Primate Portal

BME 200/300

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Abstract

The goal of the Primate Portal project is to create a modular in-cage positive reinforcement device to train nonhuman primates (NHPs). Training is currently overseen by researchers and takes many hours of in-person time for the researchers to collect data and ensure the trials are done correctly. The primary competing design, the Thomas Primate In Cage Training System, is currently the leader in automating this process, but it comes at a cost of over $100,000. The Primate Portal allows this training to be automated in the primate home environment, and it lets the researchers reallocate their time to other areas of research at a much lower cost. This is done through an in-cage mounted touchscreen that provides trials and supplies the NHP with juice when a trial is completed correctly. If the NHP provides an incorrect input, no reward is dispensed, and a new trial begins. The casing was stress tested in SolidWorks, the pump was tested for volume output per time run, and volume output accuracy. Results were satisfactory with a case factor of safety greater than 2, a dispense rate of 0.3 seconds per milliliter of liquid, and 1.8 percent error per 1 ml of liquid dispensed. Overall, this data shows that Primate Portal is not only safe for NHPs but also reliable to dispense preferred amounts of liquid.

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Introduction

Motivation and Global Impact

A better understanding of the advanced mind of nonhuman primates (NHPs) has the potential to advance the field of neuroscience and make an impact on the world of biomedical research. Traditional research methods rely on human interaction with the NHPs during the training; however, a device that limits human-NHP interaction and is designed to be used exclusively by the NHP would improve the quality of research by reducing NHP stress. Positive reinforcement training leads to meaningful results by reducing the stress and increasing the motivation of NHPs [1]. For example, an NHP might be consistently rewarded with juice or an edible prize for successfully completing a task. The Primate Portal is a device designed to utilize the principles of positive reinforcement learning, rewarding the NHP with juice for successful inputs. Our system will contribute to ethical research practices using the 3 Rs: replacement, reduction, and refinement [2]. The Primate Portal will advance scientific data collection while maintaining the wellbeing of NHPs.

Existing Designs

While several in-cage primate training systems have been developed in the scientific literature, the only commercially available design is Thomas RECORDING's InCage Training System (ICTS) [3]. The Thomas ICTS is a cage-mounted device that contains a shock- and waterproof touchscreen. It supports connections to external devices to upload data as well as operate eye trackers or other cameras. However, the device has several drawbacks, including limited software extensibility and a prohibitively high cost of roughly $100,000. Because of the limited number of commercially available designs, an inexpensive and extensible design is highly desired in the neuroscience research community.

Figure 1: Thomas Primate In Cage Training System

Problem Statement

Research with NHPs can be difficult for researchers and NHPs and lead to inadequate results if done incorrectly. Using a device that requires the researcher to remove the NHP from the cage can cause the NHP stress, potentially lowering the quality of the data collected, and requires the researcher to be present for the duration of the task, which uses up the researcher's time. There is a desire in the neuroscience research community for a safe, modular, and automated NHP training system that uses positive reinforcement to deliver rewards for completing cognitive tasks to research further about the complex cognitive systems of NHPs. The system must be easy to use, inexpensive, easily detachable for use with different cage units, compatible with the NHPs' home environment, and flexible for modifications and improvements in the future.

Background

Overview

Researchers working in the field of cognitive neuroscience have the goal of explaining "how the activity of the brain creates the mind" [1]. Researchers have been greatly aided in their pursuit of this goal through the use of nonhuman primates (NHPs). NHPs play such an important role in neuroscience research because they have a brain structure similar to that of humans [2] and can be trained through positive reinforcement to form associations between stimuli and carry out complex behavioral tasks in experiments [3]. Dr. David J. Herzfeld, assistant professor in the UW–Madison Department of Neuroscience, runs a research lab studying "how neural circuits in the brain control complex behaviors like moving your arms and making decisions" [4]. The main species of NHP used by Prof. Herzfeld's lab is the rhesus macaque, *Macaca mulatta.* The rhesus macaque is native to south, central, and southeast Asia and has a lifespan of 40 years. The rhesus macaque also has a brain structure similar to that of humans [5], sharing a 93% homology with humans [6].

In the Herzfeld lab, NHPs are trained to complete complex tasks like the match-to-sample task, which evaluates working memory [7]. Currently, the NHPs must be placed in restraint devices while they undergo positive reinforcement training, which places stress on the NHPs as they are taken out of the environment of their home cage. Accordingly, the *Guide for the Care and Use of Laboratory Animals*, published by the National Research Council, recommends that "Alternatives to physical restraint should be considered" [8]. Thus, there is a demand in the Herzfeld lab, and the neuroscience research community more broadly, for a device that can be attached to an NHP's home cage to allow behavioral task training, including reward delivery, without removing the NHP from the cage. This would improve the psychological wellbeing of the NHP and save researchers hours of time spent supervising the training.

Standards and Regulations

Due to their lifespan and ability to learn, rhesus macaques are commonly used to research complex cognitive processes. This implies that relevant standards and regulations regarding animal research must be followed. When working with any NHP, it is of utmost importance that safety is considered throughout every aspect of the project. The following standards, regulations, and codes outline this.

First, the *Code of Federal Regulations* (CFR), Title 9, chapter 1, subchapter A, part 3, subpart D, focusing on the specifications for the humane handling, care, treatment, and transportation of nonhuman primates, must be followed [9]. This states that the device must be safe, having no sharp edges, no free cabling, no toxic materials, or other hazards. This aligns with what the Institutional Animal Care and Use Committee (IACUC) requires during NHP research inspections [10]. IEC 60601 is an international standard regarding electrical safety for devices that are designed to be used in a lab setting. Compliance with this standard is crucial to ensure the safety of the NHPs [11]. Another standard that must be followed is the Animal Welfare Act, specifically title 9 section 3.89 [12], which states that the device must be secured and that enough liquid must be given to the NHPs. As outlined in the requirements, all nonhuman primates must be given water every 12–24 hours. 9 CFR §3.75 *Housing facilities, general* also applies: in particular, the device must be "free of excessive rust" and "jagged edges or sharp points that might injure the animals" [13]. The device should also be able to be cleaned regularly. Lastly, the *Guide for the Care and Use of Laboratory Animals* should be followed throughout the design process of the Primate Portal device to ensure an ethical design that is safe for NHP use [8].

Background Research

As a basis for the Primate Portal project, there are a couple of fields which need to be understood and researched to successfully design the device. The main topics researched consist of how the electronics will work, what types of applications the primates interact with as training, what materials should be used for the mechanical aspects, what liquid reward system should be used, and, lastly, research regarding the primates themselves (Overview section in background). Looking at the circuitry and electronic system, the team researched multiple different components, which will be discussed and utilized later in the Design section of this report. Some important details of the circuitry must be noted. When using any motor or pump, back emf (electromotive force) must be considered—in this case, with the peristaltic pump. As the current in the solenoid of a motor changes rapidly (e.g. when turning the motor off), the magnetic field in turn will change rapidly, creating a current in the opposing direction [14]. This opposing current is called back emf and can be very harmful to the system. To prevent back emf from causing harm to any electronic system, the flow of current must be controlled, meaning it must only be able to travel in one direction. This can be fixed using a one-directional diode to force current only in one direction. Otherwise, any components that interact directly with the pump must be able to withstand the back emf created by the pump. More research was done to understand the basics of a Raspberry Pi as well as how it can be used to control hardware. A Raspberry Pi is a small, cheap computer generally used to control small systems, such as the Primate Portal. The Raspberry Pi has many applications, but in the context of the Primate Portal, the focus is on how the GPIO (General Purpose Input/Ouput) pins are laid out and how they can be used to input and output signals [15]. Shown below in Figure 2 is the GPIO layout of the Raspberry Pi 3B+ [16].

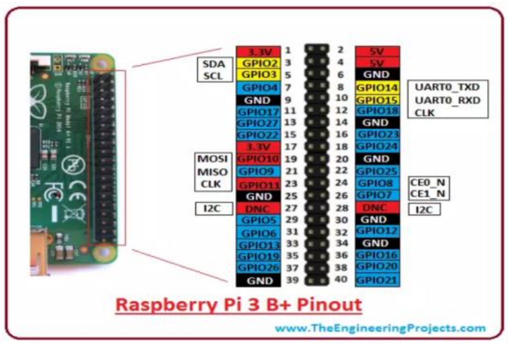


Figure 2: Layout of pins for the Raspberry Pi 3B+ GPIO [16].

Another important consideration of this project is the type of material that will be used as the general enclosure containing the electronics. A few materials were researched, with the most notable being aluminum and steel. Generally, steel is a stronger and more durable material, but it is much harder to use during fabrication than aluminum. Figure 3 below shows some general characteristics of both steel and aluminum and how they compare to each other [17].

Property	Steel	Aluminum
Cost	Low	Moderate
Ultimate Tensile Strength	400 – 2000+ MPa	75-500 MPa
Density	0.28 lb/in3	0.1 lb/in3
Corrosion Resistance	Low (carbon steel) to moderate (stainless steel)	High
Malleability	Low	High
Machinability	Moderate	High
Weldability	High	Low
Castability	Low	High
Application Examples	Construction, infrastructure, automobiles, appliances, tools, fasteners	Aircraft, electrical wiring, electronics, utensils, foil

Figure 3: Comparison table of both steel and aluminum [17].

Summary of Design Specifications

The Primate Portal device is to be used daily, being loaded and unloaded in the morning and night respectively. Researchers should require minimal training to be able to attach and detach the device from the NHP's cage. The project itself has a budget of $5,000. The device must be "free of excessive rust" and "jagged edges or sharp points that might injure the animals" for compliance with the *Code of Federal Regulations* [13]. The system must be shock- and waterproof so as not to injure the NHP. The software should be easily extensible, allowing researchers to program new behavioral tasks. The design specifications are covered in greater detail in the Product Design Specification (PDS) in Section A of the Appendix.

