that the magnets connect properly.
5.) Make sure that the spoon system is glowing green at the start.
6.) The button inside the tray can be used to change the number of bites before a sip of water
    a. The spoon system turns on with the mode set to 3 bites but if the button is pressed than the number of bites can be changed to 5 bites.

Cleaning and Maintenance

Why cleaning and maintenance is important?

Cleaning and maintenance of the spoon system is very important since the circuit can collect dust causing to short circuit at inputs and outputs. Frequent cleaning will allow the system to work properly for longer.

How to clean and maintain the spoon system?

- Dry dusting cloth to remove the dust and dirt collected over time
- Avoid contact with severe heat and take care when storing the spoon system
- Make sure when the spoon system is in storage, the battery is disconnected
- Wet wipes can be used to clean the outer plastic capsule

Troubleshooting

If the spoon does not glow green once turned on, make sure battery is connected properly. Also make sure to see that the battery is charged as well and try a new battery is possible. Also make sure the toggle switch has not gotten lose every time and is toggled to the “on” position. If the spoon is still not working, then please reach out to the ECE department through email which is displayed below in the contact section.

Safety Note

- Do not operate without supervision
- If system is not in use, please disconnect the battery
- Disinfect and clean the system after every use

Environmental Claims

For disposal, please reach out to the ECE department or Dr. John Palma to determine the best route to avoid environmental harm.

Contact Us

If any problems arise when operating the spoon system or any questions, feel free to contact us at the email stated below:

