A Smart Toilet Appliance that Detects the Lid Position and Automatically Flushes

A Major Qualifying Project Report

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Abstract

The group was tasked with creating a hands-free flushing mechanism due to COVID-19. The group used an Arduino to create a program to detect when the toilet lid was closed and flush the toilet automatically. Our prototype requires the toilet lid to be closed before the flushing function can be activated. The working prototype uses a push button switch to let the Arduino know when the toilet lid is down. The group's prototype has room for improvement and is only applicable in certain types of household toilets.

Acknowledgments

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Zhang Zhaolong assisted with the revision of our 3D printed pieces and helped dispute any technical difficulties the team experienced.

Thank you to everyone that assisted the team in the development of our project!

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Executive Summary

The group was tasked with creating a hands-free flushing mechanism due to COVID-19. This pandemic has resulted in countries shutting down their economies and lockdowns. The group worked remotely to complete the project due to the university campus being closed. The group was able to create a working prototype that can flush a toilet touch-free. Applying similar kits on commercial toilets will require further research and development as the team was only able to test their prototypes on household toilets.

The group understands that even household toilets have different flushing mechanisms and toilet seats. The toilet that was used to test the prototype had a push button instead of a chain. The flushing mechanism is activated by pushing the button instead of pulling a chain up. The toilet lid is not flat with two bumps to raise it above the toilet seat. Instead it has a raised lip all around the entire lid. This forced the group to put the activation bar on the top of the toilet lid instead of underneath. The group used an Arduino instead of a Raspberry Pi to create a program to detect when the toilet lid was closed and flush the toilet. The Arduino was chosen because it is simple and cost effective and provides sufficient capability cheap. If a Raspberry Pi had been used, a larger power supply, monitor, keyboard, and mouse would be needed.

Our prototype requires the toilet lid to be closed before the flushing function can be activated. The group chose the motion sensor instead of the typical infrared sensor seen in public bathrooms. Infrared sensors that detect motion are not ideal as someone just walking by the toilet can trigger the toilet to flush. There are occasions where toilets will also not flush after usage due to various reasons. Putting the motion sensor on the top of the water tank and allowing the user to control when they want to flush the toilet minimizes the number of accidental flushes.

The group picked a push-button switch to detect whether the toilet lid was down instead of other methods due to time constraints. Originally the group wanted to use an inductive sensor as those are smaller and simpler in usage, but the coding became a concern as time went by. The push button can be controlled by simple code but requires a holder to keep it upright on the outside of the toilet bowl. An

activation bar was also designed and 3D printed so that when the toilet lid came down and the user gave the command to flush the toilet, the Arduino would check to ensure that the lid was closed before execute the flushing command. A box was also designed and printed to house the Arduino and the breadboard along with the motion sensor. The box was placed on top of the water tank on its back side to prevent pets or others from accidentally flushing the toilet when the lid is down.

The group landed on this prototype after many changes in parts and several reiterations of redesigning. The design may not have aesthetic appeal like others on the market, but the key feature of the prototype is that it will not flush the toilet unless the toilet lid is down. Most toilet flushing kits that are ready to be installed do not need the toilet lid to be closed in order for the toilet to flush. Closing the lid before flushing the toilet allows the user to be exposed to fewer bacterial and viruses that may be harbored within the toilet bowl. Traditional toilet flushing kits are aimed at convenience and contactless, but this prototype takes one step further and helps reduce the spread of diseases within bathrooms.

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1 Introduction

Coronavirus disease (COVID-19) is an infectious disease which broke out in December 2019. The first identified case was in Wuhan, China, and then it quickly spread through the entire world. Coronavirus is a bacterial and viral infection that is believed to be transmitted the easiest by sneezing, coughing, and closely followed by the droplets created from the flushing of a toilet (Gebra, Wallis, Melnicks, 1975). The spreading of diseases has become much more serious after the COVID-19 pandemic which sent the world into lockdown. As of June 26, 2020, there are roughly 4 million reported cases and over 48 thousand death cases. Over 1.3 million reported cases in the US weighs one third of the world total cases. The death toll in the US is almost 120,000 which is also roughly 33% of all deaths in the world recorded (Coronavirus Cases).

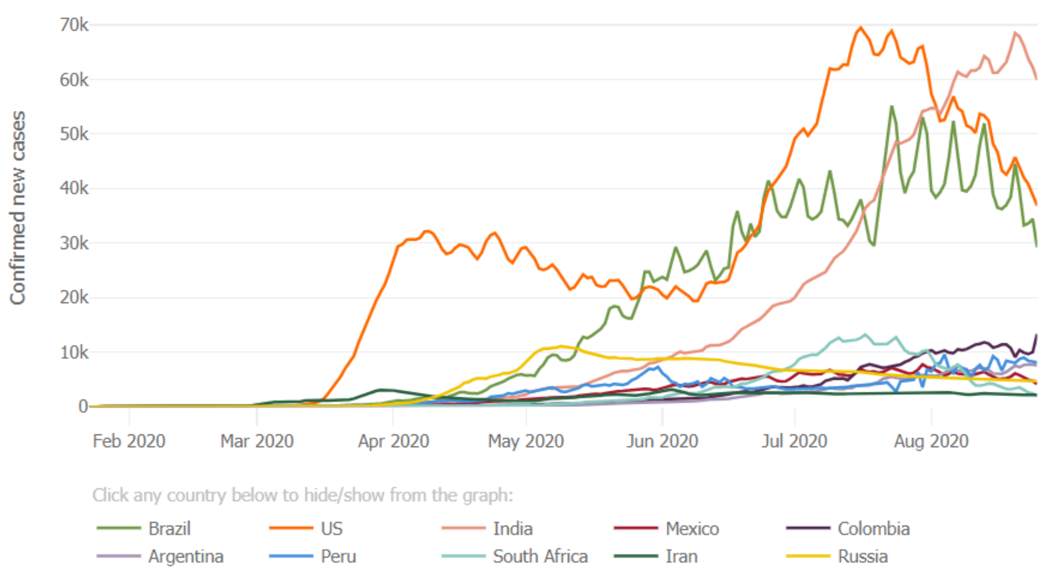

Figure 1 COVID-19 Cases (New Cases of COVID-19 In World Countries)

Restrooms are where various germs can easily spread and can harbor COVID-19. Flushing a toilet can propel small water droplets as mist into the air, coating everything around the toilet with it and being potentially inhaled by those using the toilet. Therefore, closing the lid before flushing becomes necessary. This is further backed up by articles like “Toilet Flushes May Spread Legionnaires’ Disease”, “Microbiological hazards of household toilets: droplet production and the fate of residual organisms." and “Flushing the Toilet May Fling Coronavirus Aerosols All Over” which can be found in the Bibliography section of this paper. The goal of this Major Qualifying Project (MQP) is to design a flushing system which can function only after the lid is closed and automate the flushing of household toilets to reduce human contact on surfaces.

1.1 Problem Statement

This project is trying to alleviate the transmission of COVID-19. From the findings in Volume 30 Number 2 of “Gerba, Wallis, and Melnicks’ ” book, the group has reason to believe the flushing of toilets increases the spread of the virus. Other bacterial and viral infections can also be spread through the droplets propelled into the air by the flushing of the toilet (Sheikh, K., 2020, June 17). Thus bringing forth the idea to have a controlled system to eliminate any human error and remain as sanitary as possible.

1.2 Purpose

The purpose of our project is to design an automated flushing system that only activates the flushing function after the lid is closed, and thus, reduce the amount of contaminated water released by the process of flushing toilets and human contact on surfaces.

1.3 Objective

The objective of the project is to create a prototype to automate the flushing of a toilet in homes based on the environments the group could test it in. The group only had access to household toilets since commercial toilets are set up differently. The toilet flushes from a motor pushing an arm which pushes the button within the water tank.

By automating toilets to flush either autonomously or by command, human contact can be eliminated relating to flushing a toilet. Eliminating or reducing the amount of human contact needed to use a toilet effectively reduces the number of contaminated surfaces which also reduces the chances of spreading diseases in homes.

Bacteria and diseases can cultivate and brew inside the toilet bowls. When bodily waste is excreted the bacteria inside of that person can also be found in the toilet bowl. The study conducted (Charles P. Gerba, Craig Wallis, Joseph L. Melnick, n.d.), rated homes as the ones with the most bacteria inside the towel bowl. This ranked higher than restaurants, service stations, and research institutions. By closing the toilet lid before we flush the toilet, the bacteria buildup within the toilet bowl will not spray out and spread within the bathroom.

One of the obstacles for owning a toilet that closes the toilet lid before flushing without using your hands is the price. Toto is a brand that originated in Japan that creates toilets with these features. Japan is regarded as a very clean country and their toilet technology reflects this. In the United States it is most common for bathrooms to have toilet paper while many bathrooms in Japan have a bidet that cleans up without any touching. More toiletry companies like Dollar Shave Club have begun selling toilet wipes and explain to the customers that these will be more sanitary compared to using toilet paper as the wipe does not rip like toilet paper. Therefore, places like Japan have resorted to bidet systems but these along with automatic toilet lids can be very costly.

Being more aware of the health risks relating to the buildup of bacteria inside our toilet bowls is the best way to promote a cleaner home. Commercials have marketed sanitary wipes as a necessity during flu season along with other alcohol-based products to clean surfaces and keep our hands clean. The number of bacteria being harbored in our toilet is something many overlook. Bringing awareness to the potential health risks present in the bathroom may encourage consumers to consider automating their toilet lids and flushing. This is especially important right now because COVID-19 is a new virus from the Corona strain. Doctors are still coming out with new developments and findings regarding how the virus works. Therefore, closing the lid on the toilet before flushing anything down will reduce the number of bacteria being circulated within homes.

2 Background Research

2.1 COVID-19

COVID-19 is part of the coronavirus family that ranges from the common cold to diseases like Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS). COVID-19 was first detected in Wuhan, China in December 2019 (World Health Origination, 2020, April 17). The virus is believed to be linked to a seafood market in Wuhan, although the first case reported on December 1st, 2019 had no link to the seafood market (Johns Hopkins Medicine, 2020, August 2).

The virus is known to spread through droplets expelled from people that are infected through coughing, sneezing, or talking. It is important to stay about 6 feet away from others and wear masks to reduce the likelihood of the droplets being spread. Washing your hands regularly and not touching your face also helps to prevent you from getting infected. The incubation period for the virus is about 14 days meaning you may not show symptoms of being infected but carry the virus and infect others (World Health Origination, 2020, April 17).

At first, the virus did not bring much concern to many countries until the number of infected started to rise rapidly. Initially it had not been discovered that someone carrying the virus could be asymptomatic which made it much more difficult to track and contain the virus. The US cancelled inbound and outbound flights to several countries to minimize the number of infected people entering the US. People who showed signs of the common cold were encouraged to quarantine themselves for two weeks in case they were harboring the virus. COVID-19 affects everyone differently ranging from a small cold to difficulty breathing resulting in hospitalization and needing a ventilator. A national state of emergency was declared, and states started to enforce city-wide quarantine and all non-essential businesses closed down. This left thousands of Americans unemployed. Schools converted to being completely online means around the month of March leaving campuses vacated. Not all states followed the same COVID-19 procedures, and this caused great discrepancies in the amount of cases across the U.S. Many businesses started to encourage wearing face masks or mandate people to wear a face mask whenever entering or they were not allowed inside. The stock market quickly crashed from the news of many businesses shutting down, bankruptcies, high unemployment, loans being defaulted on, and tenants struggling to pay for rent and necessities.

The government later passed multiple bills to help stimulate the economy and keep the economy afloat like the CARES act and the stimulus checks. American companies will get bailed out of bankruptcies if the government deems these companies too big to fail. America does not want to lose these companies due to political or financial reasons. GM and Chrysler were bailed out back in the 2008 housing crisis (Hartman, M., 2019, April 29). If any companies that America deems as too big to fail face financial hardships due to the COVID-19 economy shut down, we can expect the government to step in once again and bail these companies out.

Currently outside of social distancing, wearing masks, and not touching our faces without cleaning our hands, we do not have any way to combat the virus. There have been many home remedies or attempts to help speed up the recovery from the critical phase, but currently there are no confirmed methods that work universally. A vaccine has been in the works for months now, but there is no time frame for one. Updates regarding the advancement of the vaccine can be read from the FDA website. Depending on your immune system, you may experience no to light cold symptoms ranging to severe health risks and difficulty breathing.

2.2 Information about the spread of disease through the toilet

Bacteria

Flushing toilets will generate vortex; it displaces the air in the toilet bowl. Vortices move upward and the centrifugal force pushes aerosol particles into the air. Depending on the condition, aerosols may carry various kinds of bacteria that can be inhaled easily by the human. In addition, studies have proved that multiple bacteria exist in the human GI tract that can be excreted through human feces. If those bacteria enter parts of the human body other than the gastrointestinal tract, they may cause issues to human health.

Figure 2 Bacteria 1 (Farnsworth)

Enterococcus Faecalis is one of the most common species of germs found in Enterococci bacteria. Enterococcus Faecalis live mostly in the gastrointestinal tract, but it can also be found in the mouth and vagina. One of the traits of this germ is that it is highly resilient -- they can survive in high sodium chloride concentrations, high pH, and live for up to 30 minutes at 60 degree Celsius (Osmosis, 2019). E. Faecalis is normally harmless in the intestine, but once it spreads to other parts of the body it may cause serious infections. Patients may have sepsis, endocarditis, and meningitis by letting E. Faecalis enter blood, urine, or a wound (Watson, S., 2018, September 29).

Enterococcus Faecium a type of bacteria lives normally in the gastrointestinal tract of a multitude of animals; it can also be found in the mouth and vaginal tract. This germ can survive for long periods of time in soil, sewage, and inside hospitals on various surfaces. E. Faecium is mostly considered as a superbug. It has strong drug resistance; can colonize many organs of the body including the skin and survive for long periods on inanimate objects (Microbewiki., 2012, January 29). E. Faecium can cause nosocomial bacteremia, surgical wound infection, endocarditis, and urinary tract infections (Microbewiki., 2012, January 29).

Clostridium Difficile is a type of nosocomial bacteria which can spread through air, water, soil, and feces of humans and animals. Normally it spreads through health care facilities, but it's also possible to get infected by touching clothing or other surfaces that had contact with feces and then touch the mouth or nose. Symptoms of getting infected include diarrhea more than 10 times a day, severe cramping, fever, nausea, loss of appetite, dehydration, rapid heart rate ("What is Clostridium Difficile").

Legionnaires' Disease

Legionnaires' disease is caused by a bacterium called legionella. Legionnaires' disease is a severe form of pneumonia -- lung inflammation usually caused by infection (Legionnaires' Disease). This disease is a type of respiratory disease, so elderlies, smokers, and people with weak immune systems are particularly easy to catch Legionnaires' disease. The existence of legionella, the bacterium which causes Legionnaires' disease, is ubiquitous in nature, especially in the water or soil. Its most comfortable living temperature is between 25°C to 45°C, 35°C (Mayo Clinic, 2019, September 17). Therefore, places like cooling towers of the water-cooled air conditioner or water tanks, if it's not cleaned frequently, are suitable habitats for legionella.

A recent report shows people may inhale bacteria in the contaminated water which is released into the air when flushing the toilet (Rettner, R., 2020, June 11). According to the journal "Emerging Infectious Diseases", two cases have been reported contracted Legionnaires' disease in France are likely through inhaling toilet water that was aerosolized during flushing.

Coronavirus Disease

Wearing masks and following social distancing policy may not be enough for preventing spreading coronavirus. According to the CDC official website, the virus that causes COVID-19 has been found in some patients' feces. Another study shows that the water pressure of flushing a toilet can send aerosol particles almost 3 feet into the air, and the particles will linger in the air long enough until the next user to be on bathroom services (Sheikh, K., 2020, June 17). The particles might also land on surfaces in the bathroom and then infect people who had contact with the surface.

In a simulation of toilet flushing mechanism, it shows that when flushing, water pours into the toilet and thus creates a vortex, which displaces the air in the toilet bowl. The force pushes out about 6 thousands tiny droplets and even thinner aerosol particles, and depends on the number of inlets in the toilet, 40% to 60% aerosols produced are high above the seat (Sheikh, K., 2020, June 17). From the simulation scientists also found out that the toilet plume can carry infectious coronavirus particles which already appeared in the surrounding air or in a person's feces. The journal has also mentioned coronavirus will not only spread through respiratory droplet, but as well through virus-laden feces (Xiao, F., Sun, J., Xu, Y., Li, F., Huang, X., Li, H....Zhao, J., 2020).

Normally, the coronavirus is mostly found in lungs and upper respiratory tract. But studies have found it may also dock in the small intestine. Symptoms of patients show they may experience diarrhea, nausea, and vomiting (Sheikh, K., 2020, June 17).

2.3 Current Toilet Sanitary Measures

Good toilet and toilet hygiene can improve the health of life. In the current era of informatization and rapid development of science and technology, more high-end technologies are used in toilets. Changes in toilets are rapid. Many bigwigs in the field of technology have also foresight pointed out that the replacement of toilets has this very large development space, which also indicates that there are many business opportunities and markets to be developed. For example, Sameer Berry said, "Everything these days is connected and smart, but I feel like the bathroom is a very untapped area," (Wee, 2018)

2.3.1 Touchless Toilet Flush Kit

Touchless toilet flush kits are kits that can be installed into household toilet tanks and thus turn a household toilet into an automated toilet. On one hand, an automated toilet does not require human contact with surfaces in the toilet, which reduces the chance of catching diseases spread through touching skin or mucous membrane. On the other hand, it is not uncommon to see people kick the toilet lever when they don't want to touch the handle. Since human contact is not required, turning toilets into automatic flushing toilets will prolong lifespan of a toilet.

Touchless toilet flush kits often have several traits. First, they are cheap and easy to install. Most of the kits can be packed in a small box, and it usually takes less than 20 minutes to install, so people are willing to buy such convenient products to update their household toilets. Second, many of the kits have a dual flushing system. The sensor in the pack will automatically detect the time of the object appearing in the front. Based on that, the system will switch between full water flushing and half-water flushing. In the course of time, it will save tons of water. Another common trait many flushing kits have is that its power consumption is extremely low -- only five or six batteries can support tens of thousands of times of flushing.

2.4 Toto Ltd

Just like lots of other countries in the world, most of the toilets in Japan are bidet toilets. And those toilets in Japan are more elaborate than in other countries, both on appearance and functionalities. Toto Ltd. being the largest toilet manufacturer, was founded in Kitakyushu in 1917. It is famous for developing the "washlet" and derivative products. A washlet is a trademark registered by Toto, which is a type of cleansing toilet seat with a water spray feature that cleans private parts after excreting.