Integrated Circuitry Box Design

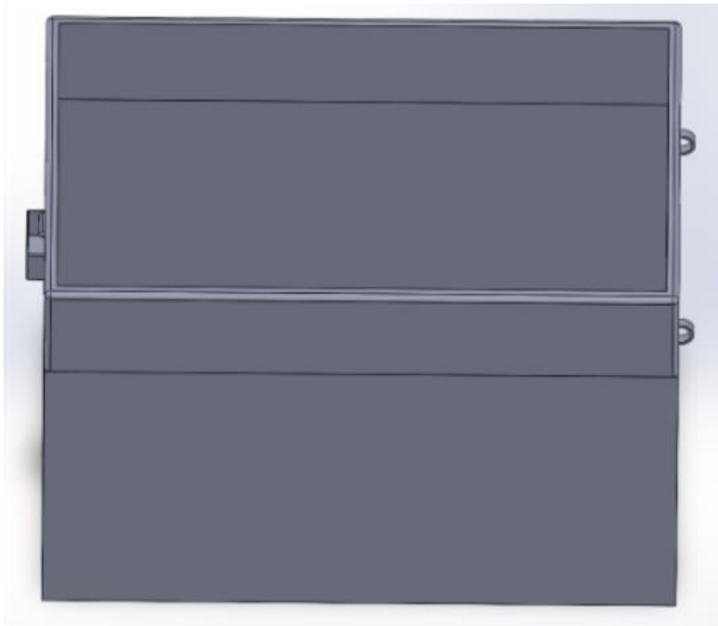


Figure 4: CAD model of integrated circuitry box design

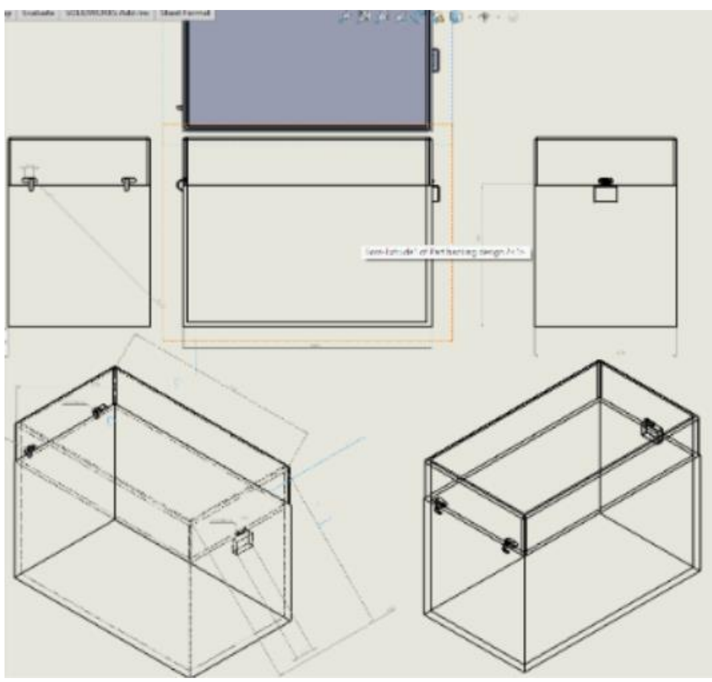


Figure 5: CAD drawing of integrated circuitry box design

The integrated circuitry box design is very compact. It combines the screen casing with the circuitry box. It does not have a dedicated pump housing, so the nozzle could be moved with research needs. The design has a detachable hinge on the right, and a latch on the left. This will attach around the cage with the display on the inside and the circuit box on the outside.

Lateral Nozzle Design

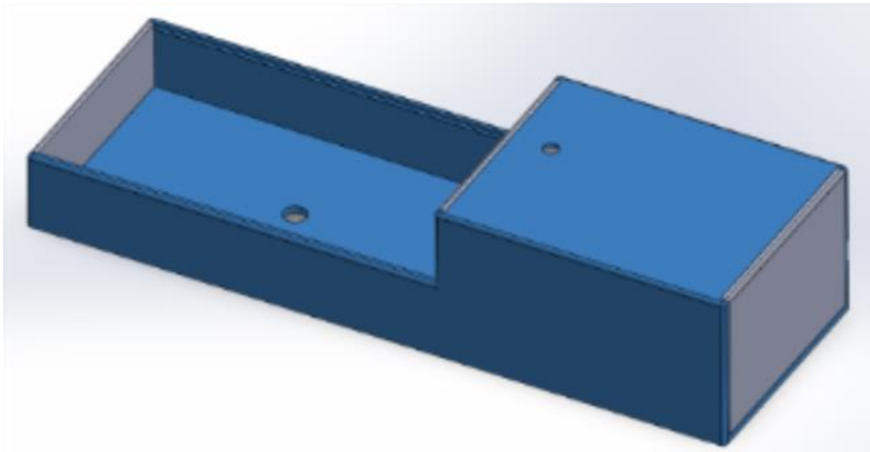


Figure 6: CAD model of lateral nozzle design

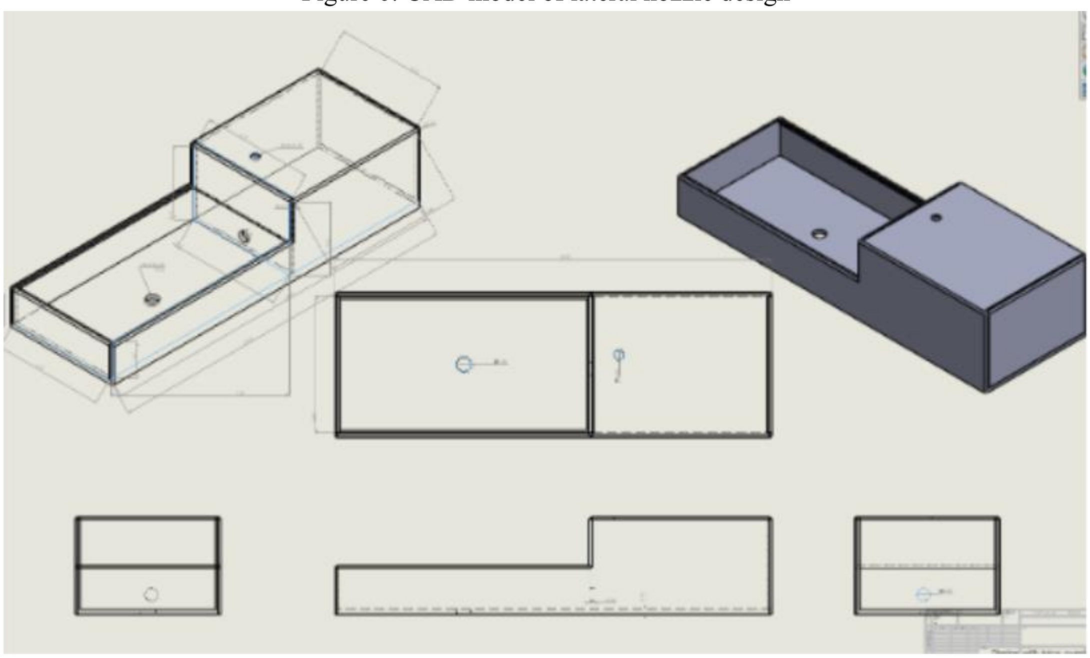


Figure 7: CAD drawing of lateral nozzle design

The lateral nozzle design has a hole for the nozzle to the right of the compartment for the touchscreen. The touchscreen compartment has a hole for wiring. Per our client, the NHP will likely have its mouth at the nozzle for most of the duration of the experiment, so it will be performing the experiment on the touchscreen while looking to the left.

Longitudinal Nozzle Design

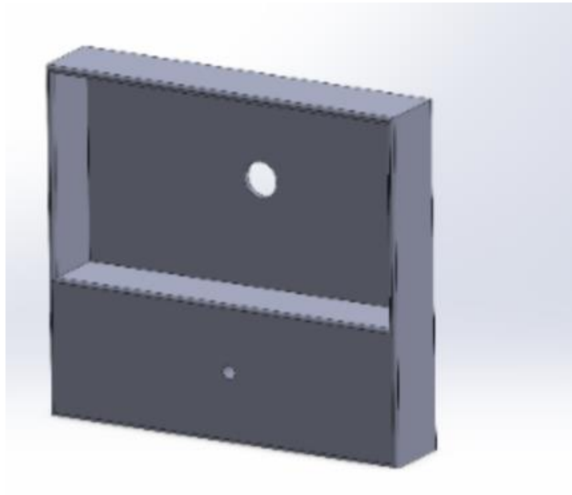


Figure 8: CAD drawing of longitudinal nozzle design

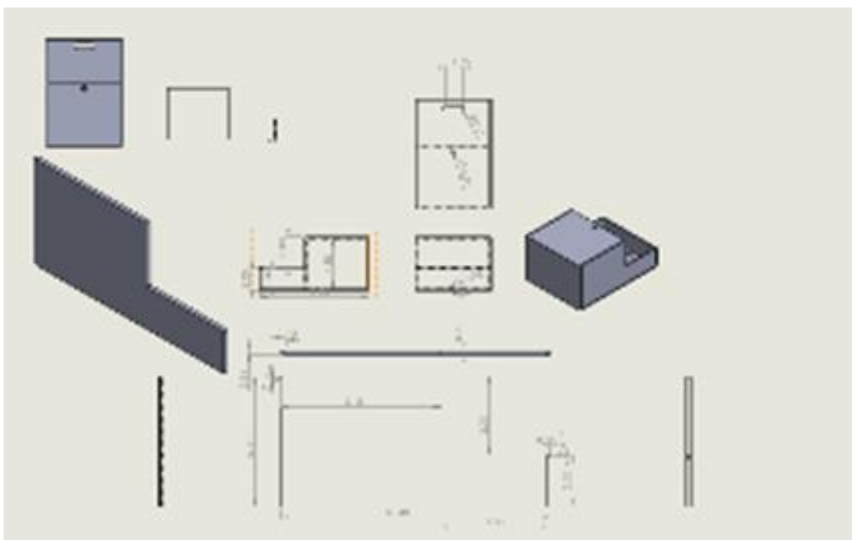
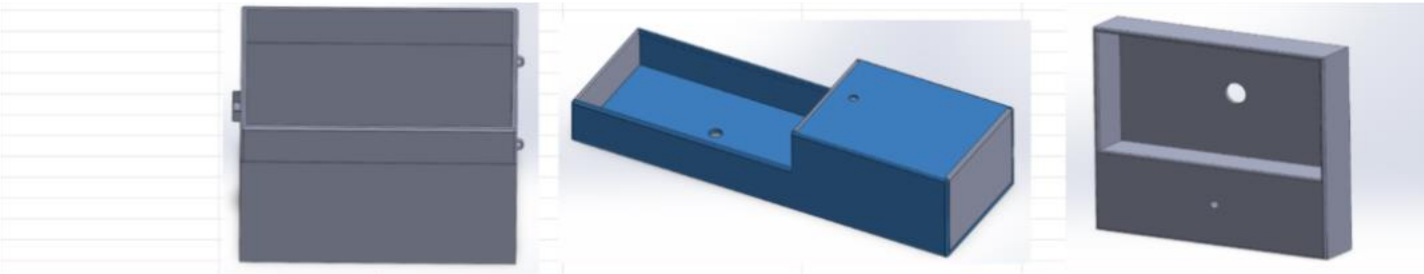