Dr. John Palma – John_Palm@uml.edu

Appendix C

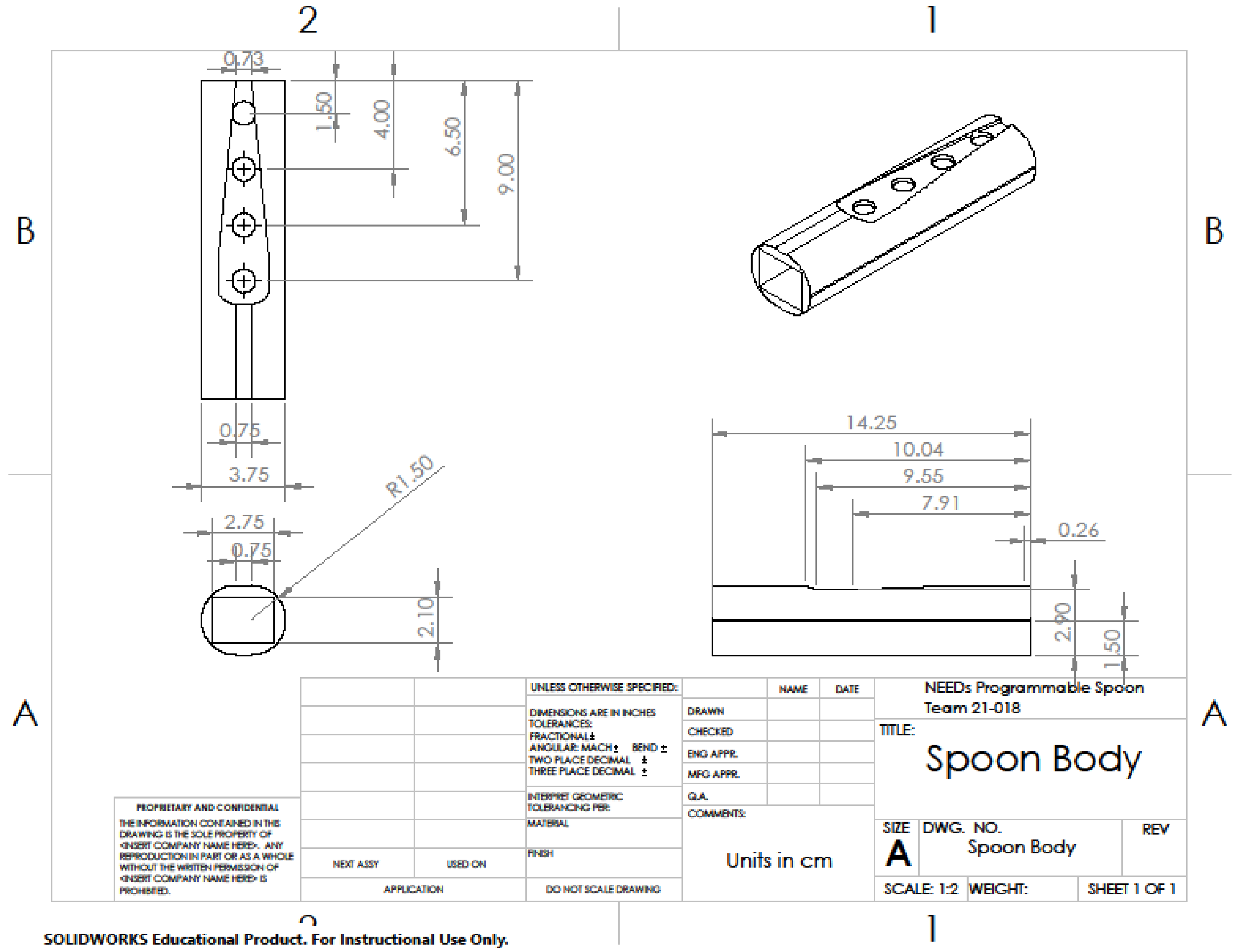