There are many problems with the current toilets in the United States. In public toilets, it is easy to find that the water in many toilets is always more than three-quarters. And for users, it is very uncomfortable to splash water on the skin. This is one of the side effects of "pulling up the water level". American toilets are prone to blockages. The toilet drainpipes in the United States are relatively narrow, which has a considerable risk of clogging for toilets that are generally water-absorbing. Waste and the water in the toilet flushes into a device like a "collecting tank". This process generally requires a pipe at least 5 cm wide. The team finds that many American toilets do not have a toilet cover at all. Strict In a sense, especially under the influence of today's epidemic, this is a fatal mistake. The team has explained the difference between closing and not closing the toilet. Good toilet cleaning measures can essentially reduce the spread of bacteria.

In terms of the use of toilets and the popularization of high-end advanced toilets, the United States has not set a precedent in the world. This is caused by market reasons and cultural habits. In the use and development of advanced toilets, Japan is well-deserved. Many foreign tourists have an impression of Japan's tourism, not just the scenery and culture, but also the Japanese toilets. Japan generally has a high degree of automatic control equipment, which includes automatic cleaning devices, seat temperature heating devices, automatic drying devices and sterilization and deodorization functions, and some toilets even carry music devices.

Japan's "toilet revolution" started as early as the 1980s. One of the companies named TOTO, at the time, TOTO launched Washlet, the first electric toilet seat with an integrated bidet. The advanced toilet entered the US market in the 1990s, but it did not win the market. One of the reasons is its high price. The second reason is the cultural reason. Japanese people are very concerned about their own cleanliness and give the impression of others. Bathing and hand washing are so frequent that users would see many Japanese people wearing masks on the street, which effectively prevents the spread of the virus.

In general, there is no demand for such products in the United States, which requires the popularity of many competing companies in the market to the American people and the American people to really feel the comfort brought by smart toilets.

3 Methodology

3.1 Explanation

This project is aimed towards helping deal with a global issue that has risen in the last few months. The group has been looking into sensor and motor options that work with the Arduino to realize our goal of making an automated toilet. The parts were compared to each other and the needs helped narrow down our parts selection. Since quarantine is still in effect the group worked on the project remotely without physical contact. One person oversaw the mechanical realization as others worked closely with another group that was creating a prototype that closes the toilet lid without using hands. Both groups were using the same toilet since each group had a teammate that were roommates. This allows both designs to work together seamlessly in the same environment under the same conditions. The rest of the team divided the writing work evenly with deadlines on when each section needed to be completed by. Since the group was not able to meet in person and some of the teammates had other commitments outside of the project like family and work, the project moved slower than if the group had worked on the project in person. Also due to limited supply of materials and longer shipping times, parts took longer than usual to arrive which reduced the amount of time to troubleshoot the prototype and improve on the design. The design mid-way through had to be changed from using an inductive sensor to using a push button as the push button requires less time to integrate and have a functioning prototype. The group also could not physically help with troubleshooting as no one in the group had an Arduino except the teammate doing the mechanical realization.

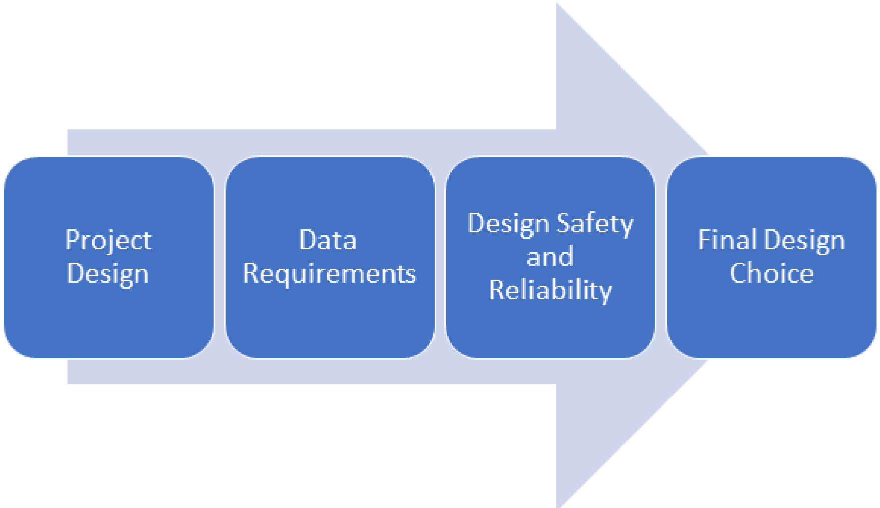

Figure 3 Methodology Outline

3.2 Project Design

3.2.1 Overall Summary

In terms of purpose, the core of the experiment is to design a flush system which is a non-touch type detect whether the toilet lid is closed, and to give instructions for flushing. In the beginning. The team needs to have a feasible plan for the overall implementation of the design and produce the theme logic. It is necessary to split the large design into smaller parts and solve them one by one. When the design and logic are both established, materials are purchased for actual realization

For the design, it is first necessary to consider the convenience of the design, so that most people feel relatively easy to use and have long-term effects. This requires people of all genders to use the toilet method, including people of different heights, and their average arm's length. The aesthetics of the product appearance is also one of the factors considered. A good design can be competitive at a high price or occupy more markets at a moderate price in future commercial mass production.

The core design of the project needs to explain how all these components and equipment realize the designed functions, which include the selection and logic of each sensor, the overall program logic, and the coordination between related components. Code needs to be specific to the meaning of each instruction accompanied by a clear explanation. Relatively accurate calculation and analysis are required through auxiliary software (Arduino IDE, MATLAB, and SolidWorks). The purpose of this implementation is to facilitate subsequent program improvement and system analysis after some failures.

For the selection of material and components, the processor and sensor need to be selected and compared at the beginning of the design, and based on the parameters design needed, choose the most cost-effective or the most easily realized product. The remaining alternative materials can be discussed in design to aid with subsequent design. It is necessary to consider related materials, such as connecting wires, soldering guns, double-sided adhesive tapes and so on. At the beginning of the experiment, all the parts needed are roughly estimated to ensure that the experiment is completed within the specified time and should not appear. The fact that the materials did not arrive on time affected the progress of the experiment.

From a safety perspective, the team needs to consider the safety of the equipment, whether it is harmful to human health, and whether it is necessary to keep minors or children away from the equipment to prevent unnecessary harm. For the safety of products that need to be considered, especially in the bathroom, circuit components are easily exposed to moisture directly or indirectly. It can cause the sensor to lose its function, and it can cause harm to users. Based on experiment requires a motor with a relatively large torque to ensure that the child's accidental touch can cause damage to the body, this safety factor can be relatively avoided from the appearance design, the location of the motor, and the logic of the program.

Additional attention, for example, the project team needs to consider the power supply of the battery in use, assuming that the number of times a day is used to simulate the estimated time that the battery can be used, which is convenient to remind users about the time to replace the battery. In addition, the design needs to consider whether the battery can provide sufficient rated voltage to make the motor work normally under long-term use.

Finally, the overall design needs to consider the hardware cost required to design the product, which means that it is necessary to use cost-effective materials as much as possible to become the best designed product. This is a reference price aid for mass production in the future. In this design process, the team or needed references come from public papers, program templates, statistical parameters, Arduino development platform and SolidWorks to assist in implementation.

In order to allow the user to freely manipulate the sensor, it is relatively simple to give sensor instructions and effectively obtain feedback, and the team needs to consider such factors, such as price, safety, difficulty of use, maintenance cost, etc.... All saying above, the WPI team needs to meet the design in four perspectives, which are the realization of product function; the safety of the product in long-term use; the reliability of the product in long-term use; and the cost of the product and maintenance cost.

3.2.2 Design Functionality

For the first implementation of the program design, the team proceeded in a relatively easy way and got a fully functional sample. This is helpful for subsequent data feedback and experience accumulation. The first set of integrated design concepts is to make the processor perceive the user's instructions to flush or finish the toilet. Secondly, based on the feedback of the first instruction, the team used the sensor to determine whether the toilet lid has been closed after use; Finally, based on the determination result of detecting whether the toilet lid is covered with the sensor part, the Arduino gives the motor two instructions to flush or not to flush. After completing a series of commands, all sensors return to default values and are ready to be used for the second time. In this process, the LED lights can be used as the standard for inspection status, and it is easier to get feedback information during the test phase. Regarding the microprocessor, Arduino R3 was chosen because it has the minimum requirements to meet the functions required by the design and a relatively cheap price. In addition, Arduino has a relatively more open platform and a lot of resources. In addition, the team needs a sealed box to hold the processor to prevent it from getting wet, and a long enough cable to connect the three sensors.

3.2.3 Parts Design

Motion sensor design

Regarding the choice of the motion sensor, since non-contact detection is required in function, it is relatively possible for a distance-type detection device or a light-source-type detection device to achieve the required functions.

The first solution is to use Ultrasonic sensor as a motion sensor for detection. Ultrasonic sensor, as an ultrasonic detection sensor, has the function of detecting objects in the front range. The speed of propagation of electromagnetic pulses and recovery is the speed of sound propagation in the air, so the use of toilets basically meets the requirements of high-speed reading. Its detection distance also completely covers the required detection distance. (For specific information, please refer to the Design Choices section and the Data requirement section for more relevant data.) The difficulty of using an Ultrasonic sensor is that any small object can be detected in the area in front of the Ultrasonic sensor, which can cause misjudgment of induction with very high probability. Whether it is caused by human accidental touch, insects, pets, etc., it can increase and affect the judgment of the motion sensor detection part, thereby giving extra signals to the Lid detection part which is unnecessary. In order to avoid such a situation, in the process of design, Ultrasonic sensors need to meet the requirement of detecting the required distance in an instant and enter a created method for recording time. In the process, the team needs to use counter logic to avoid when the distance is reached. In the design process, it is necessary to set a "state" for each different condition, so that it is relatively easy to distinguish each other. When the distance changes again, the Ultrasonic sensor uses the same logic and time method to record a new point in time. When the time difference is longer than a specified time, it can be proved that the Ultrasonic sensor does need to execute logic.

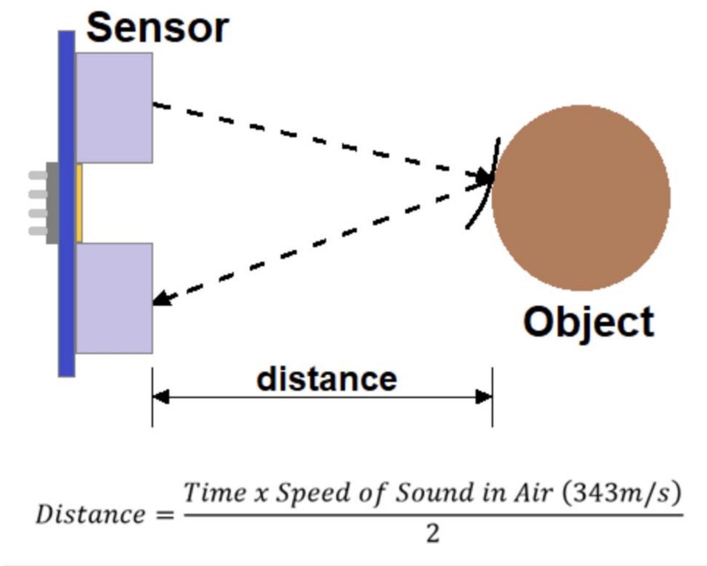

Figure 4 Ultrasonic Sensor

For the selection of the placement position of the Ultrasonic sensor, the Ultrasonic sensor would be placed on the upper side of the toilet tank and installed in a self-made waterproof box. One surface of the box is a curved surface or a similar shape that can provide an angle. There are two holes on the curved surface for the pulse signal of the Ultrasonic sensor to be transmitted and received. The positions of these two holes would be on the slope and above, and the specific angle would be calculated in the data analysis section. The purpose of the Ultrasonic sensor with a relatively upward angle is to make it easier for people to reach out to detect, because the toilet is relatively low. When the user finishes using the bathroom, he or she needs to get up and stretch his or her hand in the direction of the Ultrasonic sensor and hold it for at least for example 2 seconds. In this case, the Ultrasonic sensor can set the distance change and the time of the hand stay. When the conditions are met, Arduino can be given to check whether the toilet lid is closed.

The second solution is to use IR sensor as the motion sensor, which includes passive IR sensor and Activity IR sensor. The purpose is to let the IR sensor detect whether there is something approaching and whether the stagnation time is up to the standard. When the above requirements are met, it can execute the detection of whether the toilet lid is closed. In this experimental plan, the WPI team would propose a change plan as an alternative, but it cannot be realized. The purpose of the proposed change in the design concept in the article is to give the relevant design team a reference point.

Micro-switch to detect the lid

According to the signal detected by the motion sensor, the detection sensor needs to meet the requirements of detecting whether the toilet lid is closed, and gives new instructions to the Arduino R3 according to whether the toilet lid is closed to achieve subsequent functions. For detecting whether the toilet lid is closed, the first solution designed is to use the principle of Switch to detect whether the secondary parallel circuit is HIGH MODE or LOW MODE and based on the feedback to determine whether the toilet lid is closed. In the design, a Micro-Switch or similar structure sensor needs to fix it at a position on the lower side of the toilet seat. When the toilet lid is closed, the lid of the toilet can push the Trigger of the Micro-Switch downward to cause the circuit to switch to the path. To protect the circuit, the team needs a series resistor to ensure the safety of the circuit when it has not been triggered for a long time. To better identify the circuit, an additional LED was added in this part of the design process to confirm the status of the Micro-Switch. In addition, for the fixed location of the Micro-Switch, the team needs to consider its 3D modeling and all parameters when purchasing the Micro-Switch. In addition, for the tested toilet, the vertical height from the bottom of the toilet to the cushion, the thickness of the cushion, the thickness of the toilet lid, and the ceramic arc at the bottom of the toilet must be measured during the design process. These data help to design a three-dimensional model to assist Micro-Switch to achieve its functions. Considering the user's comfort, the position of the Micro-Switch cannot coincide with the toilet lid and toilet seat. If they overlap, the user may be injured when the user sits down, or the user may destroy the functionality of the Micro-Switch. Either of the two needs to be avoided as much as possible in the design process. The ideal and safer way is to parallel the Micro-Switch to the toilet seat and toilet lid. The connection between the bottom of the toilet seat and the Micro-Switch is realized through 3D modeling. The actual connection of specific things can be completed by double-sided tape.

Another advantage of this is that it completely avoids contact with the toilet seat. Assuming that the Micro-Switch is fixed on the toilet seat, although new modeling time and design can be saved, when the toilet seat moves upward perpendicular to the toilet (that is, when leaning against the toilet lid), the mechanism may be triggered by mistake, resulting in function failure, and relatively difficult to deal with. When the Micro-Switch trigger lever is parallel to the toilet seat and toilet lid. Even how the toilet lid is moved can not affect the Micro-Switch detection. Fix a rectangular lever perpendicular to the toilet lid and the Micro-Switch on the toilet lid, and the position intersects the trigger mechanism of the Micro-Switch. In this case, when the toilet lid is closed, it can automatically trigger the Micro-Switch to change the circuit so that the Arduino can receive instructions. (Closed or not) The problem that needs attention in the overall design process is that the value of each data meets the requirements of height and length. For the 3D printing process, the team needs to increase some parameters appropriately to prevent the printed parts from being nested.

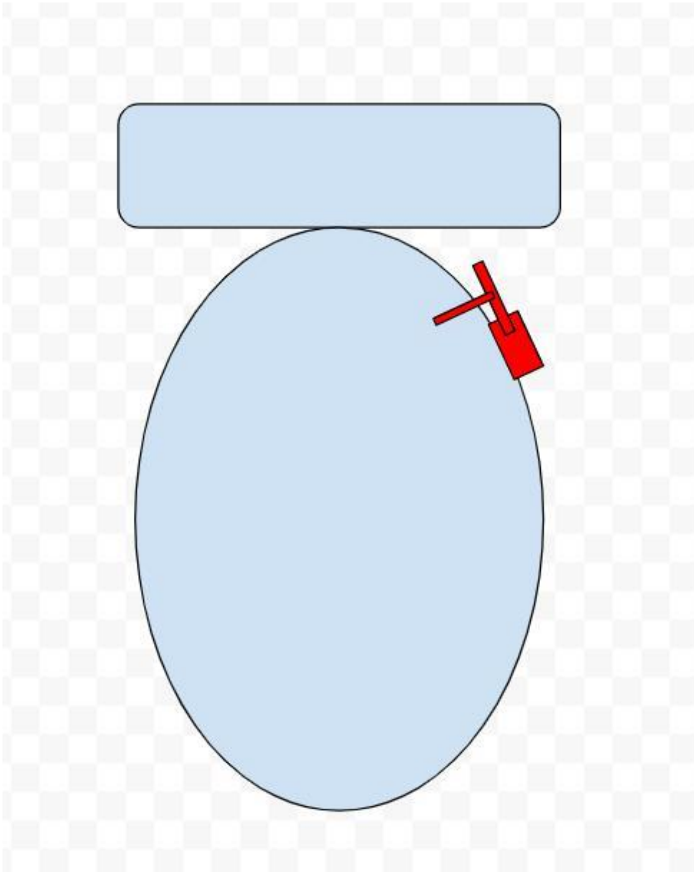

Figure 5 Position of Lid Detection

Another alternative is to use an inductive sensor to detect the toilet lid. When the metal approaches the inductive sensor, the current detected by the inductive sensor would increase. The implemented design plan is to fix the inductive sensor at a position on the lower side of the toilet and place a metal block on the toilet lid and fix it within the range deliberately detected by the inductive sensor. Arduino detects the amount of current received by the inductive sensor when the toilet lid is not closed, and the amount of current detected by the inductive sensor when the toilet lid is closed. The former is marked as lid closed and the latter is closed. Like the Micro-Switch idea, when the motion sensor gives a detection command, the inductive sensor detects the current. When it is the closed current, the next program is executed. If it is not a closed current, it is deemed uncovered.

Motor sensor

After the Arduino reads the part of the Motion sensor and the instructions of the Detect of lid part, Arduino R3 needs to give the motor instructions to drive the motor. When the motor is running, it can provide the speed and torque, and change the direction of force during the realization process or adapt to the needs of flushing the toilet. In terms of motor selection, the options at the beginning of the design are DC gear motor, Servo motor and stepper motor. The experimental team needs to roughly measure the actual force required to push the experimental target toilet. The specific method is to fill an empty beverage bottle with water, close the lid and use one end of the lid to naturally press the water button. Until the team kept testing to add different amounts of water, when the amount of water is just enough to push down the toilet flush button naturally, use a spring dynamometer to measure the total weight of the water bottle and the water inside. On this basis, the reason why stepper motor is not a priority is that stepper motor is driven by magnetic force. In the case of relatively high downforce and relatively low rated voltage, the stepper motor generally does not have enough torque. For the motor, the final design is to use Servo motor or DC motor.