Figure 9: CAD drawing of longitudinal nozzle design

The longitudinal nozzle design has a hold for the nozzle under the compartment for the touchscreen. The touchscreen compartment has a hole for wiring. Per our client, the NHP will likely have its mouth at the nozzle for most of the duration of the experiment, so it will be performing the experiment on the touchscreen while looking up.

Design Matrix



Criteria (weight)	Design 1 Raw Score	Design 1 Weighted Score	Design 2 Raw Score	Design 2 Weighted Score	Design 3 Raw Score	Design 3 Weighted Score
Safety (35)	3/5	21/35	4/5	28/35	5/5	35/35
Ease of Use (25)	4/5	20/25	4/5	20/25	5/5	25/25
Cost (5)	5/5	5/5	4/5	4/5	4/5	4/5
Ease of Fabrication (15)	5/5	15/15	4/5	12/15	4/5	12/15
Ease of Assembly/Disassembly (20)	3/5	12/20	4/5	16/20	4/5	16/20
	Sum	73/100	Sum	80/100	Sum	92/100

Figure 10: Design matrix

Design Criteria

Safety (35) – The safety of the device is the most important part of the design. The device will be used by intelligent nonhuman primates (NHPs) during regular hours. The device should restrict access to dangerous areas such as those with wires to the NHPs to ensure they cannot be electrocuted. The device must comply with 9 C.F.R. § 3.75 (c) Surfaces which state that surfaces that NHPs touch must "be free of excessive rust" or "jagged edges or sharp points that might injure the animals".

Ease of NHP Use (25) – The device will be used by the NHPs daily to continue their training away from the researchers. The device must be easy for the NHPs to use to ensure that research can continue, and that NHPs learn how to effectively give data.

Cost (5) – Cost is not a major concern for us, as our client has expressed his agreement to fund our project up to the amount of $5,000.

Ease of Fabrication (15) – The device should be relatively easy to fabricate to allow the reproduction of the product by our client in the future. This means that it should require minimal machining, circuitry, and coding to recreate.

Ease of Disassembly and Reassembly (20) – The device should be easy for the user to disassemble and reassemble. The device should be easily taken off and put back on the cage during daily cleaning of the cage in a way that does not disturb the NHPs.

Design Scoring

Design 1:

Safety: 3/5, Relatively safe, but NHPs are closer to wires, and they may be easier to access, which could be dangerous. The seams between the touchscreen casing and the circuitry box casing may also be large enough to allow urine inside, possibly resulting in electrocution of the NHPs.

Ease of Use: 4/5, Very easy to use for the NHPs. The freely movable nozzle means that the researcher can set it anywhere that they see fit, possibly resulting in new ways to test the device. However, this nozzle would be harder to secure to the cage, so if the NHPs pulled it off of the wall of the cage, the device would not work properly.

Cost: 5/5, This design is very cost effective because it would only require the materials to make two five-sided-boxes to house the touchscreen and circuitry systems.

Ease of Fabrication: 5/5, This design would be the easiest to fabricate due to it only being two five-sided-boxes held together. This could easily be done by welding five plates together or by hollowing out a metal cube, but the latter may cost significantly more to produce.

Ease of Disassembly and Reassembly: 3/5, This design may be harder to assemble and disassemble because the touchscreen cannot slide out, meaning that we would have to install an easily removable system to each part of the casing for quick assembly and disassembly.

Design 2:

Safety: 4/5, This design is very safe, but the NHPs may be able to access the touchscreen and pump systems via the removeable side panels because they do not have a locking mechanism to keep them in place.

Ease of Use: 4/5, This design is very easy for the NHPs to use, but their heads would be to the side of the screen while using the device, so it may restrict their ability to see the screen and effectively use the device.

Cost: 4/5, This design would cost more than the first design because of the need for more material and machining. The side panels and extended pump casing would require more metal than the plain five-sided-box that would be used for the touchscreen in our first design.

Ease of Fabrication: 4/5, This design would be relatively easy to fabricate because it only requires a few boxes to be made of metal. However, the added material and complexity compared to our first design would make it slightly harder to manufacture.

Ease of Disassembly and Reassembly: 4/5, This design would be very easy to assemble and disassemble because the side panels can be removed to quickly remove the touchscreen and pump systems to collect the stored data.

Design 3:

Safety: 5/5, This design is very safe for the NHPs. The touchscreen and pump systems would be fully protected thanks to the locking mechanism on the side panels, and the circuitry box would not be exposed to any urine during use.

Ease of Use: 5/5, This design would be very easy for the NHPs to use because they would be able to sit directly underneath the screen while using the device. They would not have an obstructed view of the screen as their eyes would be at roughly the same height as the screen.

Cost: 4/5, This design would cost more than the first design, but about the same as the second design because of the need for more material and machining. The side panels and extended pump casing would require more metal than the plain five-sided-box that would be used for the touchscreen in our first design.

Ease of Fabrication: 4/5, This design would be relatively easy to fabricate because it only requires a large box with a divider to be made of metal. However, the added material and complexity compared to our first design would make it slightly harder to manufacture.

Ease of Disassembly and Reassembly: 4/5, This design would be very easy to assemble and disassemble due to the removeable side panels that allow easy access to the touchscreen and pump systems for data collection. These panels would be easy to remove for a researcher as they would be locked into place with a mechanism similar to that used in crutches.

Final Proposed Design

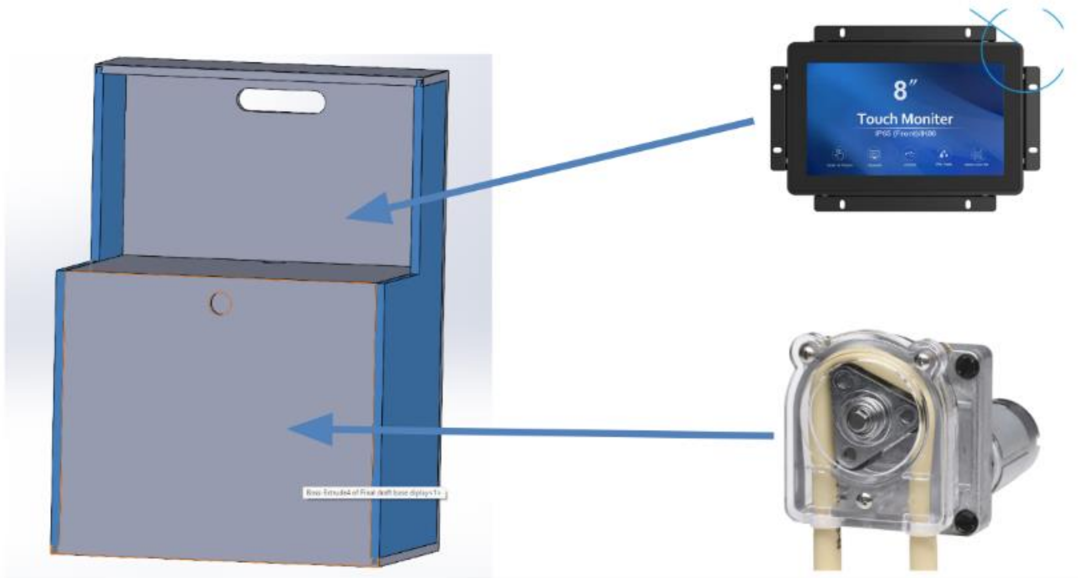


Figure 11: Final proposed design of the device

In the preliminary final proposed design, the circuitry is enclosed in the bottom part of the integrated circuitry box along with the peristaltic pump. The juice output extends through a hole in the front of the box. The touchscreen sits in a slot in the top part of the integrated circuitry box and is held in place by a locking mechanism like that used in adjustable crutches. The touchscreen is connected to the Raspberry Pi by wires that run through a hole in the top part of the box. The Raspberry Pi acts as the "brain" of the system, receiving input from the touchscreen, storing data on the microSD card, and sending signals when appropriate to the pump to dispense the reward.

Fabrication

Materials

The team will use the GreenTouch 8" Touch Monitor for primate interaction and experimentation [21]. The touchscreen was chosen as it met the necessary requirements that can be found in the PDS section 3c in appendix A while being cost effective. The display will attach via HDMI and USB Touch to the circuitry to provide the necessary connections. The team will utilize PETG with a 60% infill density to 3D print the final design along with ¼" x 3" screws to put the necessary pieces together. PETG was chosen as the filament due to its high chemical and impact resistance along with its water resistance [22]. An extensive material expense spreadsheet can be found in Appendix B.