Figure C1: This is the body of the spoon which will be washable

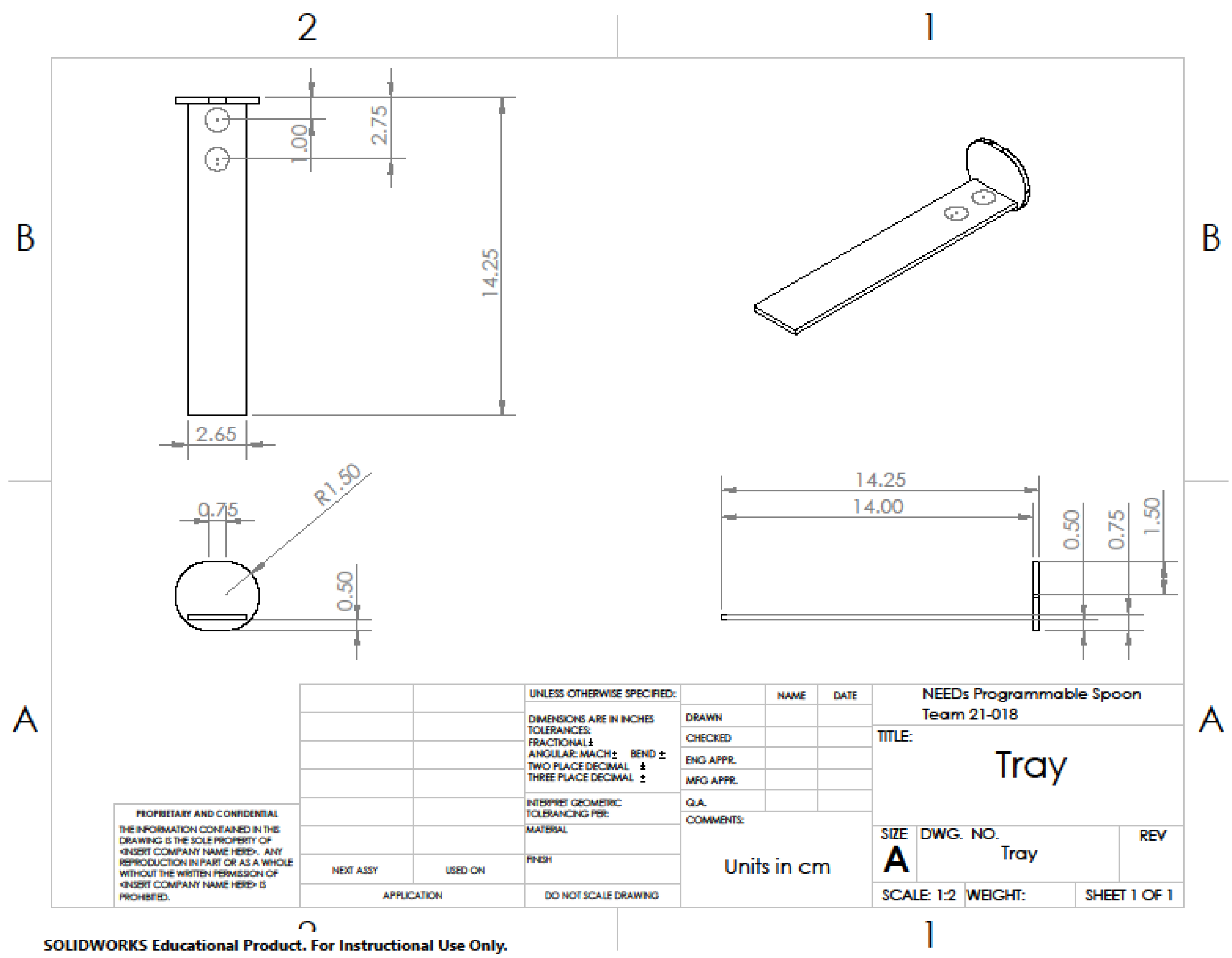
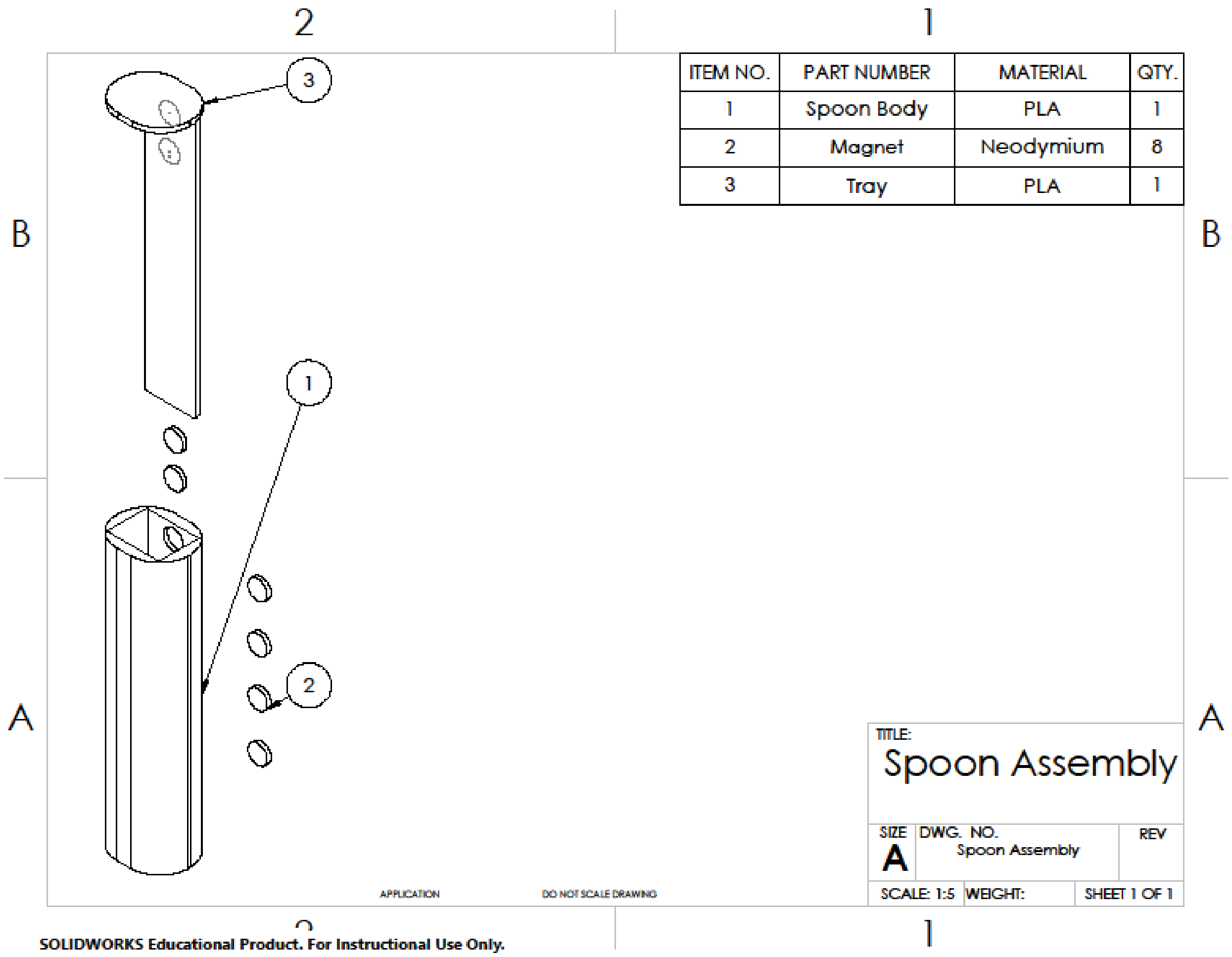