The first design plan is to transform the motor into linear force. The general method is to connect a fixed-length pin to the port of the shaft and connect another pin to the other end of the pin. The bottom of the outermost pin contacts the push bottom of the toilet to form a relatively linear force transmission. Here the team needs to calculate the depth of the toilet flush button down. Because linear transmission requires a four-bar linkage to achieve, it is achieved by three R types pinpoints and one P (sliding) type pinpoint. According to the measured linear vertical sliding depth, through dynamic analysis, it is necessary to request the specific position of each point in the process of angle change. Finally, confirm the degree of change of the input rod to confirm the torque that the motor should provide. (The WPI experimental team used DC gear motor and Servo motor to achieve this. In the end, Servo motor became the best option. The specific reasons why the DC gear motor was not used will be analyzed in the result.) To measure the change of rotation, MATLAB is used for programming and calculation in the program, and SolidWorks is also used for modeling. Assuming that the side view is a plane, an XY coordinate system is set up, and the actual position of the motor is accurate according to the toilet flush button. Model, and input the built data into MATLAB for calculation. When everything goes well, 3D printing materials can be used to realize the realization. In addition, the design can also use the evaluate tool to measure the number of angles of change after the SolidWorks modeling is completed.

For the specific design of the four-bar linkage, the purpose of the four-bar linkage is to connect the angular velocity provided by the servo motor to an aluminum horn, and then connect to a device that touches the toilet flush button through a pin to convert the angular velocity into a linear vertical sliding process. The difficulty of this process is that the process needs to accurately measure the position of the servo motor and the distance from the toilet flush button, including the distance between the time and the distance. For the trigger contact part, it is necessary to design a circular bottom surface that can be attached to the ground at the button. The fixing method is to fix it with double-sided tape, which causes this part to be sliding friction. The toilet flush button in the experimental test can be controlled. The depth is 15mm, so the distance that can be slid and rubbed is 15mm. On this basis, the angle of rotation of the servo motor connected to the horn needs to be measured. This can ensure that the four-bar linkage would not be damaged due to excessive rotation. Specific materials can be 3D modeled and 3D printed. M3 20mm screws would be used to connect the horn. The aluminum horn is used for long-term reliability. On the basis of the above, when the instruction given by the motion sensor is detected, and the toilet lid has been detected as closed, the input is delivered by controlling the degree of the motor rotation angle or the rotation speed, which is the control angle, so as to achieve flushing instruction.

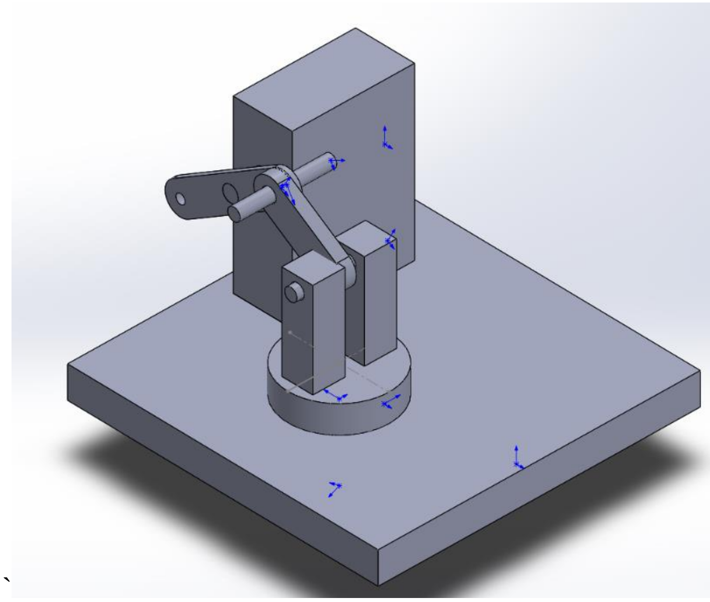

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Figure 6 Servo Motor Device

The second, easier and relatively simple design is to directly place Servo close to the toilet flush button, and also use the previous 3D modeling and MATLAB programs to assist in calculating the degree of rotation required to push 15mm in the vertical direction. The first one has fewer choices on the second material, but the two design schemes would be released for comparison. In addition, most of the servo needs to be placed in a waterproof box in the design. The reason is to ensure that the connecting circuit will not be damp or physically damaged. Second, it can improve the appearance. Third, it can prevent children from contacting as much as possible. It hurts fingers or body parts.

The last alternative is to design a gear that can just be stuck on the shaft of the motor. In addition, a cuboid needs to be created through 3D modeling, and its inner sides have the same shape as the designed gear. Then insert the gear into this rectangular parallelepiped slot. On this basis, the cuboid is fixed with two vertical planes. When the motor rotates, the cuboid can move up and down. When the rotation angle is controlled, the direction of the cuboid movement can be controlled. When the cuboid moves down, the push button can be touched to complete the automatic toilet flushing function.

3.2.4 Logical design

Combine logical

The overall design logic is basically composed of three major parts. At the beginning, it is necessary to calculate whether the distance of the hand close to the sensor meets the condition, and then according to whether the condition is satisfied, it is determined whether the required goal is achieved in time. If this part is established, then enter the operation of the next sensor part, if any one of the calculations does not meet the conditions, the whole needs to return to the origin. When the distance and time are up to standard, the principle of Switch determines whether the toilet lid is properly closed. If it is not covered, it needs to return to the original point as well. If it is covered, the circuit path will run the next flushing command, and the servo motor will be adjusted to change the relative angle to push to flush the toilet. The following is the specific logical realization of each step for this experimental example. More specific codes will be found in Appendix. Even if different platforms and differences become languages, there are still many ways to achieve the required functions. The following is a simple Flow-chart to clarify ideas.

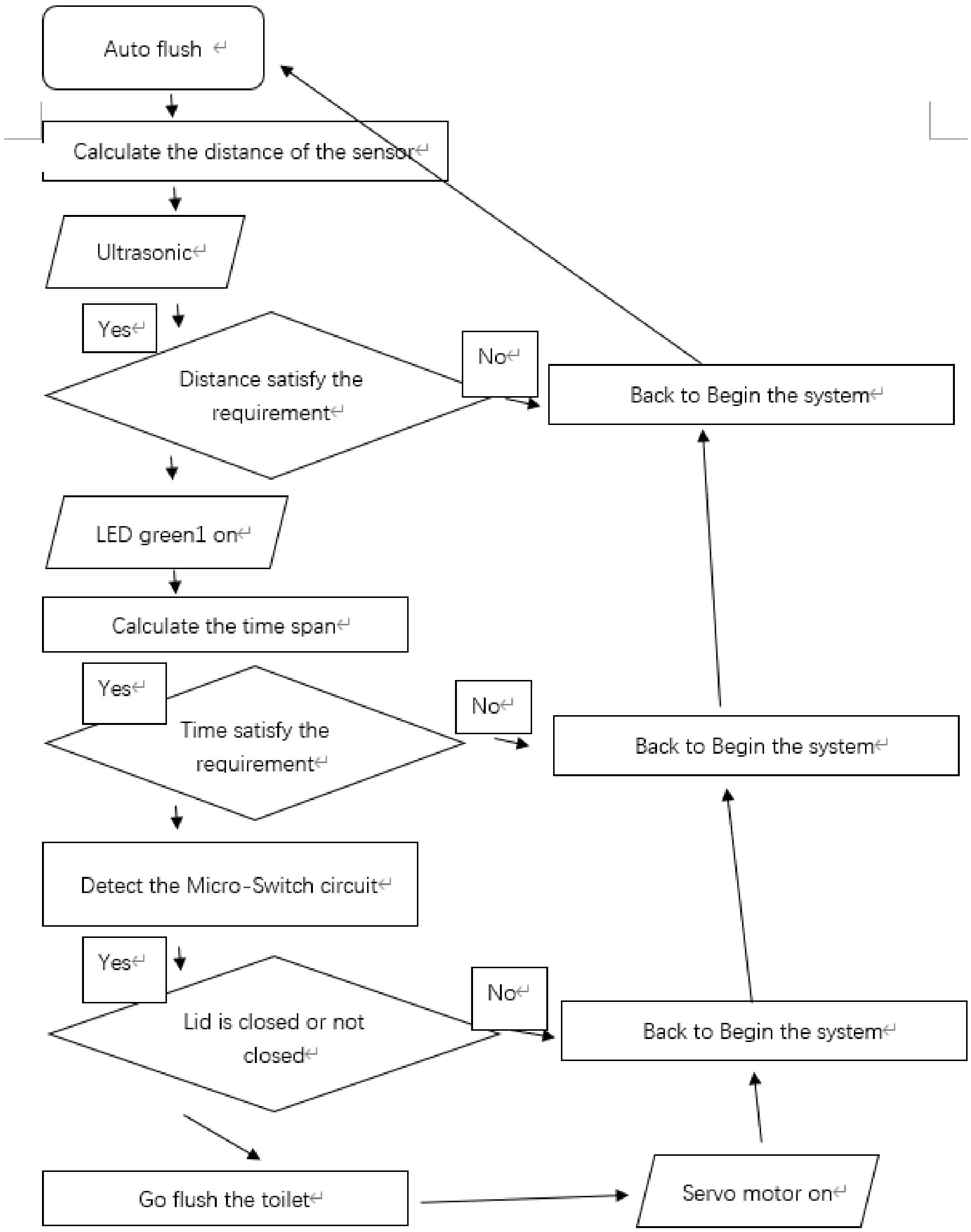


Figure 7 Logic Flow Chart

Motion sensor

For the realization of the Ultrasonic sensor to detect a fixed distance or a prescribed distance range, and to give a time judgment, the realization of a program that can run correctly is the first priority. In this experiment, designed a port to provide an electromagnetic pulse signal port, and another port to provide signal receiving. Define the amount of two int values, named trigPin and echoPin respectively. To calculate the time difference and write methods, six variables need to be defined. The first three variables are used as variables for recording time, and the unit is unsigned long. Three unsigned longs need to be defined here, and they are named begintime, stopTime, and timedifferent. begintime is used to start timing when the Ultrasonic sensor receives the required signal for the first time; stopTime is used as the second time point recorded when the distance changes during the first evacuation; timedifferent is used as the difference between the two time points. The unit of the last three variables is not a single option, but only as a reference value for recording changes. Another three ports that need to be defined are three LED lights. The purpose of the existence of the three LED lights is to give users relatively clear signal feedback in the realization, and secondly, it is easier to test and improve in the process of team design. The corresponding LED colors are green, yellow and blue. Finally, in order to achieve the test distance, two variables need to be defined in the design, which are the value of the Ultrasonic receiving time difference, which is defined as the long type, and the detection distance, which is defined as the int type. Above, all the variable definitions detected by the motion sensor and the port selection are completed.

Secondly, the design needs to give different sensors different inputs and outputs in the program. Assign three LED lights to OUTPUT type, and they will emit light in practice. Define trigPIn as OUTPUT type, the purpose is to make it able to send out electromagnetic pulses. EchoPIN is INPUT type, its purpose is to receive electromagnetic pulse feedback. For the program part of the implementation, the design is divided into two parts and discussed separately. The first is to complete the functional realization of Ultrasonic. The function that needs to be realized is the detection distance. In order to get the distance, the design needs to get the value of duration in the test, and based on the return time given by Echo, the team can calculate the distance between the object and the sensor. The calculation logic is to multiply the reception time by the speed of sound in the air divided by two to obtain the value of distance. At the same time, the team uses the pulseIn method to turn on echoPIn to HIGH to record the return time of sending electromagnetic pulses, which is recorded as duration. Based on the time given by Echo to return, to calculate the distance between the object and the sensor. The calculation logic is to multiply the receiving time by the speed of sound in the air divided by two to get a relatively accurate distance. Secondly, the second big logic is to receive the signal within a certain range, determine whether it is effective in time, and draw a conclusion. First, in order to record the time, the method of detecting the time needs to be designed. In this experiment, the miles() method is used to achieve recording. Based on the data support provided by the Data requirement, in the first experiment, assumed that when the distance detection is less than 50cm, the default is that the user has extended his hand, and the design needs to require the user to hold for about 2 seconds. Therefore, when the detection distance is less than 50, the blue LED is first ordered to light up, giving the user the designer information which is currently less than 50; so on, a built-in if statement determines that the begin time needs to be activated immediately and assigned a value. The purpose of this if statement is to sense the change and record the time when the distance is less than the first time. Since the user's hand cannot stay at the specified distance instantly, the begintime will be refreshed all the time, and the time is not really recorded, and the program finally fails. When the user withdraws his hands, the distance will change again, the detection distance is greater than 50cm, but at this moment, a new problem arises. In the design logic, the same logic needs to be used to measure the stopTIme time after the distance changes. But the difficulty is that the design needs to let Arduino know that only the time is measured in the new changes after the specific reduction, rather than the infinite measurement of stopTime when the distance is greater than 50. The solution in the design process is to add 1 on a condition1 at the end of the last if statement. This makes the value of condition1 change from the original 0 to an integer greater than 0. Logically, it can be understood that when condition1 is greater than 0, it just meets the change of distance reduction and waits to calculate the time difference. The next step is to use the same method miles() to record the time point of stopTime.

The same theory, the design does not require this statement to be executed repeatedly in the command again, causing stopTIme to be constantly refreshed and assigned, so use add 1 on condition3 to end the repeated calculation. In the experiment and in practice, in order to make the observer better see the sensor feedback, when the distance is reduced, the blue LED lights up; when the distance changes more than the detection distance, the blue LED lights off, and the yellow LED lights up. This means that the detection distance has just changed and recorded it. In the design of the Motion sensor part, it is mentioned that in order to prevent false touches, the detection of time difference is set, so the next judgment is the detection of two conditions performed in the interior of the yellow light, whether the time is up to the standard. Given this goal, use the if statement to determine whether the time is up to the standard. If this condition is met, the LED would be green, etc. which means that the command is received, ready to execute the command to detect whether the toilet is covered. If not, there is no need to execute. After performing the above process, the yellow light is still on in theory. Set the assignment of condition1, condition2 and condition3 to return to 0. In this basic situation, It can prepare for the next decision. The last state is that the distance is greater than 50 and condition1 is 0, just turn off all lights.

Execution logic of MicroSwitch

For the execution logic of MIcroSwitch, MIcroSwitch can be regarded as a switch that can control the circuit to be disconnected or connected. When the toilet lid is closed, due to gravity, the edge of the toilet lid touches the touch port of MIcroSwitch, which causes the internal switch to be pressed down and the circuit becomes a closed circuit. Two values need to be defined in the program design, namely an LED light and Micro-Switch. In order to make Arduino R3 assign two value commands, the new LED4 is actually made to use port 2, and the port of Micro-Switch is set to 7. Both values are defined as int types to meet the conditions.The pinMode method is used to make the LED in the OUTPUT state and can emit light; the pinMode method is used to make the Micro-Switch into the INPUT state, which can detect whether the circuit is closed and open, and whether the toilet lid is closed on the side. For the method used, the Micro-Switch state is determined by using digitalRead. If the mechanism is triggered, port 7 will receive LOW feedback. At this time, use digitalWrite to make LED4 glow, and the response state is that the toilet lid is closed. In the case of else, the trigger mechanism is not triggered, port 7 is detected as HIGH, and LED4 does not emit light.

Motor

For the logic of the motor, there are two situations in which it can be implemented. The first one requires an additional design of four-bar linkage. The second one directly connects the servo motor to the aluminum horn and gives the relative rotation angle to push the toilet flush button.

First, before the main program starts, it is necessary to test the controllable interval of the Servo motor, so it is necessary to write a set of procedures to determine in which interval the servo would operate normally. To give the servo motor a rotating output. In addition, because the purpose is to test the motor, it is necessary to add Serial.begin to the setup. The purpose is to know the status of the servo by printing the current value during operation. For realizing the use range of servo, a loop can be designed to read the actual degree of rotation that can be turned in the design. For better observation, a long enough delay can make the test more accurate, but it would take more time. In the process of this test, it is necessary to test the range that the servo motor can read, which helps to select the number of angles of change later. After obtaining the rotation value interval, calculating the number of angles that need to be rotated is the core of preventing the servo motor from being damaged or other parts. Here are mainly two methods of testing angles. Both methods need to measure the position of the toilet motor and the position of the toilet flush button, and the distance between the two. When the toilet flush button is at the bottom, it is the distance between the motor and the toilet.

The first method is actual modeling. By measuring the size of each part, three parts need to be simulated. The first part is the simulation modeling of the servo motor. Note the length, width, and height of the servo motor and the rotating gear. The three-dimensional coordinates. The second part is the length and initial position of the three linkages. Here is a "good" guess in the sequel design. To use PMKS completed by other WPI MQP teams to complete the simulation of the mechanical structure and the simulation of the motion trajectory. Modeling on this basis. For the design of four-bar linkage, it is first necessary to determine the initial coordinates of each point to determine whether the designed four-bar linkage meets the actual requirements. Four-bar linkages of different shapes can have completely different trajectories even if the input is the same. In the beginning, the position of the actual servo motor and the position of the rotating gear will be measured with a ruler. The design assumes that the bottom midpoint of the servo motor in the left side view state is (0, 0) coordinates. Knowing the length of the purchased aluminum horn, the two-dimensional coordinates of the upper end of a horn can be estimated first. In the third part, the experiment needs to measure the two-dimensional coordinates of the center of the toilet flush button in the side view. After measuring on this basis, the relative fix position has been determined. Next step needs to simulate the approximate motion trajectory. SAM, Working model, PMKS can all be used as reference materials. Here the team used the web software PMKS developed by WPI's previous MQP team (a project jointly completed by the CS team and the ME team). And would simulate the approximate Four-bar linkage movement trajectory on it. Take this as the support of design theory. On this basis, the design needs to realize the specific rotation angle of the servo motor. This is very important because the pressing depth of our flush button is a customized one, and an excessive rotation angle would cause our four-bar linkage to be damaged. To better and relatively accurately estimate the number of angles the servo motor needs to rotate. it is convenient to modify the code of the servo motor part later. Here can regard the four-bar linkage as an initial point as a fixed position which provides input and a fixed angular velocity clockwise. At the end is a vertical sliding part, and because of the maximum distance of sliding. To solve the dynamic process, here the team decided to use circle-intersection and loop equation methods to find the changing coordinates of each point in the process of changing the number of angles. The specific mathematical logic is based on the connection of two vector coordinates. If the initial point and the end point of the vector coordinates in the other direction are consistent with the first two coordinates, then the equations can be connected. To set the initial coordinates to the sliding coordinates as O, A, B, and C, and then rename each linkage. At the end of the equation, the team needs to check the number of angles that have been rotated when C moves down 15mm. For the first design, using four-bar linkage, the design needs to consider the size of each part and the difficulty of printing. The third part is to simulate the circular surface of the toilet flush button and its sinking position. To use SolidWorks to assemble all parts through various relationships of merge. At this time, a rough simulation of the real flush is completed. The second way to find the angle change of the servo motor is to convert SolidWorks to the side view on the left, and then use a tool to measure the angle between the motor gear and the aluminum horn and the horizontal plane. The number of angles is obtained by the Pythagorean theorem of triangles. Secondly, simulate the movement. When the four-bar linkage pushes the flush button to the lowest position, the angle between the motor gear and the aluminum horn and the horizontal plane is also measured by the tool. At this time, the angle of rotation of the servo motor can be relatively accurate by adding the degrees of the two included angles. If the design adopts the second kind of direct use of aluminum horn to push the flush button, use the same logic modeling and evaluate the angle change.