Methods

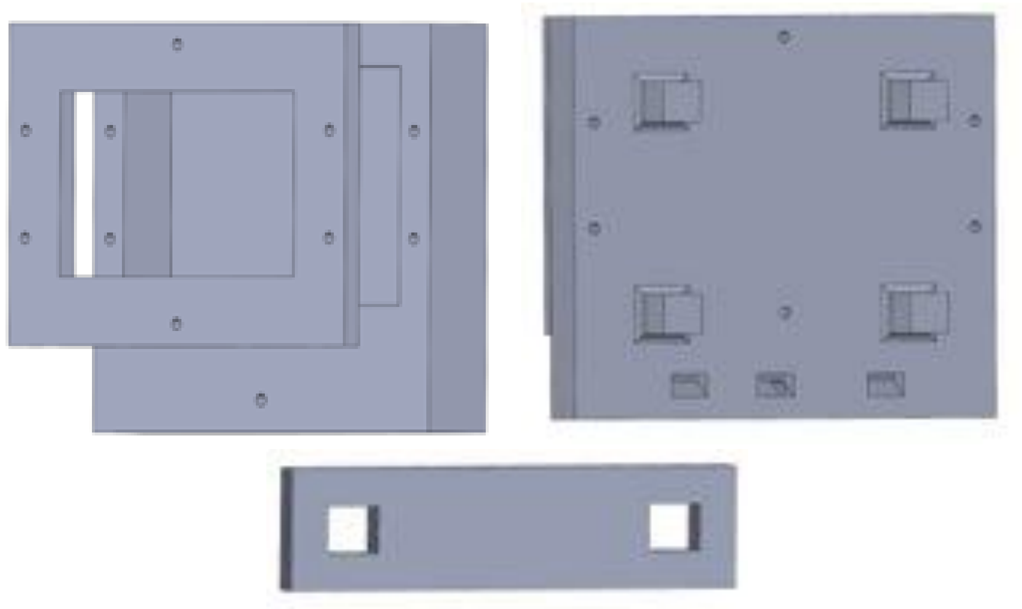


Figure 12: CAD model of Primate Portal Enclosure

To fabricate the final prototype, it was decided that 3D printing was a viable option for fabricating the complex enclosure. To ensure structural integrity, the print must be >60% infill with a triangular infill pattern. After printing, to attach the front panel to the enclosure ¼" x 3” screws must be fed through the holes. To secure the screws to the entire casing, a washer is used in combination with a nut to tighten the front panel to the casing. Finally, when attaching to the cage, ¼" x 1.5” screws are used to tightly attach the latching mechanism found in the bottom of the above figure 12 to the pegs of the enclosure. A full fabrication protocol along with measurements can be found in Appendix F for further specifications.

Final Design

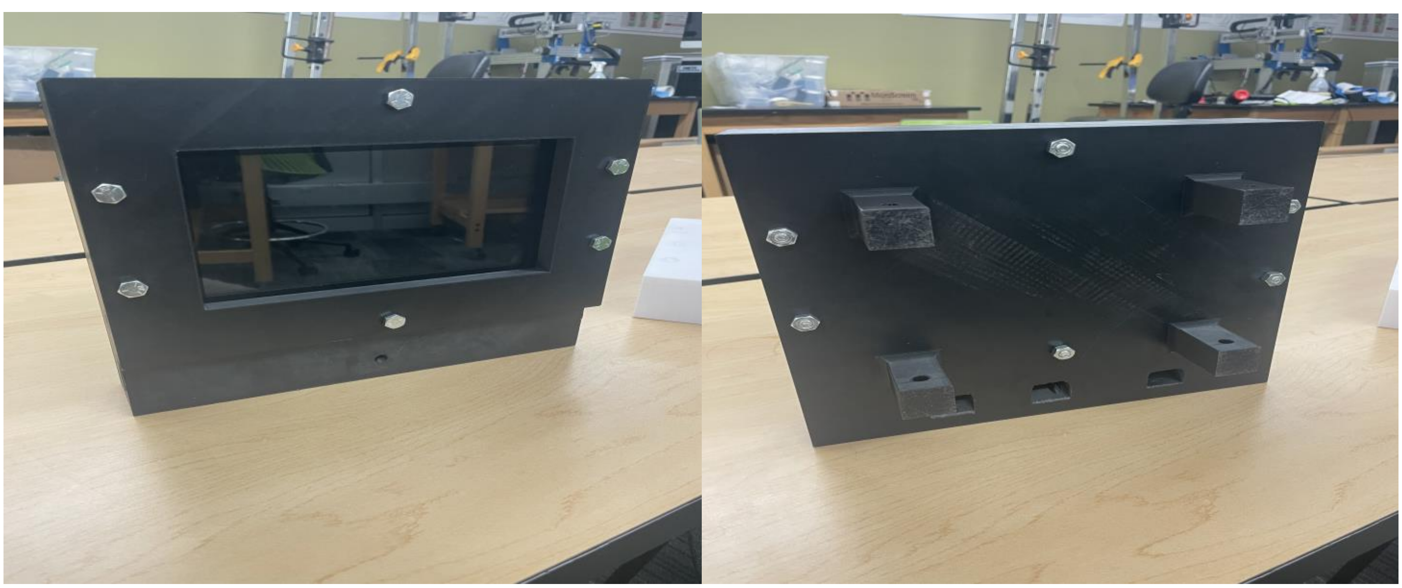


Figure 13: Final Design Picture Front(right) and Back(left)

The proposed final design has greatly changed over the course of the project to improve user experience and better match the requirements of the project. The Raspberry Pi continues to act as the “brain” of the system by receiving touchscreen inputs and outputting signals to the pump. However, the material used in the casing was changed from aluminum to PETG in order to make the fabrication process easier. The area under the screen was removed to make the device more compact, and instead the electronic components will be housed in a separate circuitry box on the exterior of the cage. In addition, pegs were added for attachment to the cage along with another piece which helps latch to the cage. Finally, a front screen was also added to keep the touchscreen in place while suspended on the cage and to help keep the entire structure waterproof.

Software

As a proof of concept that the device can run relevant cognitive-behavioral tasks, a simple match-to-sample task has been implemented to be run on the touchscreen. The match-to-sample task is commonly used in research to test working memory [23]. The software is written in Python and uses two libraries: tkinter to handle graphics (part of the Python standard library) and Pillow [24] to handle pictures. Currently, pictures are taken from Brown University's MonkeyLogic software [25].

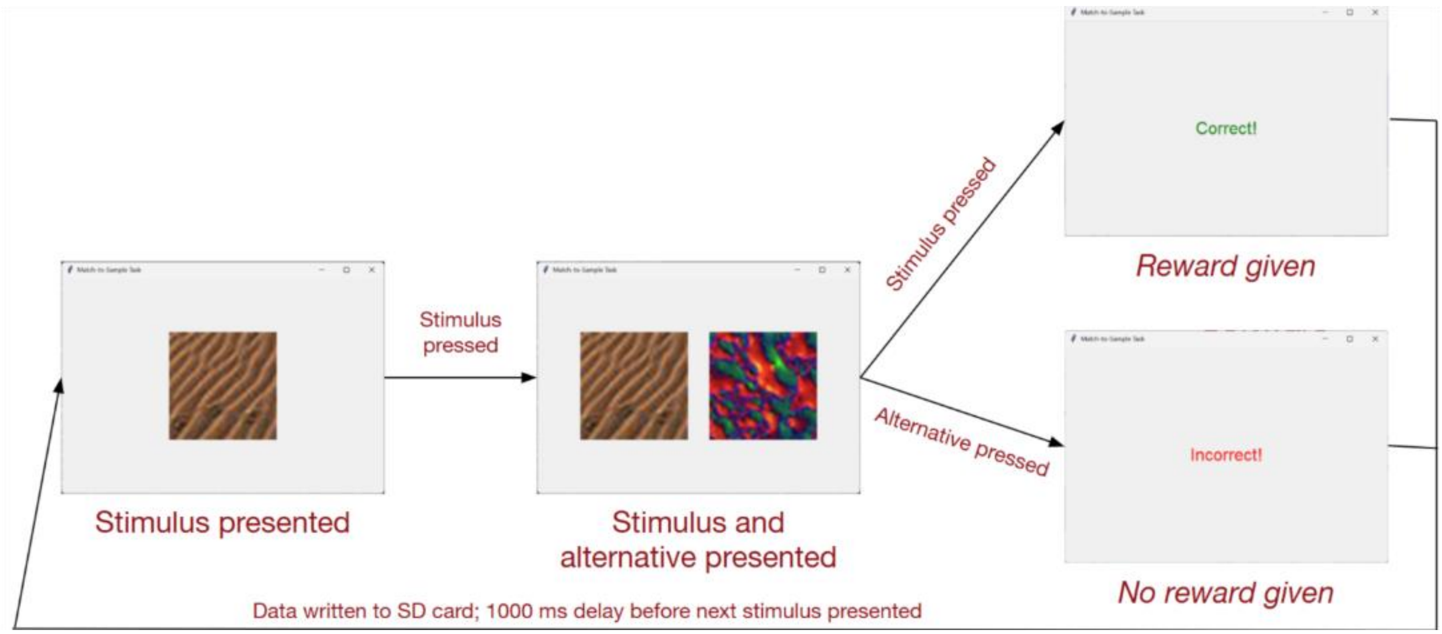


Figure 14: Diagram of the match-to-sample software's logic flow.

Testing and Results

Due to the multi-faceted nature of the Primate Portal Device, a variety of testing was done to ensure the device meets the requirements outlined in the product specifications (Appendix A). The testing was split into three categories; SolidWorks based material deformation testing, pump calibration testing and system consistency testing. Each testing protocol covered a unique aspect of the device that is required for the device to function. Further testing should be completed once the device is fully completed.

SolidWorks Testing

The team applied 88 Newtons of force in SolidWorks stress testing on the four bars that hold the case in place. From this, it was found that the failure load was 1.5 * 10^5 Pa. With a maximum expected load of 88 N distributed over 0.00129 m^2 results in a maximum expected stress of 6.89 * 10^4 Pa. Using the maximum expected stress and the failure load, it is possible to calculate the factor of safety which is 2.18. This is a satisfactory result because it is over the value of 2, meaning it can carry over double the maximum expected load. As seen from figure 13, most of the stress accumulates at the joint between the back of the case and the bars, which was accommodated by a fillet to help distribute the load.