Figure C2: This is the tray of the spoon which will hold all the internal components (vibration motor, battery, battery snap and printed circuit board).



ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	Spoon Body	PLA	1
2	Magnet	Neodymium	8
3	Tray	PLA	1

Figure C3: Drawing of Assembly

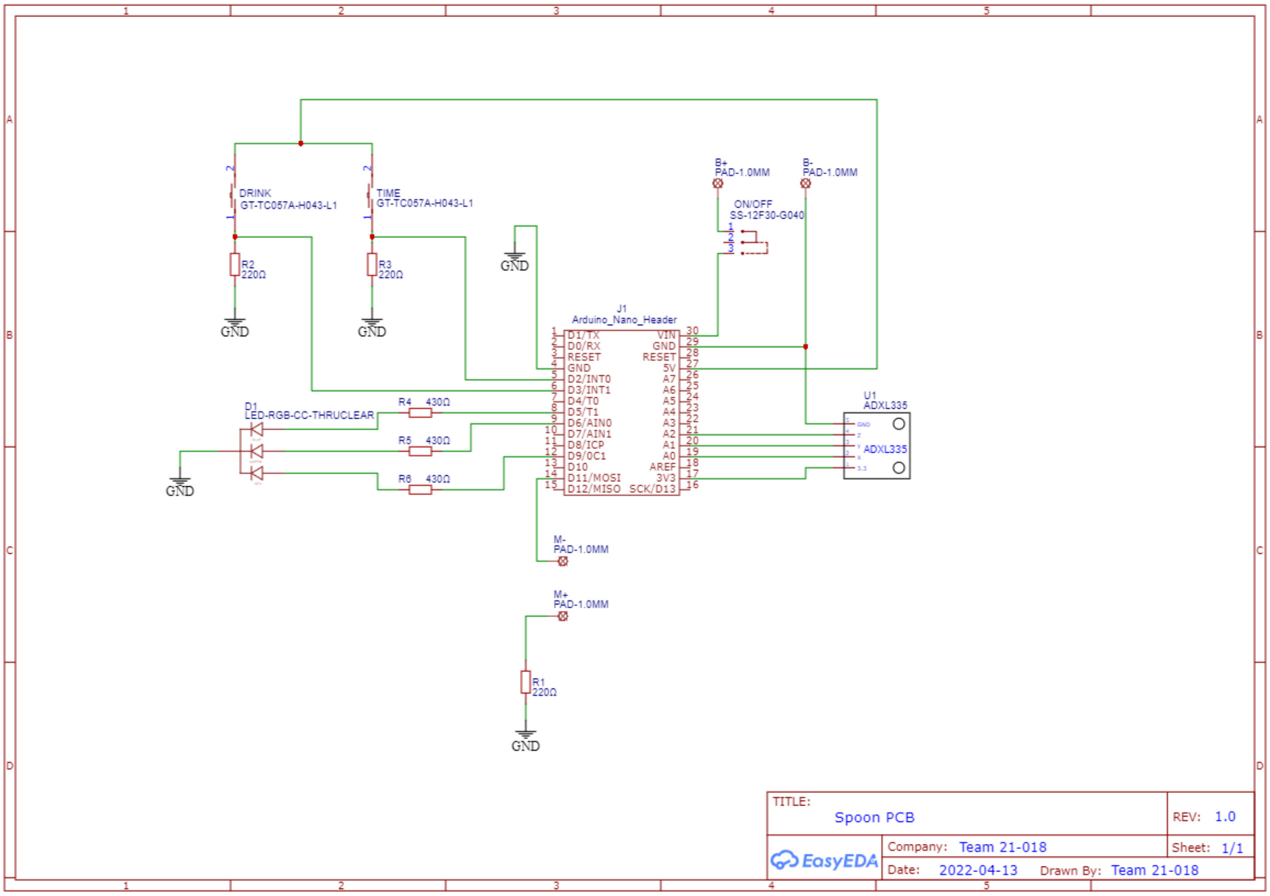
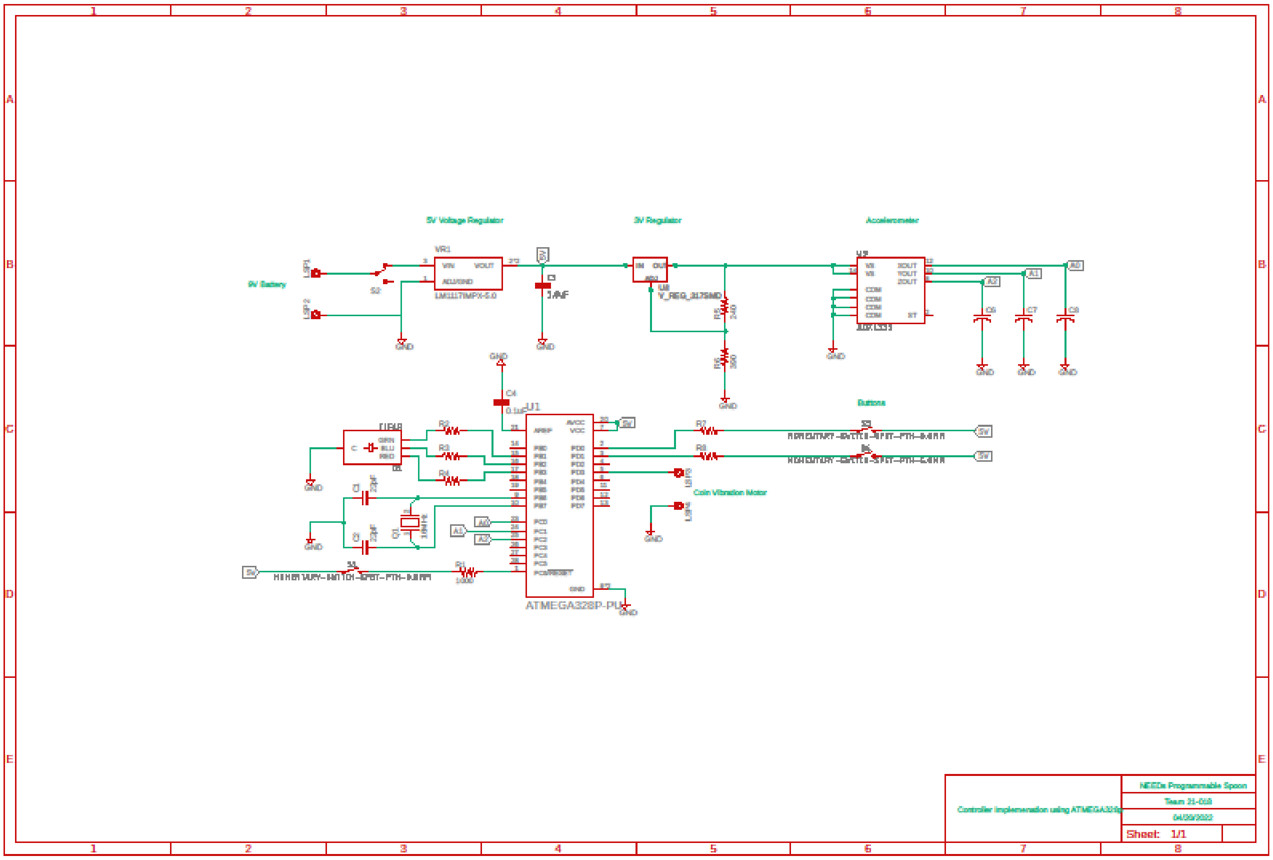