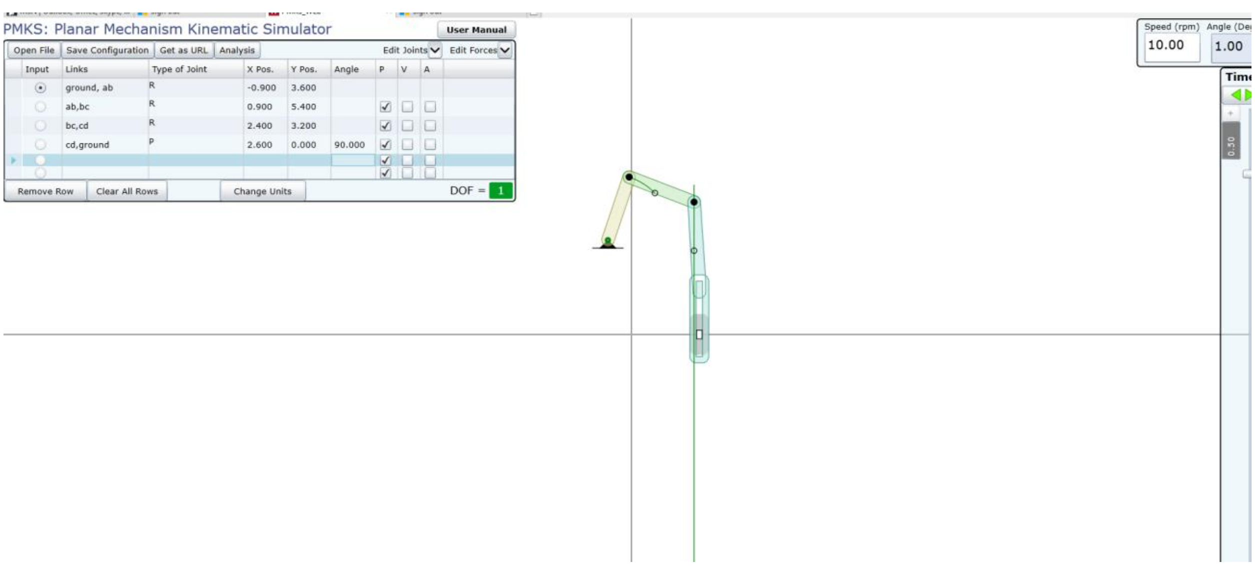


Figure 8 Four-bar Linkage Using PMKS

Finally, on the Arduino R3, the team needs to control the servo motor to have the correct rotation degree based on the above analysis, and the program needs to make the servo work normally. This is in the experimental stage, because the Micro-Switch part of the program is relatively simple and has a close logic with the servo motor program, the two parts are directly integrated here. There are two ways to write a servo motor. The first is to import the package. The second is to use analogWrite to achieve angle changes. In the first test, the include way would not be used. The team needs to define four int values. For the input and output setting part, firstly, the LED light and Switch for detecting lid detection are given the functions of output and input; secondly, the Arduino port number 11 is given to the servo motor output. In addition, the condition4 is assigned to 0, which makes it the first time The condition4 is 0 when it starts running; the Serial.begin() statement is mainly to facilitate the feedback of the monitoring port during the test phase.

For the design of the program, based on the program logic of the Micro-switch part, when the Switch's mechanism is punished and the LED turns on, it logically needs to start executing the motor command. Of course, it only needs to be executed once each time, so in the process it needs to enter 1 on condition4 to ensure the number of times the servo motor runs. Here condition4 can be understood as the ultimate instruction, the instruction that satisfies the motion sensor and the instruction of lid detection. In the if statement that triggers LED4 to turn on, a judgment needs to be built-in to make the servo motor rotate. The judgment condition is that condition4 is greater than 1. Under this condition, the rotation angle is assigned according to the rotation degree measured above and the value roughly corresponding to the degree. To give enough time for the servo motor to rotate, give the value of the degree after the rotation, and give a time delay response, and finally return to the value of the original first angle to complete the regression. After performing this series of operations, reset condition4 to zero. There are no components in the else statement, only turn off led4.

3.3 Data Requirement

Throughout the design, there were many different data required in each part. In order to do a better job in part selection and implementation during the pandemic era, and for saving the budget as well, it was necessary to at least give each data a range by calculations. So that it could be more efficient on choosing parts' brands, sizes, functions, and parts locations etc. In the following sections, the team had calculated many different data from each aspect of the pushing force, power source, motion sensor, micro-switch, and motor.

3.3.1 Force

There are two types of toilet flush that are most widely used -- lever and push-button. Data collection and project designing was based on one of the team member's household toilets. Therefore, the sample would mainly be based on the push-button type since the household toilets are all push-button toilets.

Figure 9 Toilet Types

In the first place, it was needed to know how much force was being used to push down the button. The data was crucial because knowing the force of pushing a button would be helpful when calculating how much torque was required when programming the motor. And the power consumption was proportional to torque, so once the torque is clear, the next step would be calculating the power consumption of the electric motor, and therefore both make a most suitable choice on the motor and provide essential data when coding the motor.

	Fingertip area (cm^2)				
	thumb	index	middle	ring	little
Right hand					
Mean	3.21	3.34	3.46	3.33	2.66
SD	1.60	1.19	1.26	1.18	1.10
Left hand					
Mean	3.19	3.16	3.59	3.42	2.57
SD	1.68	1.22	1.62	1.22	1.04
Both hands					
Mean	3.20	3.25	3.53	3.38	2.61
SD	1.54	1.19	1.43	1.19	1.06

Figure 10 Fingertip Area

According to the ADA standard, a typical toilet with a button on top in the US requires 2 pounds of force pushing it down ("How to Determine Force Required to Push a Door or Button or Lever"), which is equal to approximately 8.9N. However, due to aging of parts, erosion from the surroundings, and usage in the past years, there might be errors, so it was still needed to test just to be sure the product fit the sample case.

The way of measuring the force of pushing the button was to simulate the process of finger pushing down the toilet button. The simulation involved two tools – a bottle and a spring scale. The bottle should have a cap which contacts an area like a human fingertip area. Spray bottle was by far the most suitable alternative tool. The selected bottle cap top surface diameter was 1.65cm. From that, the calculated surface area was $2.138cm^2$, compared to the data given by ResearchGate down below in the figure to ensure the choice. Then flipped the bottle upside down to make its cap contact with the button surface. Keep adding water into the bottle until the bottle is heavy enough to push the button down. Next, measure how heavy the bottle was using a force scale. During this process, the bottle has its own weight, but it was so insignificant that it could be neglected. The result was approximately 10N. Therefore, the motor should generate at least 10N to 12N of force to accomplish the process of pushing down the toilet button, and on the current market, a motor that could generate such amount of force usually required 9V battery as its power supply.

3.3.2 Motion Sensor

To accomplish the job of auto-flushing, the team decided to install a motion sensor on the toilet tank. The motion sensor would detect objects that appear within its valid range. Once there was an object, in most cases, hands, showing up in its detective area, motion sensors would receive a signal that the user may want to flush the toilet now. Then the instruction would be passed on to the processor, and then to the micro-switch to accomplish the following several steps. There are multiple data required to be calculated during the process: location of the motion sensor, its leaning angle, and valid detection area.

$$175.4 - 161.7 = 13.7cm$$

In the finalized design, there would be a waterproof box containing every major part of the device, so the specific location of the motion sensor depended on the location of the box. The distance from the toilet tank back edge to the button is 7.5cm, and the waterproof box's front surface should be right next to the button so that the motor could drive linkage to push it down, and the motion sensor was designed to stick out of the front surface. Hence the location of the motion sensor was also right next to the button, 7.5cm away from the tank's back edge.

$$h = \sqrt{74^2 + \left(\frac{13.7}{2}\right)^2} = 73.682cm$$

$$bottom = \sin\left(\frac{73.682}{74}\right) = 84.689°$$

$$top = 180 - 2 * 84.689 = 10.623°$$

To calculate the ideal leaning angle of the sensor, the first step was to know the target range of the detection. According to the CDC, the average height of a 20-year-old and up American man is about 5 foot 9 inches, which in centimeters is 175.4cm (“The Average Heights of Men Around the World”), and 5 foot 4 inches for women, equal to 161.7cm (“What’s the Average Height for Women and How Does That Affect Weight?”). The Reference website provides that the average human arm length is around 25 inches, equaling 63.5cm (“How Long Is the Average Human Arm?”), but it varies significantly due to gender, race, age, height, location, and profession. In this case, average height in the U.S. and average arm length will be taken as references in the realization. Use average male height minus average female height to get an average upper and lower limit for the detection area.

The measured toilet length and height were both 74cm, therefore assumed the maximum side length of this triangle area could be 74cm. Firstly using Pythagorean theorem to get the height of the triangle, then calculate the least detection angle.

10.623° would be the least valid detection angle. To get the leaning angle, set it as unknown and use a basic trigonometric function to calculate its specific value. Using female average height minus toilet height to get opposite side length, and length of toilet as adjacent side length.

$$161.7 - 74 = 87.7cm$$

$$hypotenuse = \sqrt{87.7^2 + 74^2} = 114.749cm$$

$$leaning\ angle = arsien\left(\frac{87.7}{114.749}\right) \approx 49°$$

Thus, the motion sensor should contain at least 10 degrees of detection angle, located on the top of the toilet tank, leaning around 49 degrees.

3.3.3 Micro-Switch

The logic of the entire process was that when finished using the bathroom, wave your hand in front to the motion sensor for two seconds. After the motion sensor receives a signal of flushing the toilet, before flushing, it must confirm with the micro-switch to make sure the lid was closed. If the micro-switch was not triggered, the signal of flushing the toilet wouldn't successfully be passed on to the motor to accomplish the job. So, figuring out a place for the micro-switch that can be both nice-looking and effective for testing if the lid was closed became important. On one hand, if this switch was placed onto somewhere that would cause trouble on the normal use of the toilet, otherwise people would not want to use it if it was not practical in the first place. On the other hand, if the place chosen was mainly for ornamental but lost its accuracy on testing the lid, it will also have a negative impact on its practicality.

The initial design was to stick the micro-switch using double tape at the side of the toilet bowl, tangential to the toilet seat, perpendicular to the tank, but with a higher position than the bowl. It needed to have a vertical position at least a slightly higher than the seat. Then, design an activation bar which was perpendicularly installed on the micro-switch bar. Meanwhile, such an activation bar will be long enough to trigger the micro-switch when the lid makes contact with the toilet seat, and also short enough that it wouldn't produce any faults signal to the motor to allow it to flush even though the lid was not closed. The height of the micro-switch is 2cm, and the thickness of the household toilet seat was roughly 1.6cm to 1.7cm. Hence, the micro-switch should locate at 3mm to 4mm below the toilet seat. The width of the switch bar was approximately 5mm, so the activation bar should range from 7mm to less than 1cm.

However, there was a problem that people with gender have different habits when using the toilet. Girls would like to sit on the seat when using the toilet, but most of the time boys use toilets without sitting on the toilet seat -- they may lift the seat before they use it. This brought to a problem of how to install the activation bar to contact the seat, and what material was ideal. If the seats were to be lifted and lowered, it must have contact with the activation bar designed multiples times a day. If the bar designed and printed out was too hard, the force of lifting and closing the seat will break the device -- separate the activation bar from the micro-switch, but if materials were soft like rubber, was it going to be too soft to general enough force to trigger the micro-switch? Besides, having the activation bar fixed on the seat was not going to work because it simply cannot function to activate the micro-switch.

After discussion, the team came out with a new design, which was to still build a holder and stick it with the toilet bowl, but the activation bar will be linked with the lid instead of the micro-switch. Therefore, only after the lid closes, the switch would be triggered no matter the position of the toilet seat. In this design, only two things are must-have -- switch holder and activation bar. A holder was a device that holds our micro-switch not to move, and it was going to have the same parameter and position as the previous design -- at the side of the bowl but it did not need to be as high or slightly higher than the seat all because the new position of the activation bar. The bar would connect with the toilet lid thereby leaving multiple areas of freedom for the bar's parameters, for example the thickness and the length. It did not have to be in a specific range to fit the user's experience because it would not make any contact with users anyway. There was not a required thickness either because users can adjust the bar's contacting volume by adding or removing the bumps provided.

3.3.4 Motor

Motor acted as one of the key components in the project. It was to drive the four-bar linkage to push down the toilet button. Without it, there would not be any force to do the pushing job. People will have to flush the toilet by themselves, yet to reach the goal of reducing human contact with surfaces. Therefore, having a motor and a linkage acting as human fingers became indispensable coming down to the implementation.

The difficulty in this very designing process was the rotating angle of the motor. Because firstly it depended on its working mode. The motor can rotate with different degrees with different versions of working mode -- whether rotate a full rotation each time or with a certain angle. Besides rotating angle, its generated force was another factor needed to be considered, and the force was also related to many other different factors -- rotating speed, linkage designing including distance, which means the torque, and contacting surface area which means the pressure the button is taking.

If the motor was to rotate one full rotation each time, the prior problem would be the size of linkage connecting with the motor. The sample toilet button can be pushed down by 1.5cm by measure, and a normal high torque servo motor was usually with a thickness of 20mm. Therefore, the designed linkage bar should be no longer than 2cm to 2.5cm in length. If the motor was to rotate with a certain angle, the angle would be the prior problem. When searching for the most suitable linkage, the bars were usually having length of 7cm to 8cm which its center was to attach with the motor, that is, 3.5cm to 4cm at each side. If the linkage wanted to push down the toilet button with 1.5cm, the rotating angle would be:

$$rotating\ angle = \arcsin\left(\frac{1 + 1.5}{3.5}\right) = 45.585°$$

3.4 Design Safety and Reliability

This design is the first prototype the group has tested which means there will be many safety hazards surrounding our design that should be noted. Water or moisture entering the prototype is one of the major concerns as it can slowly corrode parts and create rust. Water damage will greatly shorten the lifespan of our prototype as parts will begin to fail. The group was not able to stress test what parts are most likely to corrode or rust first. Urine can also greatly shorten the lifespan of our prototype as it can be acidic or alkaline. The push button switch will be exposed to urine potentially when males use the toilet. Males will usually lift up the toilet seat and urinate and some of the urine can end up touching the sensor which can eventually damage the internal parts, rendering the sensor useless. To combat water and moisture from entering the housing where the Arduino and breadboard is located, O rings can be added to the seal where the box can be opened.

Electrical failure is also another big concern. Electrical failure could be as simple as the wires not being held together well enough by the solder. This simple issue would render the flushing mechanism the group has created useless. The quality control of the material that will be sourced is also of concern as it is possible to get parts that have a shorter lifespan than the average part. Electrocuting someone is the biggest concern for the safety of the user. If a section of the wire was not properly covered with shrink wrap or electrical tape, it can become a hazard. Certain wires may be hot to the touch which can cause potential fires or electrocute someone if water touches the bare wire. The best way to solve the issue regarding wiring is to use one length of wiring without combining wires together and have good soldering at the ends. This will reduce the chances of wires coming apart and making the prototype useless.

The servo motor that is used in the group's first prototype is rated for 35N. This amount of force can easily injure someone if not handled properly. Children should be kept away from it as the group has not designed it to be safe for children. If the motor slips and spins freely, the whiplash can cause bruises or hurt vital organs like eyes.

Over time the holders will experience erosion from the urine and moisture that is exposed to it. The box that contains most of the electrical component at the top of the water tank will experience less erosion compared to the plastic holder on the side of the toilet bowl. The acidity in urine can slowly corrode the plastic if it is not cleaned off every time urine gets onto the holder. The group has not tested the durability of the plastic used to print out these parts, but it is reasonable to say the plastic will experience erosion. Different materials can offer better properties and durability, but weight and the cost associated with printing out the design in said material will be higher than plastic.

3.5 Design Choices

3.5.1 For the Motion sensor:

For the choice of motion sensor, HC-SR04 Ultrasonic sensor was the choice for realizing the work of receiving instructions. The Ultrasonic sensor of HC-SR04 model could provide a detection distance of 2cm to 400cm, which meets the requirements of our experiment. The accuracy of HC-SR04 can reach 3mm, which meets the experimental needs. There were four links on the ultrasonic sensor, namely VCC, Trig, Echo and Gnd. Their respective functions were to provide power, ultrasonic transmitter, ultrasonic receiver, and ground. The working principle was roughly that the IO Trigger would emit at least 10*10^-6 high-frequency signals, and the module would automatically send eight 40 kHz and detect whether there is a pulse signal return. If the signal returns through a high level, the high output IO duration was the time from sending ultrasound to returning. The basic function of HC-SR04 was to return the time of receiving ultrasound. Based on the approximate speed of sound in the air of 340m/s, it was possible to calculate the distance of the super reputation contact surface relatively accurately according to the distance equal to the speed multiplied by the time divided by 2. For the HC-SR04 Ultrasonic sensor, its working voltage is 5v, the working current is 15mA, and its measuring range is 15 degrees.