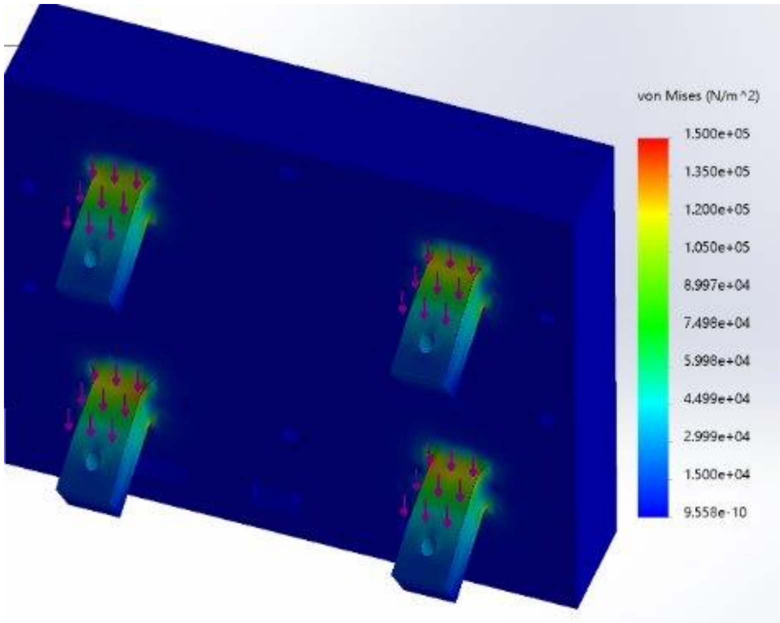


Figure 14: Solidworks Testing

Pump Calibration Testing

The pump calibration testing was conducted with the purpose of understanding the systems response as a function of time outputting liquid. The goal of this test was to see how long 24v had to be applied to the peristaltic pump to get an output of 1mL. Furthermore, this test was intended to see if the output liquid grew linearly as a function of time. The code used to control the pump is outlined in appendix D, MotorPackage.py. In specific, the following function ptime, was used to test at different time points:

```
def ptime(t=0.1):
    forward(100)
    time.sleep(t) #type: ignore
    coast()
```

Figure 15: ptime function in MotorPackage.py

As for the setup of the test, figure 15 displays a general depiction of the components of this test. The system, being controlled via SSH, was connected to a beaker containing water. The water from this beaker would be pumped by the peristaltic pump into another beaker on a zeroed scale. Water was used as 1mL = 1g, giving good insight into the volume of water moved by the system. Note that for other liquids the pumping properties may not be the same due to differing densities or other factors but those have chosen to be ignored as no liquids using in a testing sense should differ too far from water.

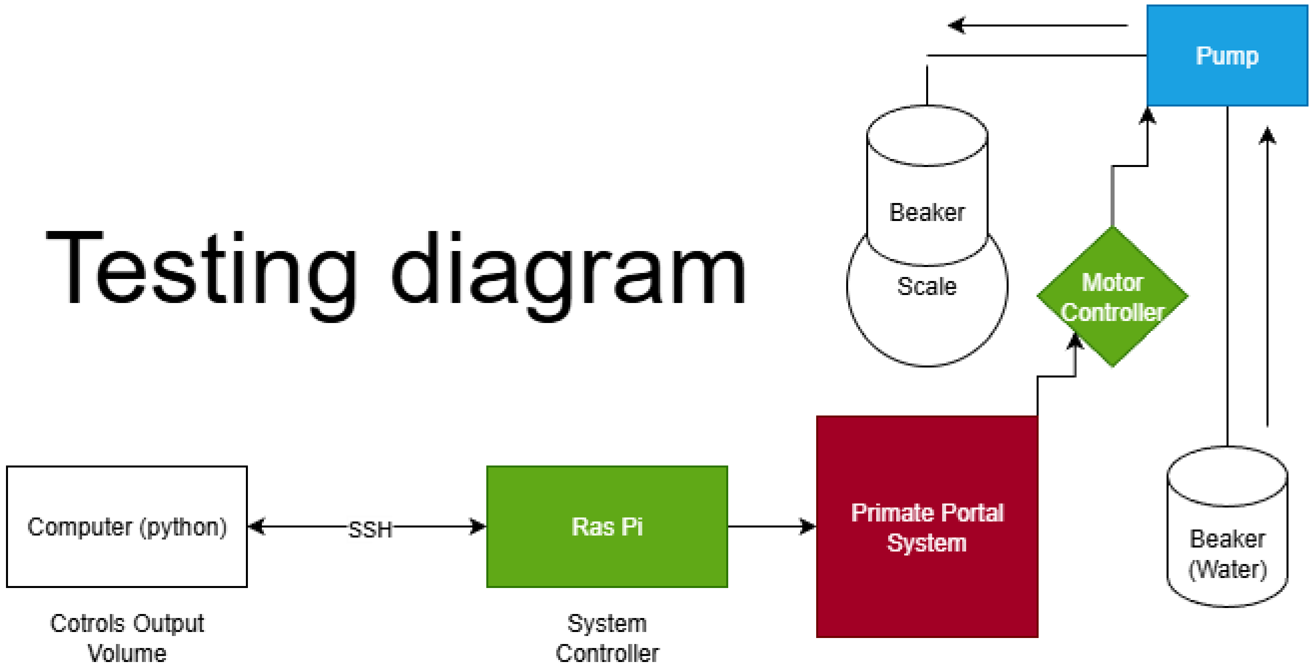


Figure 16: Testing layout for Pump Calibration tests and System Consistency tests

The test was conducted as follows:

1.) Zero scale with beaker on top.
2.) Update code to call ptime at 0.1 seconds and run code.
3.) Note down weight displayed on the scale and zero again.
4.) Repeat steps 2,3 with each selected time value (time displayed in appendix E)

The test resulted in the following calibration curve (figure 16):

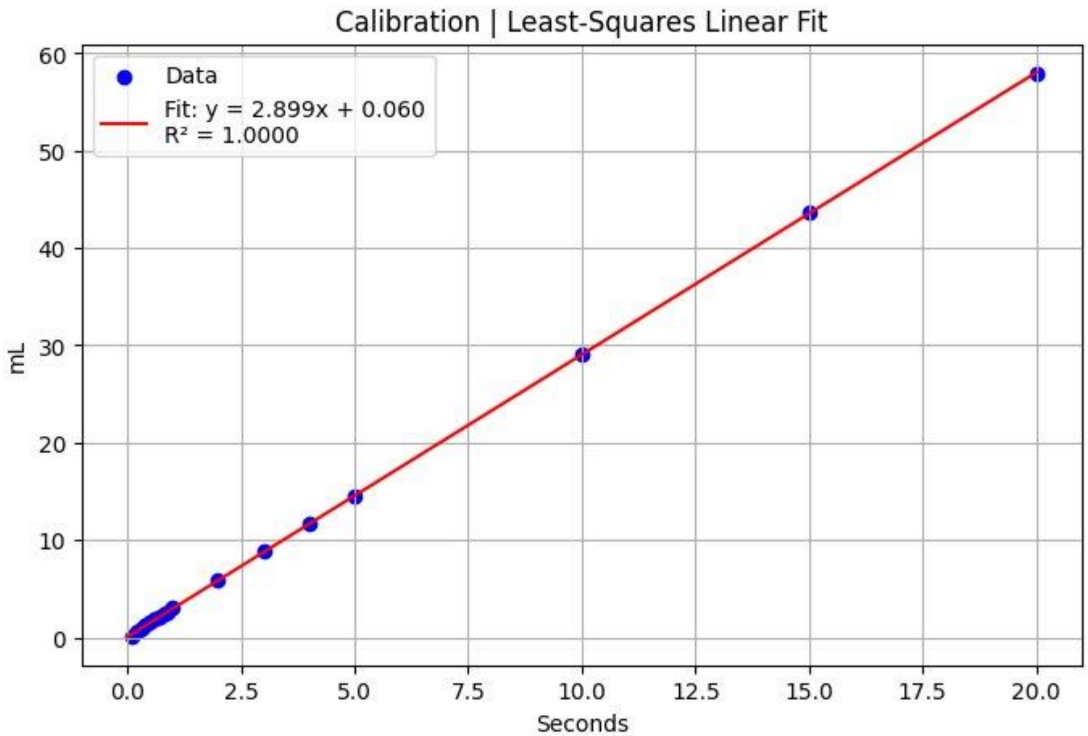


Figure 17: Primate Portal Calibration Curve

After plotting and applying a Linear Least Squares fit, a linear regression was obtained, providing a system response in mL (with water) as a function of time (seconds). This equation can be used to determine how long the pump should be running to output a specified amount of liquid to the NHP. Furthermore, the R^2 value shows a perfect correlation between the linear regression and data. The data showed that for 1mL of water, the pump should be run for roughly 0.3 seconds, which is used as a baseline for the following test.

System Consistency Testing

The system consistency testing was conducted to ensure the Primate Portal would reliably output a consistent amount of liquid as stated in the product design specifications. This test used the same testing layout as the pump calibration test, shown in figure 15. 1 mL of water was dispensed for a total of 50 trials. For each trial the dispensed water was weighed on a scale and reported. The 50 trials led to a mean output volume of 0.982mL with a standard deviation of 0.0397mL. Overall, the percent error from the theoretical 1mL was -1.838%, falling well within the 5% range. Below, figure 17 shows a histogram and box plot of the 50 data points.