Figure C4: Schematic of the circuit implemented on the PCB

ID	Name	Designator	Quantity	Supplier	Supplier Part	Price
1	LED-RGB-CC-THRUCLEAR	D1	1			
2	Arduino_Nano_Header	J1	1			
3	SS-12F30-G040	ON/OFF	1	LCSC	C2848911	0.059
4	220Ω	R1,R2,R3	3	LCSC	C352243	0.005
5	430Ω	R4,R5,R6	3	LCSC	C352418	0.003
6	ADXL335	U1	1			
7	PAD-1.0MM	B+,B-,M+,M-	4			
8	GT-TC057A-H043-L1	DRINK,TIME	2	LCSC	C843677	0.049

Figure C5: Bill of Materials for Figure C4



5/8/2022 10:31 AM f=0.72 C:\Users\pratu\Desktop\NEEDs Programmable Spoon Team 21-018 Drawing Set\Future Direction\ATMEGA328p Implemented Schematic\PCB Desig

Figure C6: Future Direction SMT Circuit using ATMEGA328p

Qty	Value	Device	Package	Parts	Description
3	1.0uF	C-USC0805	C0805	C6, C7, C8	CAPACITOR, American symbol
3	220Ω	R-US_R0805	R0805	R2, R3, R4	RESISTOR, American symbol
1	DPDT	SWITCH-SPDTPTH2	SWITCH-DPDT	S2	SPDT Switch
1	0.1uF	.1UF-CER	0402-CAP	C4	.1uF ceramic SMT
1	1.0uF	1.0UF-0402T-16V-10%	0402-TIGHT	C3	1μF ceramic capacitors
1	1000Ω	R-US_R0603	R0603	R1	RESISTOR, American symbol
1	16MHz	XTAL	Q	Q1	CRYSTAL
2	22pF	C2,5-3	C2.5-3	C1, C2	CAPACITOR
1	240Ω	R-US_R0805	R0805	R5	RESISTOR, American symbol
1	390Ω	R-US_R0805	R0805	R6	RESISTOR, American symbol
1	ADXL335	ADXL335	LFCSP-16-4X4	U3	Analog Devices ADXL335 3-Axis Analog Accelerometer
1	ATMEGA328P-PU	ATMEGA328P-PU	DIP794W46P254L2967H457Q28B	U1	ATmega Series 20 MHz 32 KB Flash 2 KB SRAM 8-Bit Microcontroller - DIP-28 Check availability
1	CLEAR	LED-RGB-CCCLEAR	LED-RGB-THRU	D1	LED-RGB Common Cathode
1	LM1117IMPX-5.0	LM1117IMPX-5.0	SOT230P700X180-4N	VR1	FIXED POSITIVE LDO REGULATOR Check availability
4	LSP10	LSP10	LSP10	LSP1, LSP2, LSP3, LSP4	SOLDER PAD drill 1.0 mm, distributor Buerklin, 12H555
1	MOMENTARY-SWITCH-SPST-PTH-6.0MM	MOMENTARY-SWITCH-SPST-PTH-6.0MM	TACTILE_SWITCH_PTH_6.0MM	S1	Momentary Switch (Pushbutton) - SPST
2	V_REG_317SMD	V_REG_317SMD	SOT223	U2, U4	Voltage Regulator