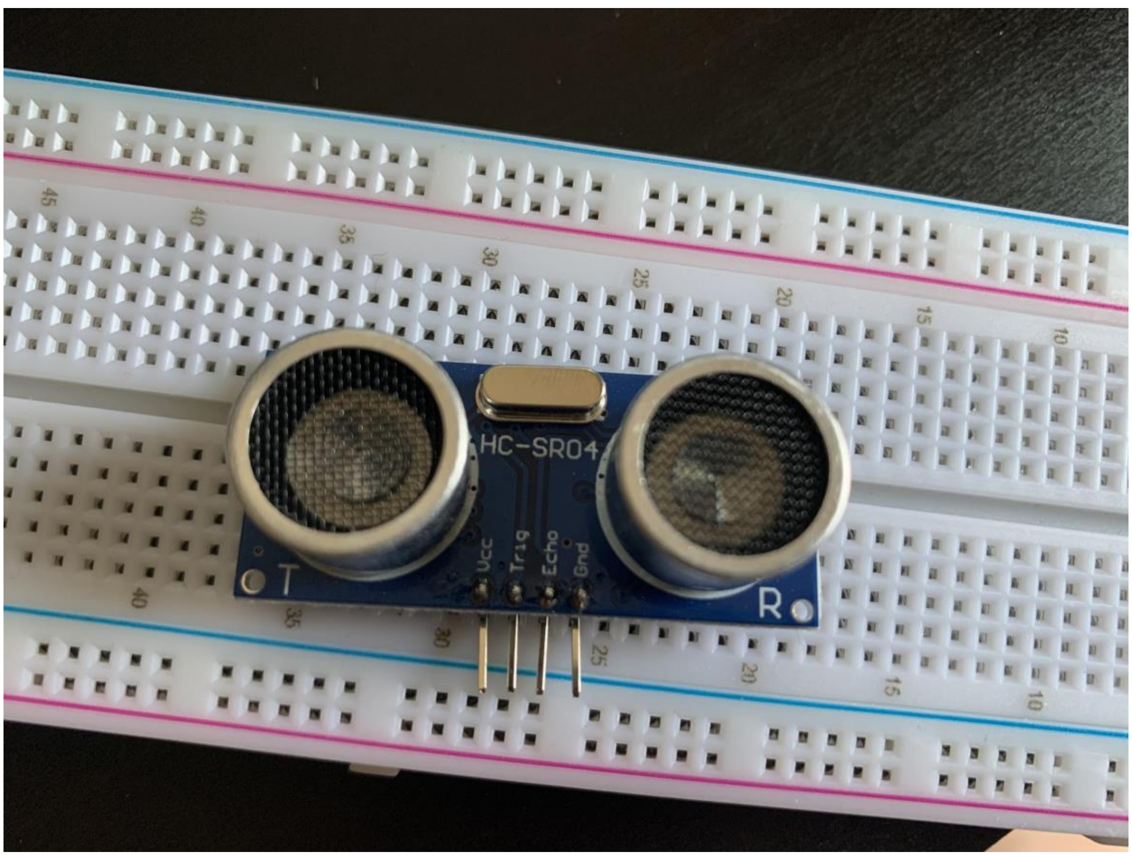


Figure 11 HC-SR04 Ultrasonic Sensor

Electric Parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Figure 12 Electric Parameter of HC-SR04 Ultrasonic Sensor

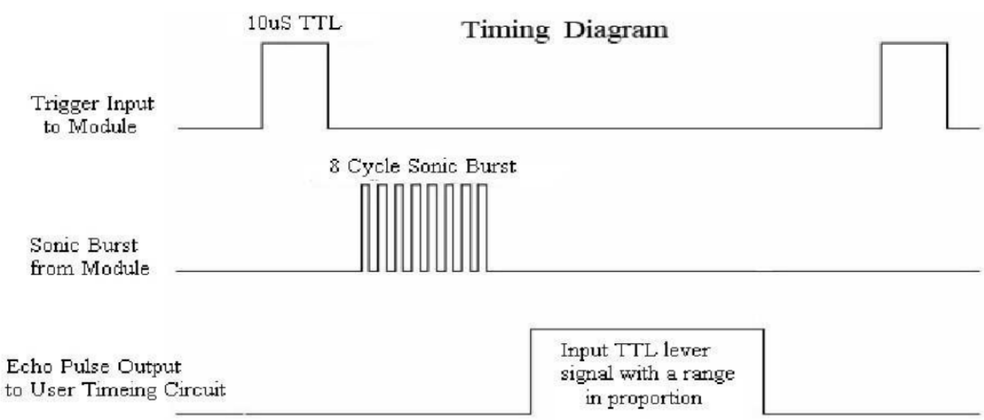


Figure 13 Timing Diagram of HC-SR04 Ultrasonic Sensor

3.5.2 Micro switch to detect lid position

To detect whether the toilet lid was closed, the project was to use a Micro Switch to detect whether the toilet lid was closed. Logically, Micro Switch was a relatively larger switch, and it was detecting the end and was more like a seesaw. One part of design was that the experiment needs to design a small flat plate to fix the Micro Switch to the side of the toilet seat. When the toilet lid was closed, the toilet lid touched the Micro Switch like a seesaw. One end of the toilet lid touches the toilet lid, causing the trigger at the lower end to be pressed. This was the entire Micro Switch. A closed circuit. When the Arduino R3 detected the previous motion part and gave instructions, and the Micro Switch sometimes closed the circuit at this time, it could prove that the toilet lid is closed. For the selection of Micro Switch, API-163-1C25 Micro Limit Switch has been selected. The reasons for choosing this model mainly because it had the basic conditions that the design needs, and met the needs of power supply, moderate size and most importantly, relatively low price, which was very important whether in experiments or future mass production, because in the end the project need to have relatively affordable price. The highest temperature it could withstand was 120 degrees, and the general bathroom would not reach this temperature, so it met the temperature demand. API-163-1C25 Micro Limit Switch can be pressed for about 100,000 times, so the service life of the sensor is relatively long.

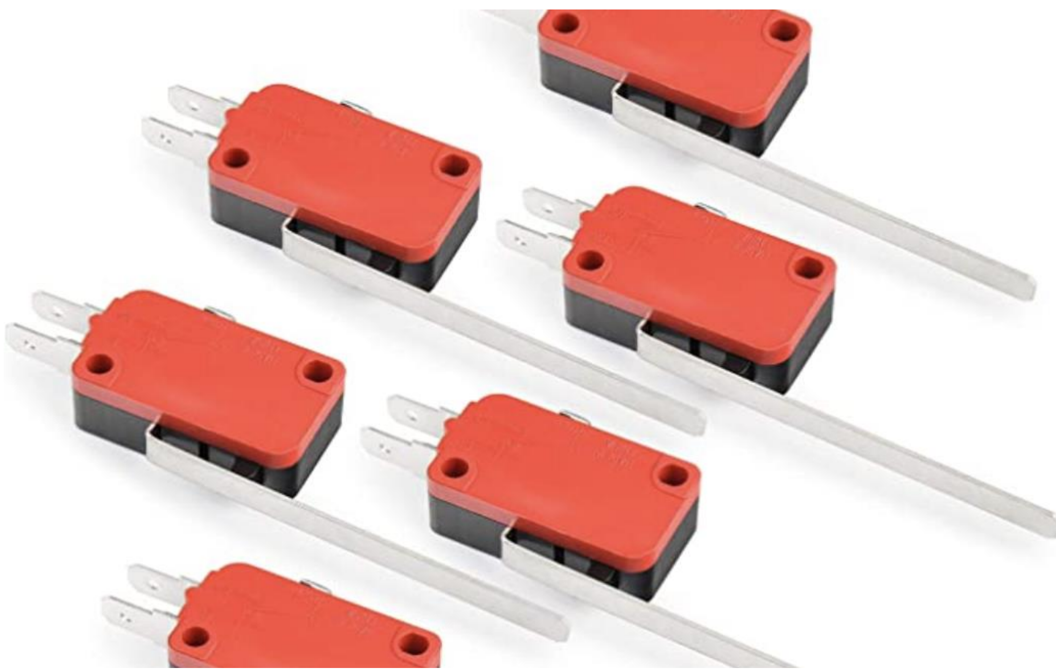


Figure 14 API-163-1C25 Micro Limit Switch

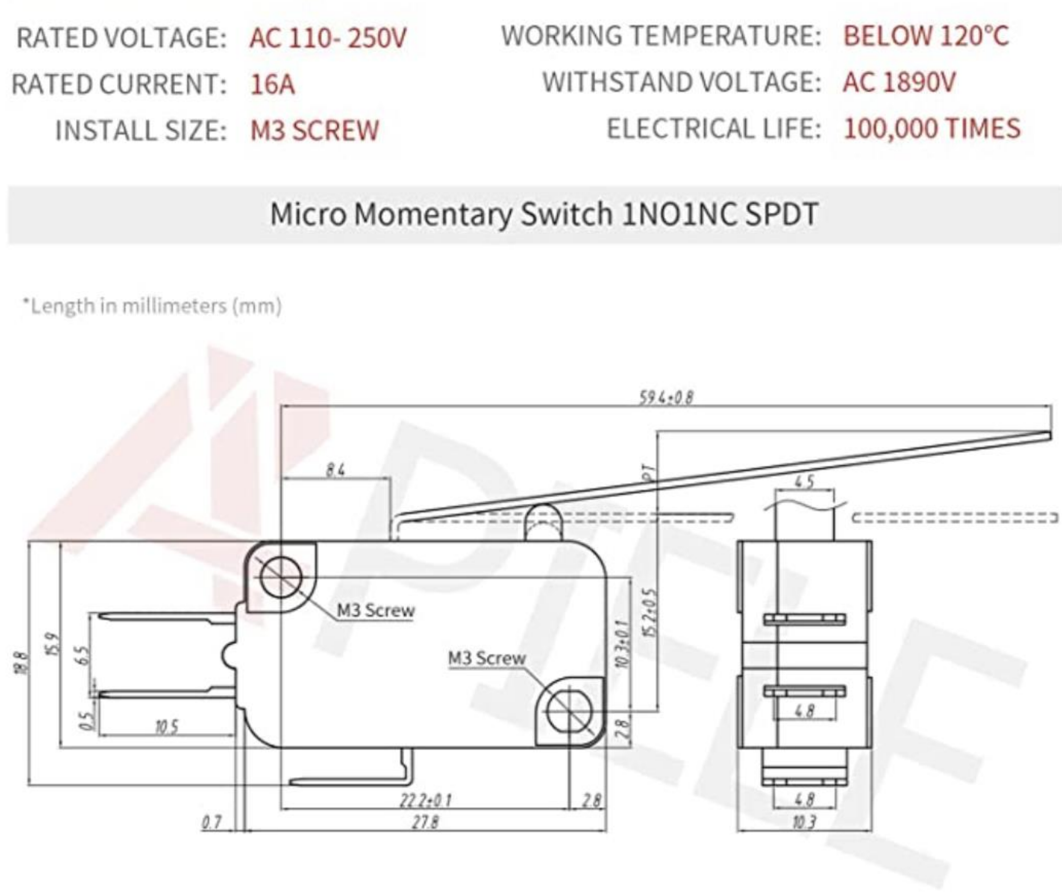


Figure 15 API-163-1C25 Micro Limit Switch Parameter

3.5.3 Motor select

For the last sensor select, the aim was to give instructions for flushing. When the motion part detected that Arduino needed to give command, and Micro Switch detected that the toilet lid closed, then the Arduino gave the motor a corresponding rotation angle and connected the flush button to flush. For the choice of motor, the choices were DC-Gear motor, Stepper motor and Servo motor. A DC-Gear motor could provide relatively large torque and had a relatively cheap price. Stepper motor can control the angle of rotation more accurately, but the relative stepper motor cannot provide relatively large torque. Based on design requirements, there was no need for the motor to rotate a lot of times and accompanied by a relatively high speed, but need to be able to control the degree of rotation relatively accurately, such as 90 degrees, and then quickly return to the initial position. The final choice of the design was a Servo motor (the reasons for selection and other motor failure analysis were mentioned in other sections). The specific selected was Metal Gear Digital RC Servo Motor. Metal Gear Digital RC Servo Motor had the characteristics of fast response and low power consumption. In the case of 5V, it could provide 35KG/cm of torque, which can meet the force needs relatively speaking.

Figure 16 Metal Gear Digital RC Servo Motor

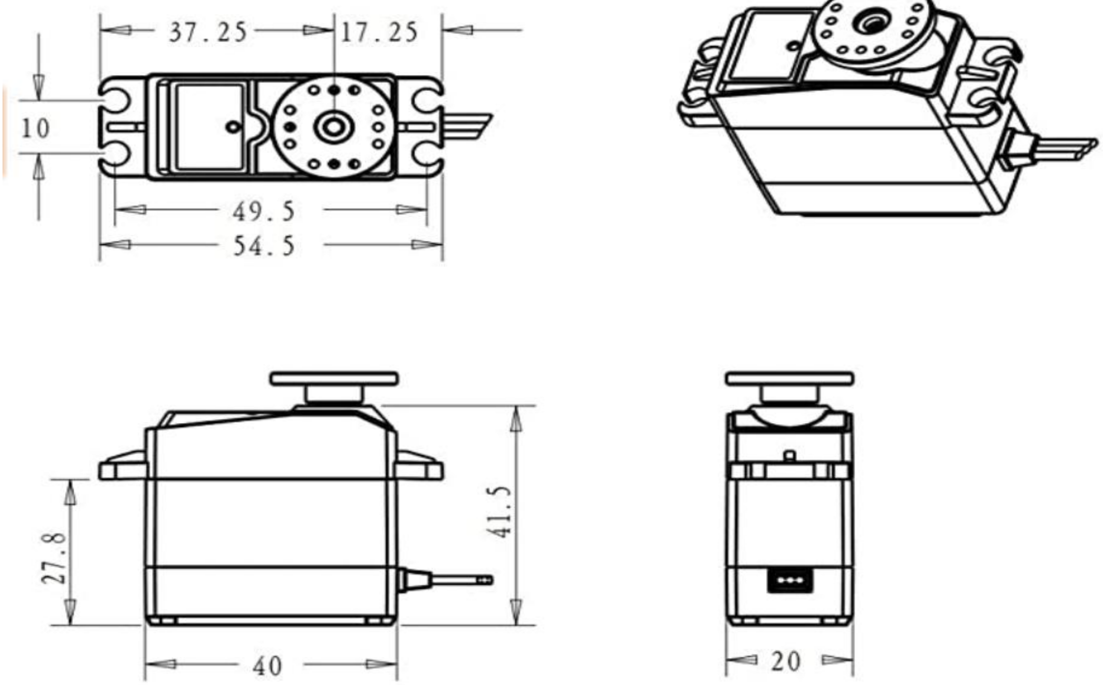


Figure 17 Three Side View of Metal Gear Digital RC Servo Motor

3.5.4 Other materials

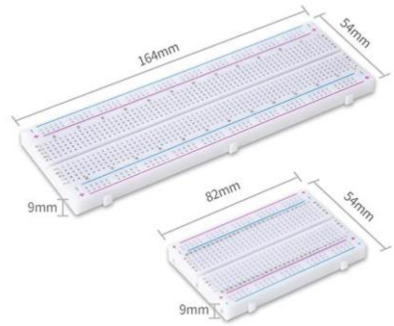
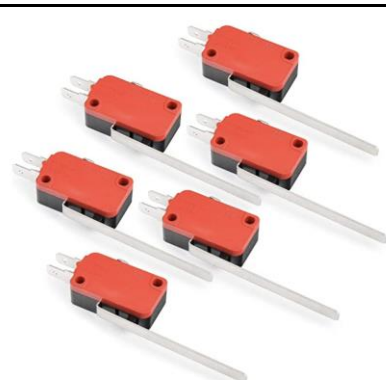
In addition to the core sensors part and servo motor part, a lot of materials were needed to complete the experimental design to realize the realization. First, from the processor side, Arduino R3 was used and purchased as a running device during the test sample phase. Arduino R3 has enough ability to complete our project, including the number of command ports, operation logic and relatively low price. Arduino is an open platform, and there are relatively many resources on the Internet for the specific implementation of functions. To connect to the Arduino, the team also purchased four types of cables, which were Male to Female cable, Male to Male cable, Female to Female Cable and 30 Feet spools 22-gauge Jumper wire- Hook up Wire Kit. Reasons for buying these types of cables Some counties need to connect to Arduino first, and some need to connect to a sensor, such as Ultrasonic sensor. If to use it directly, it would cause damage and ugliness of the sensor, and it was not conducive to subsequent modifications. In addition, the location of the Micro-Switch was relatively far from the Water-protection

Box, so it was necessary to use a long enough wire to connect the circuit between them. For the parts that need to be firmly fixed, use soldering to fix them. In addition to this, also brought a resistor package, which mainly includes 1k resistors, 10k resistors and 100k resistors. The purpose of the resistance was to ensure the safety of the circuit during the working of some Micro-Switches; to ensure the safety of the motor, and to ensure the circuit safety of the LEDs. When the required rated voltage is greater than 5v, but lower than the voltage supplied by the battery, the voltage can be brought to the desired state by connecting a resistor in series with the battery. The team purchased a 9V battery through the Amazon shopping platform to connect to Arduino R3 to provide voltage to each part. In addition, LEDs of various colors were purchased at the beginning of the design to give users the current state of the machine. And can give the team clear feedback during our testing phase. The team also purchased a lot of auxiliary equipment, such as a soldering torch, strong glue, anti-electric tape, double-sided tape, used for various types of fixing; in order to achieve some safety requirements of the design, the team purchased a 25T aluminum Horn. Replace plastic horn. Considering the long-term use and the relatively large torque of the servo motor used, the aluminum horn could be more durable. In the implementation of Four-Bar-Linkage, M3 screws and nuts were also purchased for fixing. In the appendix of the article, the purchased method and address were specifically listed to facilitate subsequent group research.

3.6 Design Cost and maintenance

For Design Cost and maintenance, the following lists the names, prices, and appearances of the core components needed to complete all the designs. The materials that need to be used indirectly cannot be listed in this chapter, but they can appear in the appendix content as indirect instructions. Additional purchases will be provided in Appendix for subsequent purchases and repair and replacement of damaged parts.

Name	Price ($)	Picture	Remark
9 Volt Everyday Alkaline Batteries	7.48		The 9V battery is mainly responsible for the power supply of Arduino
Electronics Component Pack with resistors, LEDs, Switch, Potentiometer for Arduino	7.86		The main function is to adjust the circuit voltage and provide LED lights
AUSTOR 560 Pieces Jumper Wire Kit 14 Lengths Assorted Preformed Breadboard Jumper Wire with Free Box	10.99		The main function is to connect the circuit,

Breadboards Kit	9.99		The role is to provide a platform for controlling and testing the functions between power lines and sensors.
SainSmart HC-SR04 Ranging Detector Mod Distance Sensor (Blue)	7.99		Sensors that provide the function of detecting distance and change of distance.
TUOFENG 22 awg Solid Wire-Solid Wire Kit-6 different colored 30 Feet spools 22 gauge Jumper wire- Hook up Wire Kit	14.49		Connecting the Micro-Switch and the arduino.
APIELE (6 Pcs) API-163-1C25 Micro Limit Switch Long Hinge Roller Momentary Push Button SPDT Snap Action for Arduino, Appliance and Electronic Equipment	8.87		The sensor that detects the lid is closed or not.