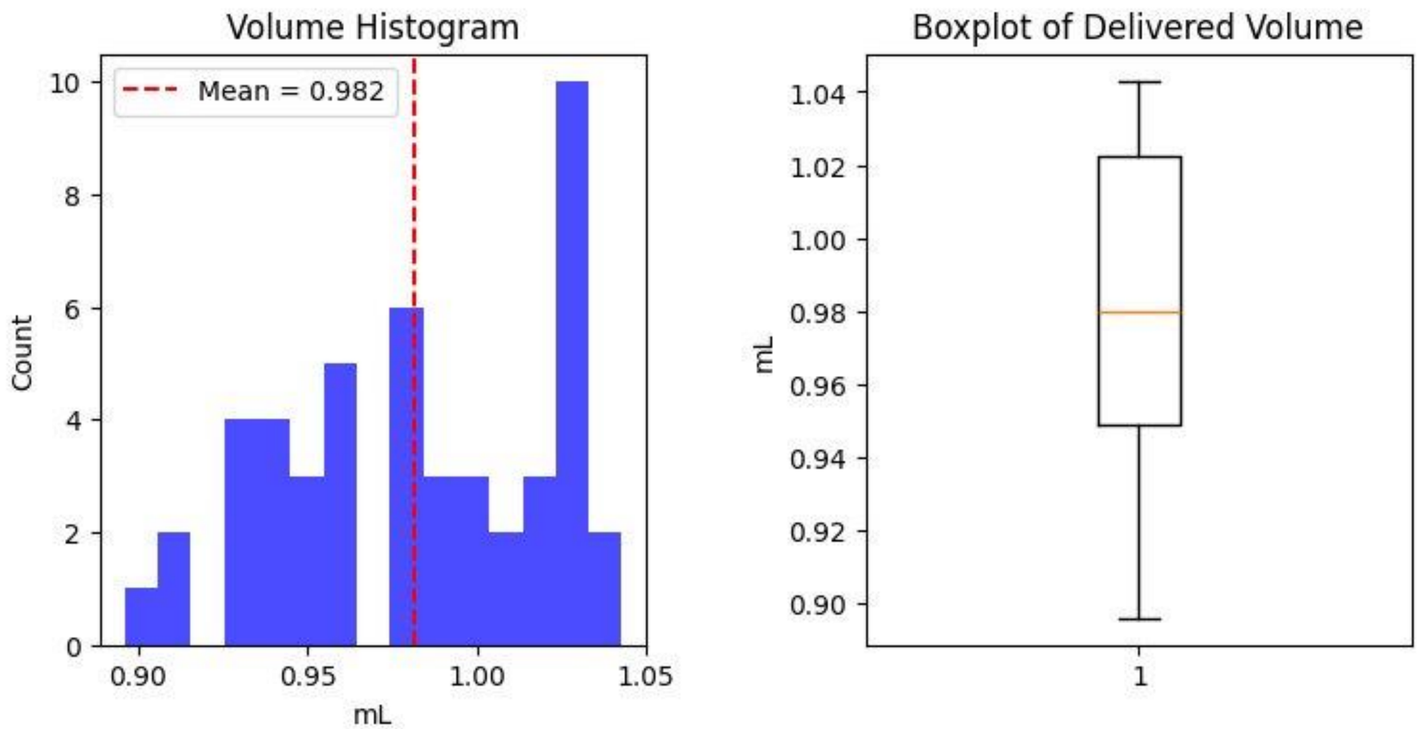


Figure 18: Histogram (left) and box plot (right) of the system consistency test

Discussion

Implications of results

Results of the SolidWorks testing were important for considerations of the latching mechanism functionality. With the application of 88 Newtons of force, there was little deformation of the attachment bars. The highest amount of stress coupled near the base of the case. The results of this test led the team to add a fillet to the bars base to increase material near the base and distribute the stress. The outcome of the stress test was a FOS of 2.18 showing a successful product. Overall, the material could be changed to increase the FOS if needed for different NHPs, but for Rhesus Macaque PETG is sufficient.

Calibration and consistency testing of the pump revealed that the pump outputs 1g of water in 0.3 seconds. When ran at 0.3 seconds there was a -1.838 percent error. The mean output volume was 0.982 mL. This shows that there is a slight discrepancy between the volume output and the time that the pump is dispensing. This could lead to underestimating the amount of liquid the NHPs are receiving from tests after multitudes of trials are run. The NHPs are liquid dependent, so it is important to know how much they are receiving per testing period to adjust to fit each NHP's needs.

Ethical & Safety Considerations

All safety requirements were met during fabrication following IEC 60601 and Animal Welfare Act regulations. There are no reachable sharp edges, ensuring the device is safe for the NHP to handle. The casing utilizes PETG material, which was stress-tested to a Factor of Safety of 2.18. This ensures structural integrity and significantly decreases the potential of failure leading to NHP harm. To prevent electrical shock, the design adheres to IEC 61010-1 guidelines and meets IP64 ratings, rendering the touchscreen and housing water-resistant and impact-resistant.

Primate portal relies on positive reinforcement training with a liquid acting as the reward. Correct answers to tasks result with the dispense of liquid, while incorrect answers lead to no dispense. The tasks are very quick and allow for plenty of liquid over the period of testing. There is no punishment for incorrect answers, so the NHPs are safe. By automating the testing in the NHP's home environment, the system removes the need for transport, significantly decreasing NHP stress levels. The device is also removable, so it is able to be routinely cleaned and inspected for failures, upholding the safety of the NHP. Overall, the device is ethical and decreases stress on the NHP when compared to the current method

Design Optimization

With the current product, there are many opportunities for improvement. Firstly, a casing restructure or material change would help provide a higher failure load allowing the device to be used with larger, more powerful NHPs. This would help increase the target audience of the product. Secondly, a more accurate pump could be used. This would help decrease the percentage error and allow for easier tracking of how much liquid the NHPs actually receive. It could also help increase the delivery speed of the liquid, allowing for a more exciting delivery for the NHP, and possibly increase training speeds. Other opportunities for change are cable management, electronics box management, and slightly larger case cavity for the touchscreen. These changes would allow for easier set up and removal of the device allowing for less stress on the researcher. This could improve the user experience and promote change to automation of NHP training.

Sources of Error

Several sources of error have been touched throughout the report, such as the pump accuracy. Additional sources of error are as follows. The shrinkage of PETG while 3D printing, which is normally around 0.5% to 1%, making the casing fit tighter than expected. Fluid viscosity discrepancy due to the use of water rather than juice used in trials. Calibration Linearity, due to linear least squares fit used to find the timing of liquid output. Subject testing discrepancies due to human testing of the equipment rather than the NHPs. Using simulated stress testing does not account for print imperfections that could lead to lesser ultimate stress.

Conclusions

Conclusion

The goal was to design and implement a mountable touchscreen device that will train primates via positive reinforcement by administering an automated liquid reward based on primate cognitive inputs on touchscreen. Previously, the team decided that the best design would be the longitudinal design consisting of a vertical design with the top section focused on touchscreen and bottom section focused on pump and circuitry storage. After further discussion with the advisors and contemplation, the team decided that electronics inside the cage would lead to safety hazards with the primates. The final design is the touchscreen in a waterproof strong frame, attached to the cage via a lock mechanism and the electronics kept on a cart out of reach from the primate. Electronics speaking, the circuitry will run through a Raspberry Pi, sending signals to the motor controller which in turn outputs to the pump to dispense juice after correct inputs on the touchscreen.

Future Work

In the future, the team would like to implement various applications to the design. Primarily, a magnetic interlocking system would assist in improving the detachability and attachability of the device to various environments in a timely fashion. Next, the team discussed adding a self-calibrating pump output in units of mL, allowing easier use of the device to the researchers. Changing the material to a more structural integral material such as stainless steel would prove to be beneficial for limiting deformation over time. Relating to the research itself, beginning animal trials is crucial to obtain accurate scientific results from our device, as well as implementing an eye tracker for more advanced research.

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Appendix

A. PDS

Product Design Specifications
09/18/2025
Primate Portal
BME 300/200 Section 304
Group Members:
Leaders: Kalob Kimmel and Logan Olivera
Communicator: Jackson Stewart
BSAC: Andrew Dirkse
BWIG: Sameer Bhatt
BPAG: Charlie Fischesser
Client: Dr. David Herzfeld
Advisor: Dr. Dhananjay Baskar

Function

The primate portal is intended to be a primate positive reinforcement training device. From a higher-level perspective, the primate portal is a touchscreen interface, outputting a liquid reward for the primate when it successfully completes a task on the touchscreen. From a more detail-oriented perspective, the primate portal is a touchscreen interface controlled by a Raspberry Pi. The Raspberry Pi contains a simple python-based user interface and database to train the primates (more specific software will be developed by client's research team). Once a correct input is received, the Raspberry Pi will output a signal to a peristaltic pump to reward the primate for its correct actions by dispensing a liquid of the operator's choice. The entire system will be safely mounted to the primate's cage and enclosed in a protective box. Overall, the system is used to gain an understanding of the cognitive function of complex neural behaviors.