Figure 7: Future Direction SMT Circuit Bill of Materials

Appendix D

Digital Output Voltage: 5V

Forward Voltage = 3V

Current limit = 20mA

Desired Current should be around 5mA (For less brightness 5mA)

R = V / I

R = (5 – 3) / 5mA = 200 Ω

Figure D1: Resistor Calculation for LED

Vibration Motor and Button Calculations

Voltage: 3V Set using PWM pin

Desired Current < 40 mA

Resistor Chosen = 220 ohms

I = 3V / 220 Ω = 13.63 mA

220 Ω effectively brings the current down below the 40mA I/O limit

Figure D2: Vibration Motor and Button Calculation

Appendix E

Code Design:

```
  if(numbBites>=totalBits)
  {
    Serial.println("take sip of water");
    digitalWrite(red_pin, LOW);
    //digitalWrite(blue_pin,HIGH);
    analogWrite(blue_pin, 127);
  }

  else
  {
    //digitalWrite(red_pin, HIGH);
    analogWrite(red_pin, 127);
  }

}
else if (roll > 210 && roll < 307 && flag_spon == false)
{
  Serial.println("Spoon in hand");
  digitalWrite(red_pin, LOW);
  digitalWrite(blue_pin, LOW);
  digitalWrite(green_pin, LOW);
  flag_spon = true;
  flag_bite = false;
  prevSpoon = millis();
  prevBite=millis();

}
if (flag_spon == true)
{
  if (millis() - prevSpoon > 1500)
  {
    getAccel();
    if (roll > 210 && roll < 307 && flag_spon == true)
    {
```

Figure 1: Initializing variables

As seen in the image above, the first structure of the code consisted of just initializing all the components that needed to be controlled by the Arduino. The first lines initialize the accelerometer for the different axis inputs which are x, y, and z. The rest of the variables that were defined are the RGB LED pins and the vibration motor which was connected to digital pins on the Arduino. The rest of the lines of code in the image above are variables that were used to allow the change in the different modes for the number of bites and the different flags that allowed the LED to turn blue to alarm the user to take a sip of water. The numbbites variable allowed to count the number of bites after each raise of the spoon and the total bites variable allowed to keep the number of bites before taking a sip of water. The different Boolean variables labeled as flags were flags that would help to mark the spoon to glow a different color for a different state such as pause between bites or pause to take sip of water.

```
void getAccel()
{
  int x_adc_value, y_adc_value, z_adc_value;
  double x_g_value, y_g_value, z_g_value;

  x_adc_value = analogRead(x_out); /* Digital value of voltage on x_out pin */
  y_adc_value = analogRead(y_out); /* Digital value of voltage on y_out pin */
  z_adc_value = analogRead(z_out); /* Digital value of voltage on z_out pin */

  x_g_value = ((((double)(x_adc_value * 5) / 1024) - 1.65) / 0.330); /* Acceleration in x-direction in g units */
  y_g_value = ((((double)(y_adc_value * 5) / 1024) - 1.65) / 0.330); /* Acceleration in y-direction in g units */
  z_g_value = ((((double)(z_adc_value * 5) / 1024) - 1.80) / 0.330); /* Acceleration in z-direction in g units */

  roll = (((atan2(y_g_value, z_g_value) * 180) / 3.14) + 180);  /* Formula for roll */
  pitch = (((atan2(z_g_value, x_g_value) * 180) / 3.14) + 180); /* Formula for pitch */
  // yaw = ( ( (atan2(x_g_value,y_g_value) * 180) / 3.14 ) + 180 ); /* Formula for yaw */
  /* Not possible to measure yaw using accelerometer. Gyroscope must be used if yaw is also required */
  delay(1);
}
```