ARDUINO UNO R3	29.95		A processor that runs the editing program and provides a port to connect each component
ZOSKAY 35kg high Torque Coreless Motor servo Metal Gear Digital and Stainless Steel Gear servo arduino servo for Robotic DIY,RC car (Control Angle 180°)	36.99		Provides the force to turn the toilet button
Aluminum 25T Servo Horn Arm for Futaba Savox Xcore HL HSP HD 1/8 1/10 RC Vehicles Motor, 2-Pack	8.99		Convert servo motor torque into force

Figure 18 Price Chart

4 Results

4.1 Code

Logic analysis and procedures of each step based on the methodology chapter. Here, all the small parts were integrated to form the final program of this experiment. After writing, modifying, debugging, and combining with the actual sensor, the following was the program manuscript that can run and meet this design. Many of these parameters were designed based on the toilets used in the experiment and were not universal. This included the detection distance limit of the ultrasonic sensor, the judgment method of the micro-switch and the rotation angle and time of the servo motor. The logical framework of the motion sensor was the relatively largest logical decision. After the time instruction was satisfied, the statement to determine whether the toilet lid was closed. If it was not closed, everything needs to reset. If it was closed, continue the built-in nesting command to give servo motor rotation. After completed the following operations, reset the status of all conditions. Prepare for a new round of judgment。

```
//final edtion of MQP sensor code (yize)
//here are all variables define
const int trigPin = 9;//ultrsonice trigger pin
const int echoPin = 10;//ultrsonice echo pin
unsigned long begintime=0; //set up of begin time variable
unsigned long stopTime=0;//set up of stop time variable
unsigned long timedifferent;//set up of time difference variable
int led1 = 13; //blue
int led2 = 12;//yellow
int led3 = 8;//green
int led4 = 2;//green
int Switch = 7; //Micro-switch
long duration;//in order to catch the back time from echo pin
int distance;//variable for distance
int condition1;//counter condition1
int condition2;//counter condition2
int condition3;//counter condition3
int condition4;//counter condition4
int Servo_motor=11;//pin for servo motor



//for the first time setup and with what kinds of funcrtion Arduino should give
void setup() {
pinMode(led1,OUTPUT);//led as output
pinMode(led2,OUTPUT);//led as output
pinMode(led3,OUTPUT);//led as output
pinMode(trigPin, OUTPUT); //Sets the trigPin as an output
pinMode(echoPin, INPUT); //Sets the echoPin as an input
Serial.begin(9600); //Starts the serial communication
pinMode(7,INPUT);//Micro-switch as in put
pinMode(2,OUTPUT);//led as output
pinMode(Servo_motor,OUTPUT);//servo motor as output
condition1=0;//let first time the counter values of condition1 as 0
condition2=0;//let first time the counter values of condition2 as 0
condition3=0;//let first time the counter values of condition3 as 0
condition4=0;//let first time the counter values of condition4 as 0
}
```

Figure 19 Code

```
void loop() {
// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
//Sets the trigPin on HIGH state for 10 microseconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);

//get the time the trigPin give and echo revieved
duration = pulseIn(echoPin, HIGH);

//Calculating the distance
//Speed of sound = 343 m/s at 20 oC = 0.0343 cm/us
distance = duration * 0.0343 / 2;
```

Figure 20 Code

```
if(distance<50)//assume user hand is close to sensor which want to flush
{
digitalWrite(led1,HIGH);//give signal to user
//first time to get the time point
if(condition2==0){
  begintime=millis();
  condition2=condition2 + 1;//this is try to avoid of duplication
}

condition1=condition1 + 1;//set up a condition that need to get stoptime

}

else if(distance>50 && condition1>1)//this represent the first time hand close then leave the sensor
{
 //this is in order to first time calculate the stop time after hand is leave
  if(condition3==0){
    stopTime=millis();
    condition3=condition3 + 1;//this is try to avoid of duplication
  }
  digitalWrite(led1,LOW);//turn off the led1
  digitalWrite(led2,HIGH);//turn on the led2 to show user the timedifferent calculation is begin
  delay(1000);
  timedifferent=stopTime-begintime;//to get the time different

  if(timedifferent>2000){//which satisfy the requestion os ready to detecte lid
  digitalWrite(led3,HIGH);//led3 trun on
  delay(2000);
  digitalWrite(led3,LOW);//led turn off
```

Figure 21 Code

```
if(digitalRead(7)==LOW){//the lid is closed
  digitalWrite(led4,HIGH);//turn led4 on letr user know
  condition4 =condition4 +1;//this is try to avoid of duplication

//begin here is to give a flush command to servo motor
 if(condition4 >1){
analogWrite(Servo_motor,60);//output for motor
delay(400);
analogWrite(Servo_motor,160);//output for motor
delay(400);
analogWrite(Servo_motor,60);//output for motor
delay(2000);

condition4 = 0;//allset so need back to zero
 delay(1000);
  digitalWrite(led4,LOW);

}
  digitalWrite(led4,LOW);
 }
else{
  //reset all conditions
condition2=0;
condition1=0;
condition3=0;
condition4 = 0;
  digitalWrite(led4,LOW);

}
  }

    //reset all conditions
  condition2=0;
  condition1=0;
  condition3=0;
  digitalWrite(led3,LOW);
    }
    else{
      digitalWrite(led1,LOW);
      digitalWrite(led2,LOW);
      }
Serial.print("condition value is :");Serial.println(condition1);//for test
Serial.print("time differnt is:");Serial.println(timedifferent);//for test
Serial.print("the distance is :");Serial.println(distance);//for test
}
```

Figure 22 Code

4.2 Realization of design

4.2.1 Water protection box design

The entire design consisted several parts: a motion sensor that detects human hands, a micro-switch that ensures the lid is fully closed before flushing, a motor that drives a device to push down the toilet button, a device designed to do the pushing job, and an Arduino board that makes the entire process possible to implement. To combine and realize all the parts, it was helpful to build a waterproof box, a micro-switch holder, and a linkage device using SolidWorks and planned to print them out from a 3D printer.

The waterproof box was designed to store the motor, the motion sensor, and the Arduino board inside -- it was the main part of the entire design. Such a box was necessary because the design included various electronic boards from either Arduino or the sensor, and different wires that connect each part together. Due to the toilet having a humid air condition, an outside box to protect our electronic boards and motor became crucial. The box should be able to prevent water drops dripping onto the Arduino board and motion sensor to cause short-circuit, and aerosols from shower or sink erode the motor to reduce the lifespan of the motor and linkage.

According to the measurements and considering the capacity of the 3D printer, the waterproof box should be as small as possible so that firstly, a compact design would have a better look for consumers, and secondly, the size wouldn't be a limitation for its installation, but this box should be able to fit for all parts stalling inside at the same time. After measuring all the parts and empty space on the toilet tank, the final decided dimension of the box was L: 10cm, W: 7.5cm, H: 10cm.

Once knowing the size of the waterproof box, it was needed to know its shape and location of each small part. The initial idea was to have the motor installed at the bottom and the Arduino board stuck on the back wall, therefore it would look like a rectangular box with length of 10cm, width of 7.5cm, height of 10cm, and a thickness with 3mm of each side. However, there was one more function wanting to achieve, that was to install the motion sensor with a degree so it could detect human hands without users reaching far after using the toilet. The value from the data requirement suggested to have approximately 49 to 50 degrees, but the final decision was 45 degrees. So, an arc shaped shell was built, with two holes drilled on it so that two of the detectors on the sensor can poke through. Another rectangular hole is drilled perpendicular to the bottom so that the linkage could stick out of the box to contact the toilet button. The shell and the box were connected by a shaft bar. Users can flip it open in case they install the motor, or they want to change batteries.

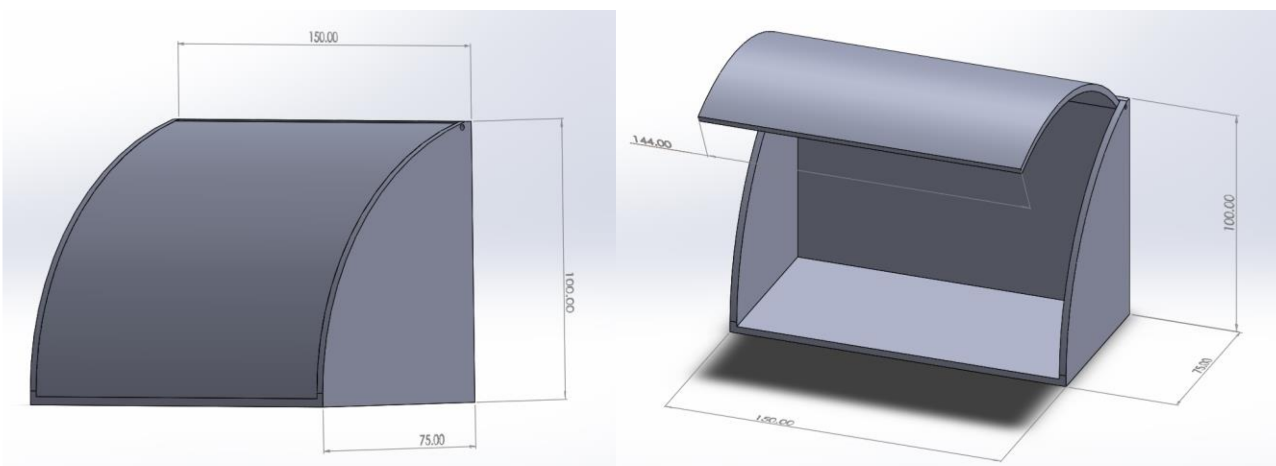


Figure 23 Front Shield

However, after the box was designed, there was a problem coming down to realize that was not considered -- error tolerance. The mechanism of a 3D printer will lead errors to various extents when building a model, so when designing a model, it was necessary to reserve spaces for errors. Thickness of 3mm clearly did not consider errors the printer would make. If any mistake appears during the process of printing, 3mm was not thick enough to bear the consequence of it. Besides, there was an arc shaped shell in the front, which just made it even harder for the printer and it was easier to make mistakes. Therefore, the prototype must be redesigned. Abandoning the first curved surface plan, the team came up with a trapezoidal box, because flat surfaces would take less risks and have higher error tolerance compared to a curved surface.

This new design contained a wall thickness of 5mm, which means it was less vulnerable than the previous one, and its flat surface will both reduce 3D printer's mistakes and tolerate more errors if any of them happen during the printing compared to the curved one. The hypotenuse surface will have 45 degrees, which satisfied the motion sensor facing angle. Same mechanism was used on the new design, the front shell related to the main part with a shaft so that it could be opened in front for installations.

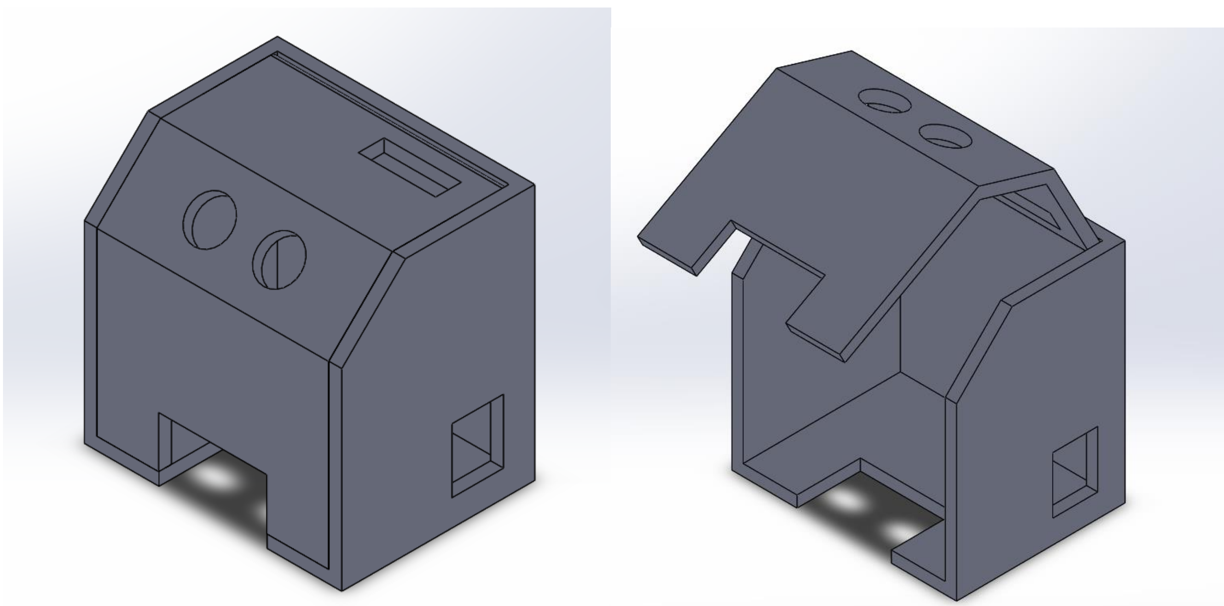


Figure 24 Final Front Shield

4.2.2 Micro-Switch Holder design

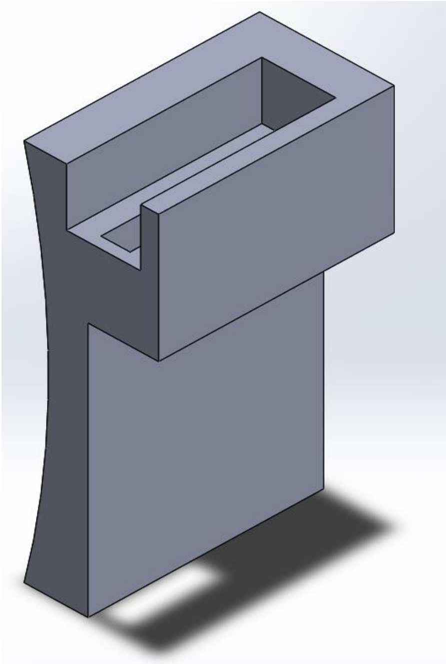


Figure 25 Switch Holder

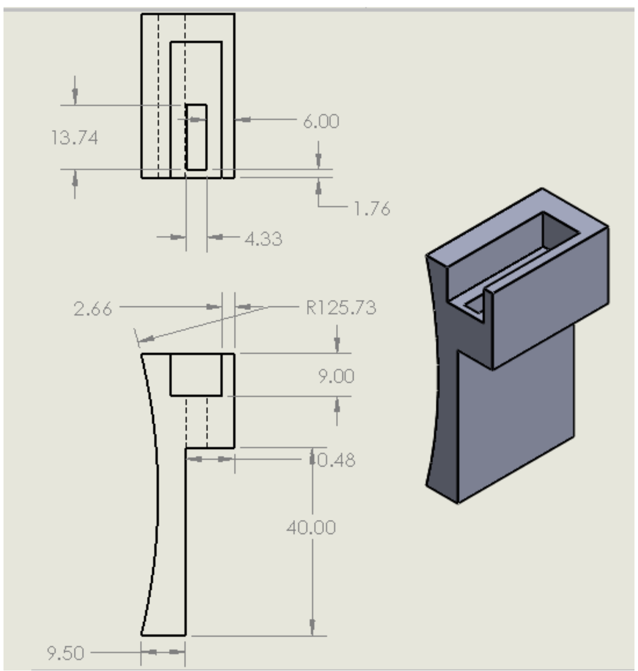


Figure 26 Switch Holder Drawing

The group designed a holder for the push button switch. The group needed the switch to sit at the same level as the toilet seat or slightly below it. If the switch were to be any higher, users could accidentally push down on the switch. Comfort would also be an issue as some users will feel the switch digging into their legs. The holder should allow the switch to be at the desired height without inconveniencing the user.

The holder has a cut made on the top face that does not go all the way through the material while the other cut goes all the way through. The cut that does not go all the way through is meant to keep the switch in place. This was added so that the switch could be secured on the holder, a wall instead of a cut was proposed, but the cut provides more support overall. The group dimensioned the cut to be slightly larger than the switch so that when the user does not have a hard time trying to place the switch within the holder. Having the cut also remove one of the four walls ensures the smaller prongs on the back of the switch do not require a more intricate design, saving money and time printing out our part. The cut that goes through the material is meant for the metal prong on the bottom of the switch. If the group wants the switch to sit flat, there needs to be a hole that allows the metal prong to be stored without obstructing the switch. The curved side allows us to mount the holder to the side of the toilet easier compared to a flat wall. Toilet bowls have a curvature to them which needs to be accounted for in order for the holder to stay mounted over an extended period of time. The group used double sided mount tape to keep the holder mounted and the holder was 3D printed using plastic.

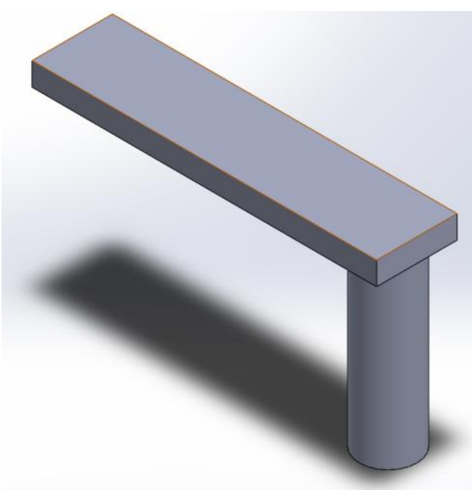


Figure 27 Activation Bar

The activation bar is necessary for our design so that the Arduino knows if the toilet lid is down. The bar is 2 mm thick and 30 mm long. This bar will be attached to the bottom of the toilet lid using double sided mounting tape. If the group chose to put the bar on the top of the lid instead, the cylindrical extrusion would have to be longer. This results in a longer printing time and higher production costs. Once the toilet seat is down, the cylindrical feature will have contacted the activation bar on the micro-switch. This in turn will signal to the Arduino that it is ready to flush the toilet. The group has expressed their concern regarding the durability of the bar as the prototype will be printed using plastic. Using metal would be ideal as they are more durable and less brittle. Further stress testing and analyzing material properties will be needed to select the best value material.

4.2.3 Motor Holder

According to Newton’s third law -- for every action, there is an equal and opposite reaction. If the linkage wants to push down the toilet button with approximately 10N to 12N of force, there would also be a reaction force facing the opposite direction and had the same magnitude of 10N to 12N, and therefore caused the motor to rotate as well. Hence, a holder that holds the motor steady became necessary. This holder should be installed inside of the waterproof box parallel to the front shell. It must follow several traits: must be able to hold the motor steady preventing it from rotating to the other direction, and its strength must be higher than 12N; it must be able to prevent motor slide along the X axis; must have a size that was big enough clip in our servo motor but also small enough to be able to be installed inside the box.