Client requirements

- Product must only dispense juice when primate successfully completes challenge
- Product must have notification system if primate isn't getting any liquid
- Product electronics must be enclosed and away from primate to ensure electrical safety
- Product touchscreen must be secure with no risk of falling off the cage bars
- Product must be easily put on and taken off by lab assistants
- Software must be easily modifiable to support different future experiments
- No incorrect training – failures stop reward output

- Highly emphasize safety
- Modular for future applications and studies
- Easy for operators to attach and remove cage
- Compatible with primate environment
- Data accessible through usb or ssh
- Minimal exposed wires
- $5000 budget

Design requirements

1. **Physical and Operational Characteristics**

a. **Performance requirements –** The primate portal product has three distinct fields in which it must meet different performance requirements. These fields are the circuitry/code of the design, the enclosure, and the peristaltic pump delivery system. The device is to be used daily, being loaded and unloaded at morning and night respectively.
As for the circuitry/code, there must be a well-defined and documented system in which, when there is a correct input passed (through the touchscreen display), a 5V pulse be output. This must be modular in the sense that it is very easy for an operator to develop a new training application that outputs the correct signal. This output will be further discussed when considering the peristaltic pump. As for a failure case, it is expected that the electronics of this system will not cause any harm to the user or operator.
Performance requirements with respect to the enclosure are of the utmost importance as to protect the users, operators and the primate portal system itself. The enclosure must be able to be easily mounted and removed from the cages holding the primates. It should be lockable in the sense only a human can remove the system, with interlocks connected to the electronics, providing a failsafe in the case the enclosure is mounted incorrectly. Most importantly, the enclosure must be safe, meaning no sharp edges, no exposed electronics and no accessible items to the primates. In no way, shape or form, should the primates be able to damage or mess with the system when it is in the enclosure.
Lastly, the peristaltic pump has its own set of unique performance requirements. The pump must respond to the 5V signal sent from the microcontroller and accept a 24V signal (variable input but 24V standard) signal to activate the pump. Back EMF effects or any other mechanical related possible issues should be accounted for. The pump must be easily accessible to swap out and clean the tubing containing the liquid. Lastly, following the same pattern as the other performance requirements, the pump system must be safe.

b. **Safety –** Safety is of the utmost concern in any biomedical device, and the primate portal is no exception. It is imperative that no injury can be sustained through use and setup of the device. As per IEC 61010-1 [1], the system must be operating under 60V, or it will need extra protection. Any current carrying wire must meet clearance regulations provided by IEC 61010-1, with a 3mm separation distance. No component in the system can exceed 60 degrees Celsius as to protect the primates. The IEC also outlines ingress protection ratings of which this device should fall under IP54 or better [2].
It is important to also consider the Code of Federal Regulations, title 9, chapter 1, subchapter A, part 3, subpart D, focusing on the specifications for the Humane Handling, Care, Treatment, and Transportation of Nonhuman Primates [3]. This states that the device must be safe, no sharp edges, no free cabling, no toxic materials or any other hazards. This aligns with what the Institution animal Care and Uses Committe (IACUC) looks for during primate research inspections. IACUC can be thought of as the "FDA" for animal research.

c. **Accuracy and Reliability –** The touchscreen must be responsive to primate touch. The juice pump must deposit 10 mL with a ± 1.5 mL margin of error when the primate successfully completes a challenge. No failure should be seen on the software or hardware side and should be rigorously tested. The enclosure must be able to withstand forceful impact (primate punches and kicks), exposure to liquids and temperature changes without any faults. If anything fails, the system must stop training completely, notify the researcher of the failure through text message or email, and pause the output of the liquid reward until fixed.

d. **Life in Service –** The primate portal is expected to be used daily for up to 8 hours a day. It should be fully functional for 3-5 years without fault (not accounting for consistent excessive tampering from primates). The peristaltic pump as well as the touchscreen display are expected to operate for the full 3-5 years.

e. **Shelf Life** – The product should last upwards of ten years if not broken or tampered with. It should also be relatively easy to repair if it does break.

f. **Operating Environmen**t – The product would be placed on the side of the cage with the touchscreen inside the bars and a unit with the Raspberry Pi and other critical components on the outside. The client has stated that the device may be exposed to urine and/or other primate excrement and thus must have a waterproof touchscreen and protected wiring and components.

g. **Ergonomics** – The client has stated that the product should be easy to use for both the primates and the scientists. For the primates, the touchscreen should be easily accessible and large enough to ensure training is completed correctly. For the scientists, the product should be easily removable from the cage and should allow easy access to any data that is stored.
Size – The touchscreen should be 7 to 15 inches to ensure that the macaque has an interactive platform for behavioral experiments. The protective case for the screen should be snugly fitted to the screen size to guarantee that the macaque cannot remove or damage the screen. Any cage attachment points will have to match the Allentown cage wire thickness [4]. The liquid holder must be able to hold enough liquid for a day's volume worth of trials, or up to 100 mL [5].

h. **Weight –** The touchscreen portion of the project must be able to be moved easily by the person removing it from inside of the cage. The average person can easily move 15 pounds [6], so that is our weight constraint of the touchscreen portion. Most 12 inch touchscreens weigh around 3 pounds [7], allowing the case to weigh 12 pounds. The component box will not need to be moved as often so it can weigh up to 25 pounds. This will include the stand, case and components.

i. **Materials –** The project will need a touchscreen that interacts with the macaque. The touchscreen will need a protective case that can handle small impacts, as well as being waterproof. The most likely material for the case will be aluminum because it is easy to machine and not toxic to the macaque. The project will also need cable management. This will be some sort of polypropylene or adjacent tubing that keeps liquid and tampering failures from happening. The electronics portion will include a peristaltic pump which will dispense the liquid. It will also need wiring, a microcontroller, power supply, and data storage. These will be stored in a component box that is nonconductive such as PLA.

j. **Aesthetics, Appearance, and Finish –** There should be no exposed circuitry. All edges should be beveled to ensure safety. The touch screen should be unobstructed to allow for maximum interaction with the subject. All components that are within urine range should be covered or have a waterproof coating. Visually it should be pleasing but looks are not a priority.

2. **Production Characteristics**

a. **Quantity-** Client requested one prototype initially. If time permitted, more prototypes may be useful for the client. Making an easily replicable design would be highly desirable as well. The device should be able to move to different systems and easily detachable.

b. **Target Product Cost-** There is only one product similar pertaining to our client's needs; however, it is an expensive and non-adaptable product. Our goal is to create a product using our budget, roughly $5,000, to create a more inexpensive and reusable device.

3. **Miscellaneous**

a. **Standards and Specifications –** IEC 60601 is an international standard regarding electrical safety for devices which could be used in a lab setting. Compliance with this standard is crucial to ensure the safety of the primates. Another standard we need to fall under is the Animal Welfare Act (AWA), specifically title 9 section 3.89. We need to ensure that our device is secured along with giving enough liquid to the primates. As outlined in the requirements, all nonhuman primates must be given water every 12-24 hours. 9 CFR [1] §3.75 Housing facilities, general also applies: in particular, the device must be "free of excessive rust" and "jagged edges or sharp points that might injure the animals." The device should also be able to be cleaned [8].

b. **Customer –** David J. Herzfeld, a new professor in the Department of Neuroscience at UW–Madison. Prof. Herzfeld runs a systems neuroscience lab (https://herzfeldlab.neuro.wisc.edu/) in WIMR using a combination of animal behavioral experiments and computational modeling. Prof. Herzfeld hopes to use Primate Portal to run behavioral experiments with macaque monkeys.

c. **Patient-related concerns –** The primates are water controlled and tend to urinate quite a lot; thus, the product must be able to withstand urination. The primates are also highly intelligent and are about the size of a toddler, so the screen should withstand shattering. The device should not have any sharp edges or wires exposed to ensure that the monkey cannot injure itself while using it. The device should have a failure mode and a way to notify the researcher if the device runs a trial in an unintended way (i.e., trains the monkey to do an unintended thing) so that the researcher can halt the experiment.

d. **Competition –** While several in-cage primate training systems have been developed and published in the literature, the only commercially available competitor is Thomas RECORDING's InCage Training System (ICTS) (https://www.thomasrecording.com/thomas-incage-training-system-icts). The Thomas ICTS is cage-mountable, with an 8-inch shock- and waterproof touchscreen and protection of internals from water and dirt. It is also possible to connect external devices like a video camera or a loudspeaker to the microprocessor and wirelessly control the behavioral paradigm and receive data. However, the Thomas ICTS has little capacity for extensibility in software and is prohibitively expensive, costing roughly $100,000 (as informed by client).

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B. Material Expense Sheet

Item	Description	Manufacturer	Mft Pt#	Vendor	Vendor Cat#	Date	QTY	Cost Each	Total	Link
Electronics										
Raspberry Pi Model 3 B +	from touchsreen and output signals to motor controller.	N/A	SC0073	UW Makerspace	SC0073	9/15/2025	1	$45.00	$45.00	https://www.raspberrypi.com/products/raspberry-pi-3-model-b-plus/
Wiring	controller	N/A	N/A	UW Makerspace	N/A	9/22/2025	1	$1.00	$1.00	
Micro SD	Store data for researchers	N/A	N/A	UW Makerspace	N/A	9/15/2025	1	$4.00	$4.00	
Motor Controller	Connects to Raspberry Pi to output signals to turn on pump device	Hitilego	3-01-833	Amazon	3-01-833	9/22/2025	1	$1.00	$1.00	https://www.amazon.com/dp/B00WSN98DC?ref=ppx&th=1
Mechanical										
A300BXS- Pump	Pump to push fluids by accepting signals from motor controller.	Anko	A300BX-S	Anko	A302BX-300-$	9/15/2025	1	Gifted	$575.00	ANKO A300BX-S | OEM Peristaltic Pump | Serial Control | Brushless DC | Models to 1700 m
8 inch GreenTouch Touchscreen	Touchscreen device with high water and impact resistance and USB ports to connect to raspberry Pi	GreenTouch	GT-TM080(2C	Walmart	GT-TM080	#########	1	$200.88	$200.88	https://www.walmart.com/ip/GreenTouch-8-Inch-Open-Frame-1024x600-HDMI-PCAP-Touch-Monitors-for-Consumer-Retail-POS-and-Hospitality-Markets/15594114325?classType=REGULAR
Power										
24V 2A 48W DC barrel power supply (2 Pack)	Power supply to safely power the motor controller, touchscreen, raspberry pi, and pump	Fletergib	N/A	Amazon	B0C6SJY34G	#########	1	$16.99	$16.99	https://www.amazon.com/Supply-Adapter-100-240V-Transformer-Connector/dp/B0C6SJY3
24V 2A DC barrel power supp	Power supply to safely power the motor controller, touchscreen, raspberry pi, and pump	Onerbl	JYH36-1204000-BY	N/A	J3611204000U	#########	1	Gifted	$13.89	https://www.amazon.com/Adapter-Replacement-J361-1204000U-J3611204000U-100-240-50/dp/B0D31FRQ9G
								TOTAL:	$857.76	

C. Testing Protocols

a. Calibration protocol (slightly changed when done)

The goal of this calibration is to calibrate to 1mL of liquid dispensed (calibrated to water in this scenario).