Figure 2: Accelerometer values

This part of the code was a function created to get the acceleration values from the accelerometer. This allowed us to use the values to see if there was any movement in the spoon and to define the values of when the spoon is in the ready position meaning when it is flat on the table. Also, it allowed us to define the parameters for when the spoon is lifted to take a bit and can also be recorded as movement.

```
void loop()
{
  getAccel();

  if(digitalRead(push_pin)==LOW)
  {
    if(totalBits==3)
    {
      totalBits=5;
    }
    else
    {
      totalBits=3;
    }
  }

  if (roll > 170 && roll < 209 && flag_bite == true)
  {
    Serial.println("Spoon on Table First Bite");
    digitalWrite(red_pin, LOW);
    digitalWrite(blue_pin, LOW);
    //digitalWrite(green_pin, HIGH);
    analogWrite(green_pin, 127);
    digitalWrite(vib_pin, LOW);
    flag_spon = false;
  }
  else if (roll > 170 && roll < 209 && flag_bite == false)
  {
    Serial.println("Spoon on Table");

    digitalWrite(blue_pin, LOW);
    digitalWrite(green_pin, LOW);
    digitalWrite(vib_pin, LOW);
    flag_spon = false;

    if(numbBites>=totalBits)
```

```
    if(numbBites>=totalBits)
    {
      Serial.println("take sip of water");
      digitalWrite(red_pin, LOW);
      //digitalWrite(blue_pin,HIGH);
      analogWrite(blue_pin, 127);
    }

    else
    {
      //digitalWrite(red_pin, HIGH);
      analogWrite(red_pin, 127);
    }


  }

  else if (roll > 210 && roll < 307 && flag_spon == false)
  {
    Serial.println("Spoon in hand");
    digitalWrite(red_pin, LOW);
    digitalWrite(blue_pin, LOW);
    digitalWrite(green_pin, LOW);
    flag_spon = true;
    flag_bite = false;
    prevSpoon = millis();
    prevBite=millis();

  }

  if (flag_spon == true)
  {
    if (millis() - prevSpoon > 1500)
    {
      getAccel();
      if (roll > 210 && roll < 307 && flag_spon == true)
      {
```

```
        //digitalWrite(red_pin, HIGH);
        analogWrite(red_pin, 127);
        digitalWrite(blue_pin, LOW);
        digitalWrite(green_pin, LOW);
        //digitalWrite(vib_pin, HIGH);
        analogWrite(vib_pin, 127);
        flag_spon = false;

        while (roll > 210)
        {
          getAccel();
          delay(200);
        }

        prevBite=millis();

        if(numbBites==totalBits)
        {
          flag_sip=false;
          numbBites=0;
        }

        numbBites++;
      }
    }
  }


  if(millis()-prevBite>biteInterval)
  {
    flag_bite=true;
    prevBite=millis();
  }

  delay(10);
}
```

Figure 3: Main Loop Code allowing the different states for the spoon

For the main part of the code, the loop method was established. The Arduino recognizes the spoon is on the table in the ready state for the first bite. At that point, the green LED is ready to be lifted for the first bite. Once the bite takes place, the vibration motor is turned on as well and reminds the user to put the spoon down and chew. The spoon at the start when powered on is programmed to let the user have three bites before the reminder to put the spoon down and take a sip of water. If the button is pressed, it will change the mode from three bites to five bites. This part of the code is programmed to let the user take the set number of bites before asking the user to rest the spoon and take a sip of water. The spoon will glow green first and then once the spoon is lifted it will glow red, and once placed back down it will stay glowing red for that set amount of time. After it will glow back to green and then after the set number of bites, the spoon will glow blue once the time interval is complete for the red glow.