On the base of the motor's shape, the initial build was a 3 sided frame to fix the motor with the opening side facing in front, and has a length of 15mm -- since the motor is installed facing sideways, it was a relatively suitable length to clip the motor which also reserved space for both the raised section in front and the wires at back. The width of the motor itself was 20mm given by the official data. The width was not supposed to be too large because it might affect its position inside the waterproof box and hence have impact on the motor's rotating gear or even the Arduino board. The width should not be too small as well because lack of encapsulation will reduce its stability to the motor. 21mm was a good choice -- it was close to the motor's side width so it can perfectly fit the motor, and more importantly, it gave some spaces for error that may occur by the 3D printer. Thickness of the holder should consider multiple factors. For the top and bottom part, what needed to be considered was the height of the raising sections of the motor which four screws would be coming through. The height of the motor's front surface was 54.1mm, and the inner part is around 48mm, therefore the thickness of each edge was supposed to be larger than 3mm. However, considering the error tolerance and stability of the holder, the upper and lower edge were designed to be 7mm. The left part of the holder initially was designed to be 3mm, but then there came a problem that the 3D printing material may not be strong enough to hold that much strength with such thin design. That was, the reaction force from the motor might break the holder from the middle at some point, especially working for so many times in a moist environment. So 5mm to 7mm was a good range for the holder. It gave more support on the side and such range would not give much pressure on the back wall where the Arduino board will be stuck on.

To fix the motor with more strength, four studs would be designed to go through each of the four holes on the motor. From the measurements, the diameter of each hole was around 2.5mm to 3mm. For leaving space for errors, 2mm could be a suitable diameter for the studs. Meanwhile, holes would be drilled for screws on all four studs to give one more protection to the motor. All screw holes would be designed through SolidWorks; sizes of the holes would be based on screws that come with the motor.

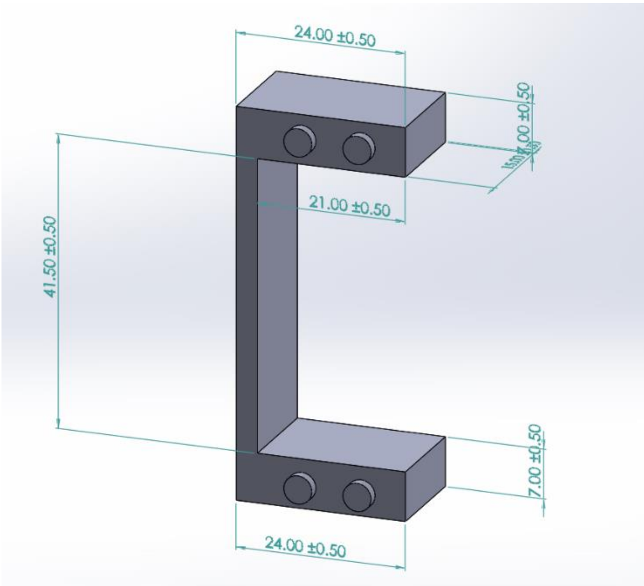


Figure 28 Motor Holder

Unfortunately, when implementing the first design, the four-bar linkage was found to be a laborious lever device meaning instead of saving force, it required more force than usual to push down. The old motor was not strong enough to push down the button. So, a change happened before printing everything out. The old motor was abandoned, and a new, even more powerful motor was introduced -- it provided 35kg of force every 1cm. The old motor holder design and four-bar linkage was abandoned as well.

The new design was to lay down the motor, having its entire front surface sticking out of the waterproof box cap, a hole drilled on the cap which size was just enough for the motor’s front side. Dumping the four-bar linkage, having only the horn that came with the motor installed and to do the pushing job. For the motor holder, instead of having a separate part sticking inside the waterproof box, having two blocks built originally in the box at both sides of the drilled hole was obviously more stable than the old holder.

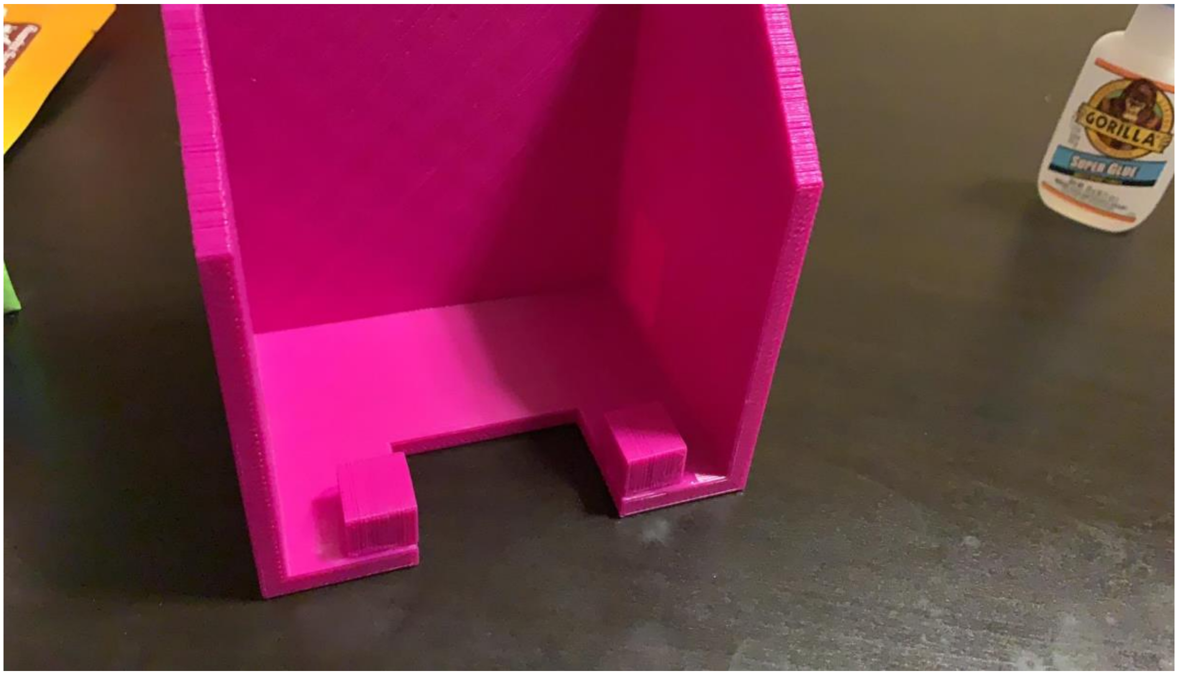


Figure 29 Motor Holder Realization

4.2.4 Motion sensor detection

After completing the program part of the motion sensor and working with the LEDs, the next step was to solder the Ultrasonic sensor and three LED lights with the Arduino R3 used. In the process of execution, the required materials were three LED lights, the colors of which were blue, yellow, and green respectively corresponding to LED1, LED2 and LED3 of the program port. On this basis, a considerable number of connecting wires need to be prepared. The purpose was to connect each port. At the same time, three 10K ohm resistors need to be prepared during the design process. Each resistor was connected in series with each individual LED light when splicing the circuit. The priority order was that the cable is first connected to Arduino R3, and the end was connected to a 10K resistor, followed by a resistor. The end was connected to the relatively long end of the LED light, and the other end of the LED light was connected to an extra wire. This can ensure the safety and normal use of each LED lamp. This operation needs to be completed three times.

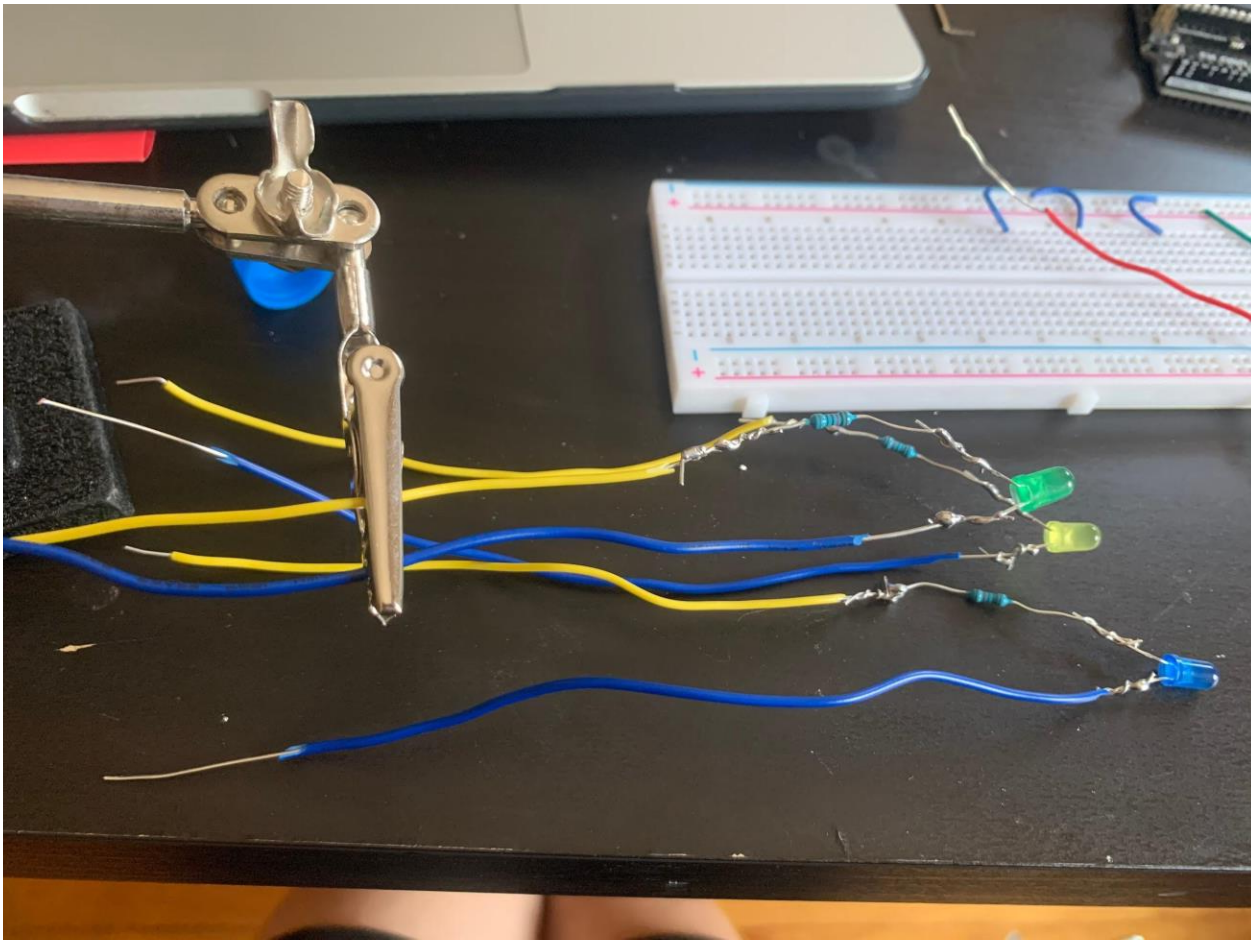


Figure 30 Connecting LEDs with Resistors

In order to facilitate the use of soldering later, the process of connecting the two wires would use a method similar to "DNA" twisting, which facilitated later soldering (liquefied tin was a relatively large tension and was difficult to attach directly). The reason for connecting another wire at the end of the LED light was that all three wires needed to be finally connected to the ground wire, but the bottom wire had only one interface. After completion, the three wires need to be twisted into one in the same way as "DNA". Connect it to the ground wire of Arduino R3, so that the three circuits can operate.

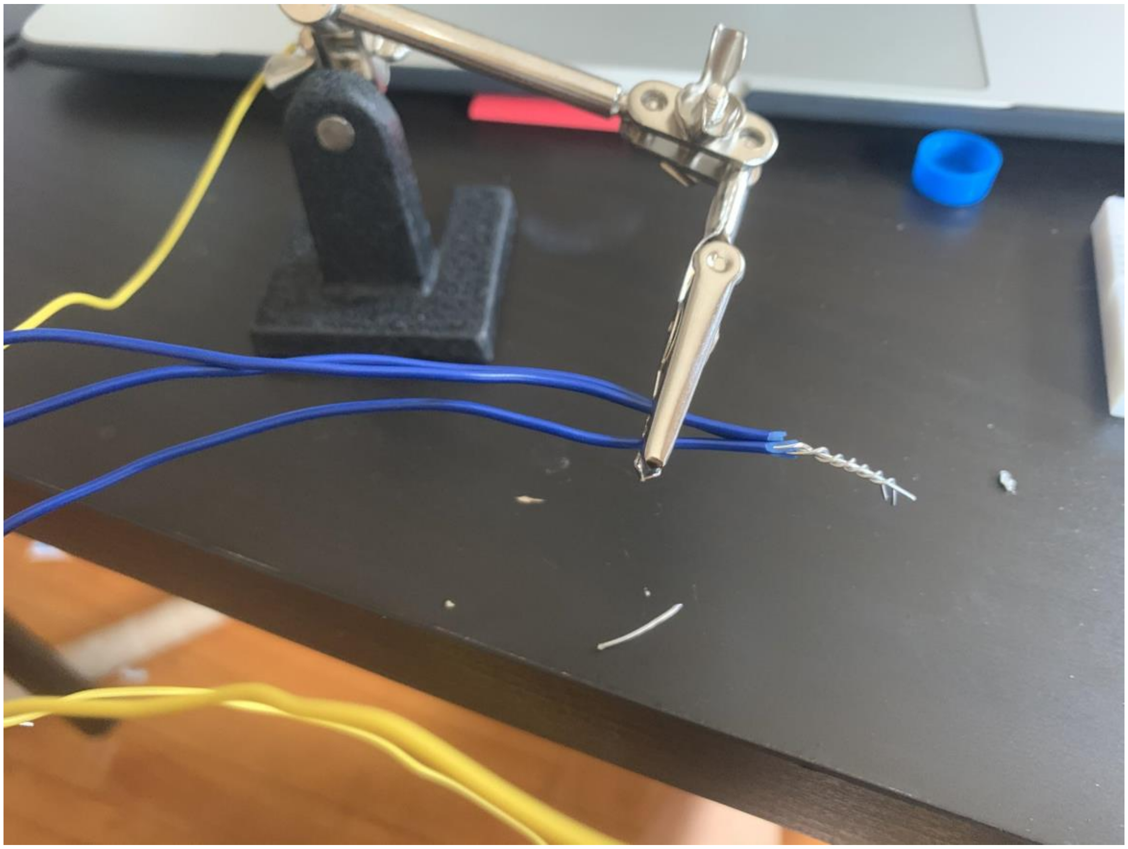


Figure 31 ”DNA way” Screw Wires

The process of connecting Ultrasonic was relatively complicated, and there were four wires that needed to be connected. After the first attempt, if the team used wires to connect the four ports directly, because the Ultrasonic four ports were very close in time, in the soldering process, soldering them together multiple times made the function invalid. The solution to this problem was to use female to male cable to directly jam the four ports. The trigger and echo parts in the middle were directly connected to the corresponding ports of the Arduino, and the power cord and the bottom line fixed with a wire in the same "DNA" shape at the end of the female to male cable for later connection with the power cord.

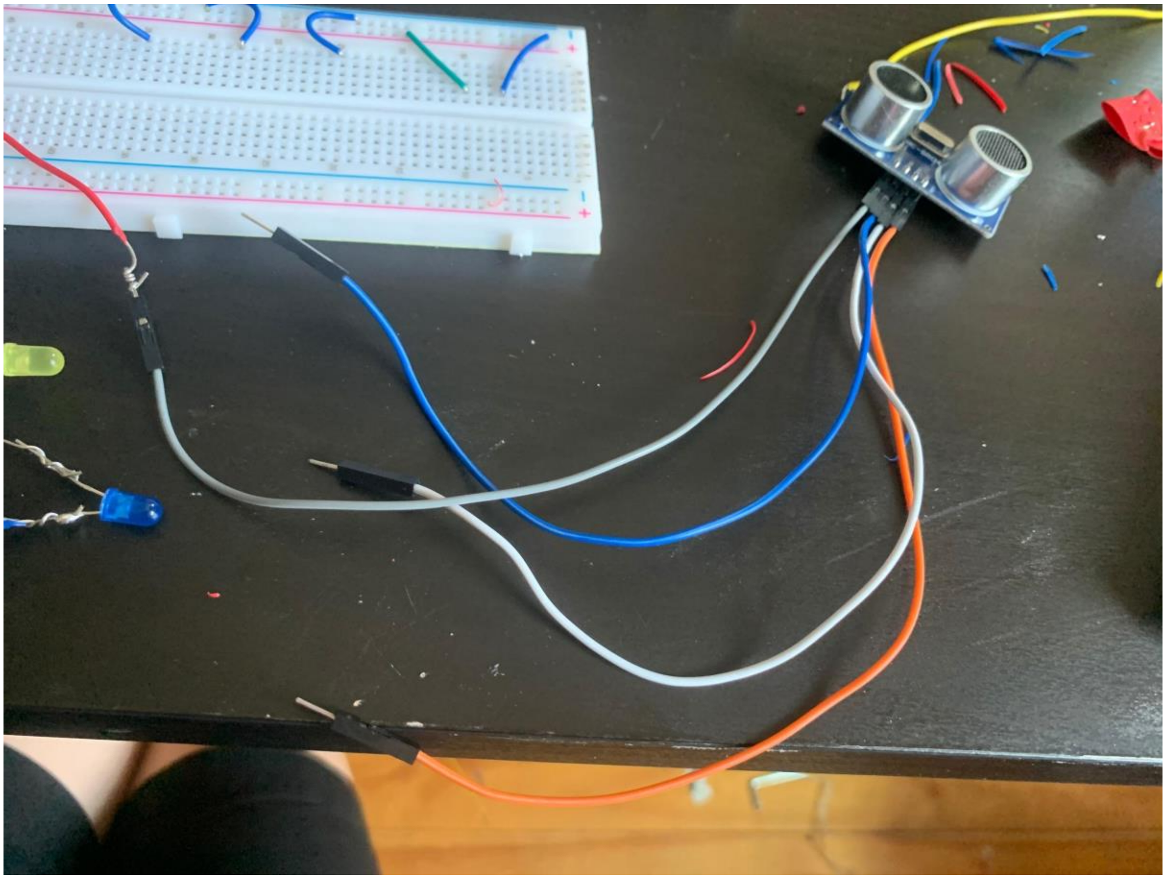


Figure 32 Male & Female Wire Connection

After completing the above steps, the team used two wires about 10 to 15cm in length to connect the 5V power port and GND port of Arduino R3. The team used a Swiss army knife to process the end of the wire to expose a sufficient length of the metal surface. On this basis, connect the Ultrasonic power cord to the 5V wire and the ground wire to GND. The above had completed the basic realization of Motion sensor detection.