Materials needed:

- primate portal system
- beaker
- water
- scale

Procedure:

1.) Place the beaker on the scale and 0 the scale

2.) Refer to the script MotorPackage.py, on this script the two things to be aware of are the variable pump_time initialized at the top line ~ 12 and the function:

```
def pump(time = pump_time):
   forward(100)
   time.sleep(time) #type:ignore in seconds
   coast()
```

Set pump time to a given time (maybe around 0.5 seconds)

3.) run the script to output a given amount of liquid

to actually use the function add at the bottom of the script:

pump()

this should pump water out of the peristaltic pump. Capture this water in the beaker and weigh. The ideal weight should be 1 gram as 1mL = 1g for water

4.) If the weight is off, adjust pump_time accordingly and repeat this process (zero beaker + water). Do until the outputted amount of water is 1g +- 0.05g

D. Motor Controller Code

```
import RPi.GPIO as GPIO #type: ignore
import time

# Set pin numbers
RPWM = 18   # PWM-capable physical 12 - brown
```

```
LPWM = 19   # PWM-capable (or 13) - physical 35 - orange
REN  = 23   # physical 16 - yellow
LEN  = 24   # physical 18 - teal

F_PWM = 2000  # use 200 Hz for visual LED test; 20000 for motor

pump_time = 0.3# Calibrated time (ms) for output of liquid

GPIO.setmode(GPIO.BCM)
GPIO.setwarnings(False)

GPIO.setup(REN, GPIO.OUT, initial=0)
GPIO.setup(LEN, GPIO.OUT, initial=0)
GPIO.setup(RPWM, GPIO.OUT)
GPIO.setup(LPWM, GPIO.OUT)

forward_pwm = GPIO.PWM(RPWM, F_PWM)
reverse_pwm = GPIO.PWM(LPWM, F_PWM)
forward_pwm.start(0)
reverse_pwm.start(0)

def clamp(x): return max(0, min(100, x))

def forward(duty):
    duty = clamp(duty)
    GPIO.output(REN, 1)
    GPIO.output(LEN, 1)
    reverse_pwm.ChangeDutyCycle(0)
    forward_pwm.ChangeDutyCycle(duty)

def reverse(duty):
    duty = clamp(duty)
    GPIO.output(REN, 1)
    GPIO.output(LEN, 1)
    forward_pwm.ChangeDutyCycle(0)
    reverse_pwm.ChangeDutyCycle(duty)

def coast():
    GPIO.output(REN, 0)
    GPIO.output(LEN, 0)
    forward_pwm.ChangeDutyCycle(0)
    reverse_pwm.ChangeDutyCycle(0)


# Calls forward for a given amount of time
# Time will be calivrated for now will run for 500 ms
def pump(mL = pump_time):
```

```
    forward(100)
    mL = mL*0.3
    time.sleep(mL) #type:ignore
    coast()



def ptime(t=0.1):
    forward(100)
    time.sleep(t) #type: ignore
    coast()
```

E. Pump/System Testing Raw Data

Trial	mL	Current
1	1.029	0.14
2	0.896	0.14
3	1.04	0.14
4	1.224	0.14
5	1.177	0.13
6	0.94	0.14
7	1	0.14
8	1.006	0.13
9	1.02	0.14
10	1.022	0.14
11	0.95	0.13
12	0.999	0.14
13	0.94	0.14
14	1.025	0.14
15	0.943	0.14
16	1.032	0.14
17	1.025	0.14
18	1.03	0.14
19	0.953	0.14
20	0.933	0.13
21	0.933	0.14
22	1.043	0.14

23	0.987	0.14
24	0.961	0.14
25	0.946	0.13
26	0.98	0.11
27	1.024	0.14
28	1.033	0.1
29	1.03	0.14
30	0.977	0.13
31	0.926	0.14
32	1.027	0.14
33	0.913	0.14
34	1.019	0.14
35	0.98	0.14
36	0.914	0.14
37	0.98	0.14
38	1.01	0.13
39	1	0.14
40	0.955	0.11
41	0.94	0.14
42	0.95	0.9
43	0.977	0.12
44	0.988	0.14
45	0.932	0.14
46	0.957	0.13
47	0.985	0.14
48	0.977	0.9
49	0.96	0.14
50	1.026	0.14
Avg	0.99028	
Std	0.058719	

Time	mL
0.1	0.108
0.2	0.585
0.3	0.985
0.4	1.25
0.5	1.557
0.6	1.853
0.7	2.14
0.8	2.35
0.9	2.628
1	3.027
2	5.844

3	8.796
4	11.725
5	14.514
10	29.073
15	43.612
20	57.97

F. Fabrication + Attachement Protocol

Goal

This document should enable any person with sufficient technical ability to fully fabricate the physical design to attach the touchscreen to the cage.

Required Materials and Equipment

- GreenTouch 8" Touchscreen
- 3D Printer
- PETG
- 6 1/4" x 3" screws
- 4 1/4" x 1.25" screws
- 6 1/4" washers
- 10 1/4" nuts
- Primate Cage

Protocol

1. Use a 3D Printer to print all 3 parts of the design(Front Panel, Latch Attachment, Larger Case). An infill of >60% will be necessary with a triangular fill pattern. In addition, supports will be necessary throughout the entire print, use tree supports for optimal printing and results.
2. Feed the wires through the back of the enclosure and plug them into the touchscreen. Place the touchscreen into the large cavity on the enclosure.
   a. Ensure that the touchscreen is close to flush with all of the walls in the encasing, if not, some edits to the dimension of the cavity may need to be done
3. Place the front screen on top of the enclosure and make sure the edges are flush with the encasing. It is symmetrical so orientation doesn't matter
4. Place the 1/4" x 3" screws through the front panel + enclosure. Tighten the washer and nuts to make sure nothing can detach or break
5. Place the enclosure on the cage such that the 4 pegs on the back fit through the holes in the cage
   a. Ensure that each peg has contact with the cage, otherwise elements may break off
6. Slide the latch attachment pieces into place, with two of them being used horizontally. Screws will be placed at the top to ensure the fit is tight
7. Analyze everything which has been attached and ensure nothing is moving or loose.

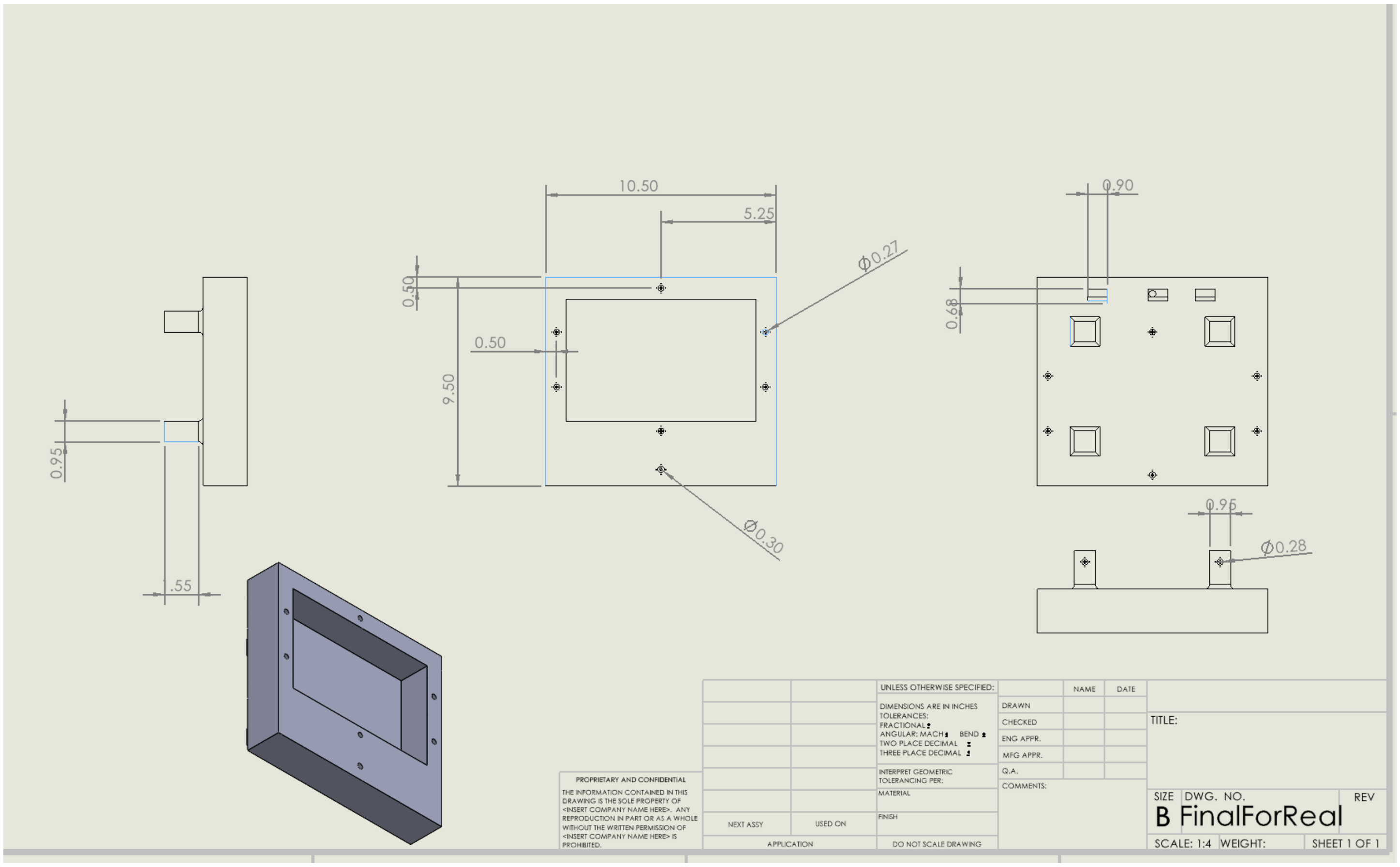

Figure 1. CAD Drawing of Final Design