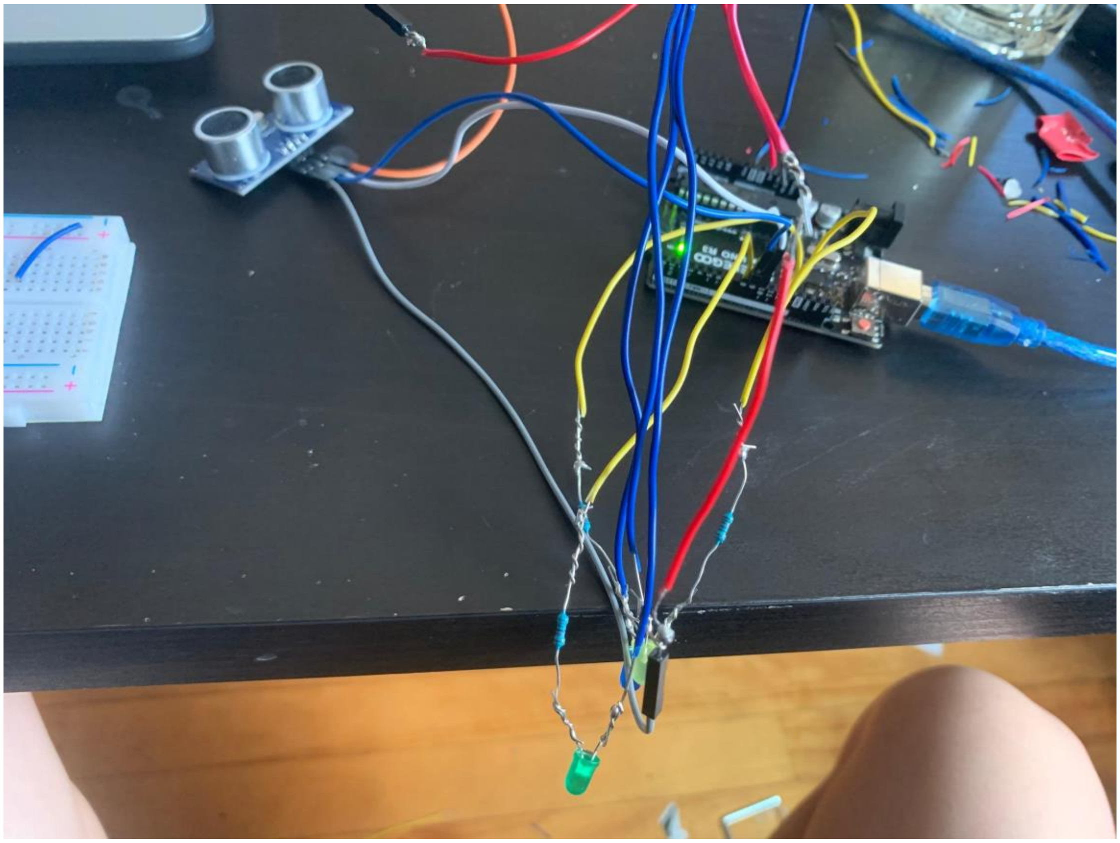


Figure 33 Final Edition of Motion Sensor Part Detection

4.2.5 Micro-Switch detection

After completing the motion sensor part, the realization of the Lid detection part needs to be completed immediately. It was necessary to prepare a purchased Micro-Switch and a long enough wire for the test. The length of the specific wire needs to be measured to the experimental toilet. A little extra length was needed here to prevent the line from being too short to fix the Micro-Switch in the fixed position. In the implementation process, the team used the same method as the motion sensor part to connect and fix the LED 4 light. Next, The team had to connect the metal contact part at the bottom of the Micro-Switch with wires, and solder the fixing point to prevent it from falling off; secondly, the team used a long enough wire to connect the wire at the bottom of the metal contact part just completed. The end of the wire was moved by twisting the bus connected to the ground wire. After the basic fixing was completed, it was finally fixed by soldering. The other wire needs to be connected to the NC port of the

Micro-Switch first, and the fixing method was soldering. After the connection was completed and the NC circuit was fixed, the end of the line was bifurcated. One part of it required to be connected to port 7 of Arduino R3 through a 10K ohm resistor in series to receive signals; the other part needs to be connected to a long wire (length Similar to the length of the wire used to connect the ground wire before) the wire connecting the main power supply. In the process of intermediate connection, soldering was required for fixing. Based on the above steps, the team completed the realization part of Micro-Switch detection. After testing, it could be used normally.

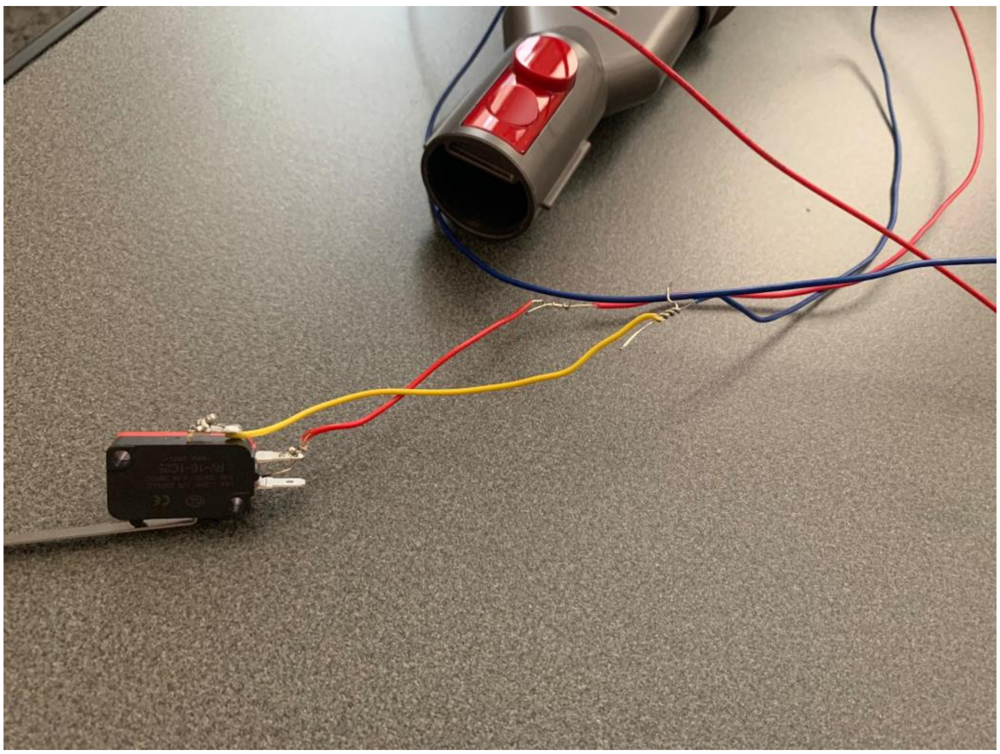


Figure 34 Switch

For the realization of some functions of the Servo motor, two realizations were carried out in the actual process. For the first time, the structure of a servo motor with four-bar linkage was adopted. However, due to various reasons, the function of automatically pushing the toilet flush button was not realized. Here, the team would introduce the realization that uses a servo motor and aluminum horn to directly push the toilet flush button. The servo motor here would have a different rotation angle requirement than the four-bar linkage, and here it was necessary to place the servo motor as close as possible to the toilet flush button, and the servo motor required to be placed on its side, otherwise the horn cannot be pushed to the toilet button. This design had involved the design of the box that prevents fixing at the back. The circuit of the Servo motor was relatively simple. During installation, Female to male cable was used to connect the three ports of the Servo motor, which were the receiving port, the power cord and the ground wire. After the connection was completed, connected a new wire at the end of the wire, twisted it together using a "DNA" method to ensure it is stable, and then used solder to completely fix it.

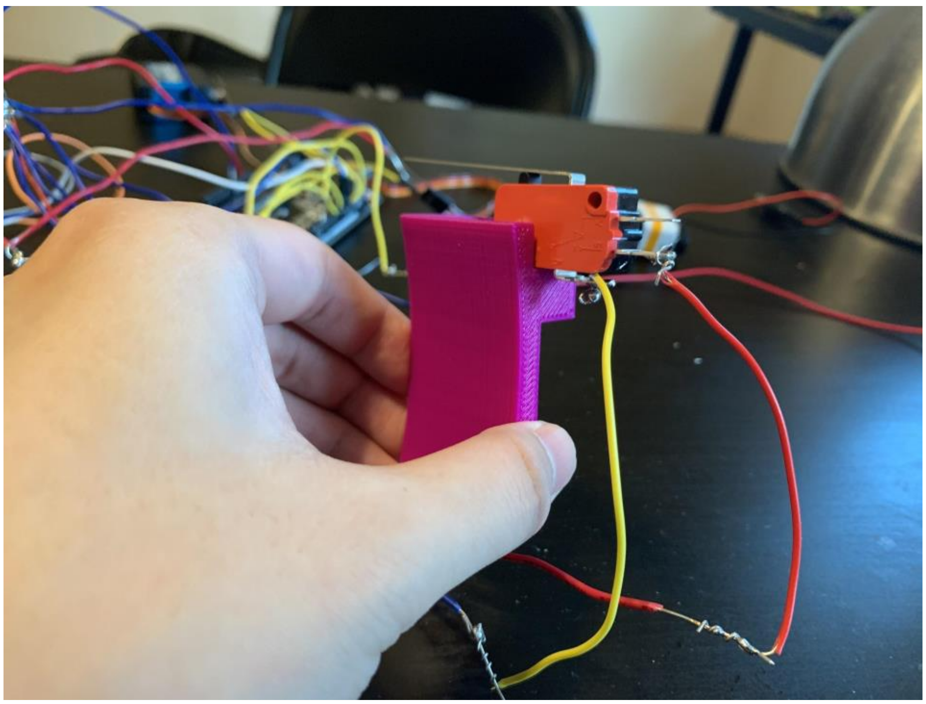


Figure 35 Micro-Switch & Holder

4.2.6 Servo motor

For the realization of some functions of the Servo motor, two realizations were carried out in the actual process. For the first time, the structure of a servo motor with four-bar linkage was adopted. However, due to various reasons, the function of automatically pushing the toilet flush button was not realized. Here, the team would introduce the realization that uses a servo motor and aluminum horn to directly push the toilet flush button. The servo motor here would have a different rotation angle requirement than the four-bar linkage, and here it was necessary to place the servo motor as close as possible to the toilet flush button, and the servo motor required to be placed on its side, otherwise the horn cannot be pushed to the toilet button. This design had involved the design of the box that prevents fixing at the back. The circuit of the Servo motor was relatively simple. During installation, Female to male cable was used to connect the three ports of the Servo motor, which were the receiving port, the power cord and the ground wire. After the connection was completed, connected a new wire at the end of the wire, twisted it together using a "DNA" method to ensure it is stable, and then used solder to completely fix it.

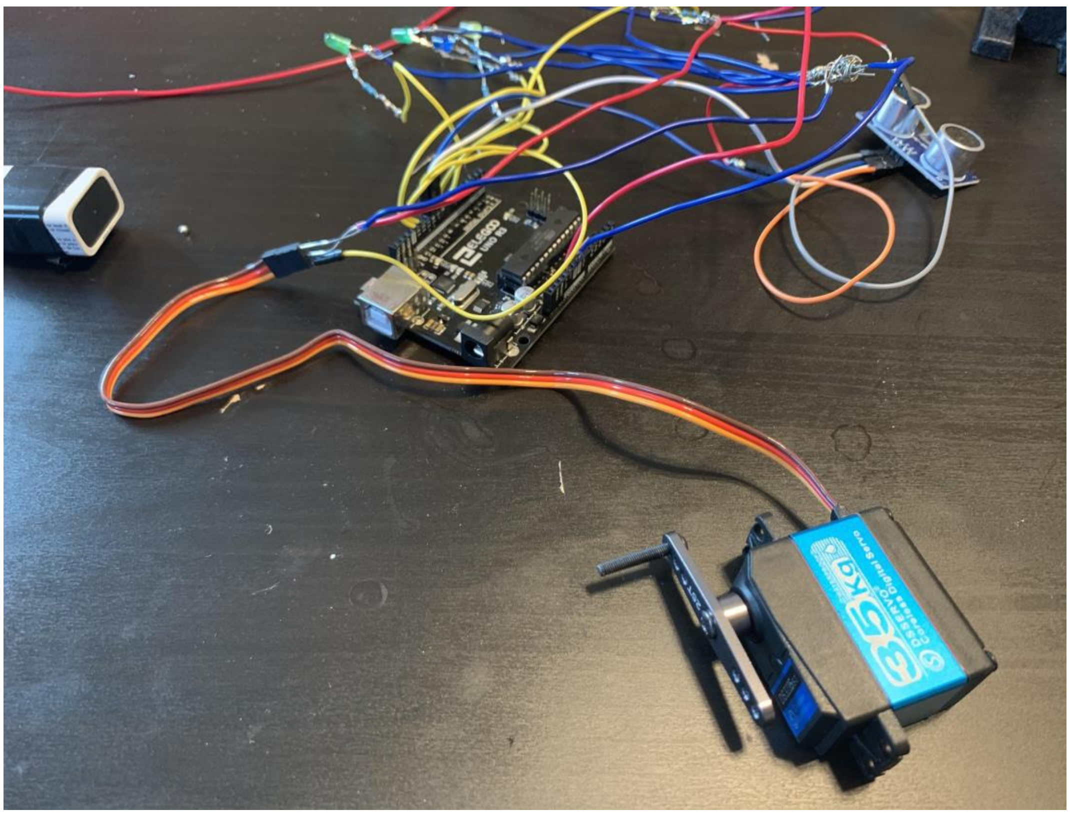


Figure 36 Servo Motor Connection

Figure 37 Servo Motor Assembly

4.2.7 Final realization achievement

When the motion sensor part, lid detection part, servo motor part and 3D printed materials had been printed successfully and could be used during the realization process. To achieve the final overall design, the design team assembled and merged all the small parts. First, the team nested the two parts of the ultrasonic sensor's trigger and echo on the lid of the 3D printed box. To make it more stable, the design fixed black tape inside. Currently, do not deal with the power line and ground wire for now. In the second part, the team fixed the Switch holder part on the side of the toilet bowl with double-sided tape according to the measured height and fixed the trigger that can be knocked to the switch directly above it. After completing the above operations, the team would pass the power cord and ground wire of the Micro-Switch into the inside of the box through the side of the 3D printed box, and then leave it aside for now. The third part was to lay the servo motor on its side and snapped it into the lower part of the water protection box so that the bottom surface was at the same height as the floor of the box. To make the servo motor more stable, strong glue could be used to fix it. If the servo motor considered other uses in the future, it did not need to be fixed. After completing the above operations, twisted the wires of the ultrasonic sensor, servo motor, and micro switch in a shape like "DNA" before soldering. Then connected it to a brand-new wire by soldering and connected the end of the wire to the 5V power jack of Arduino. In the same way, connected all ground wires, and finally connected to the GND port of Arduino through a wire.

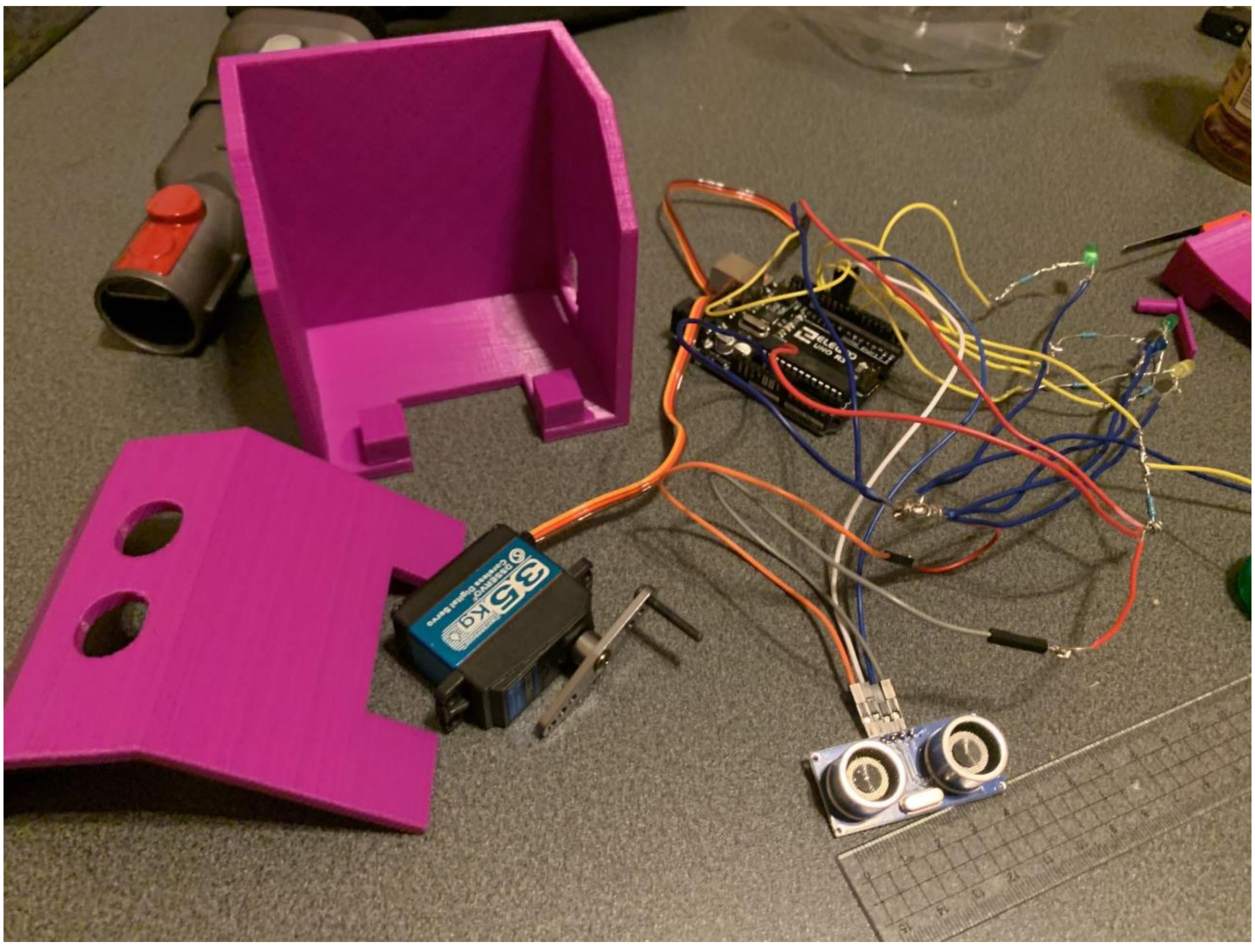


Figure 38 Servo Motor Assembly

After completing the circuit part, carefully fix the Arduino into the box, and wrap the newly completed soldered part with black tape to prevent a short circuit. Then fixed the wire inside the box.

Fastened the upper cover of the water protection box into the lower box. Finally, fixed the entire box on the side of the flush button. All steps were completed.

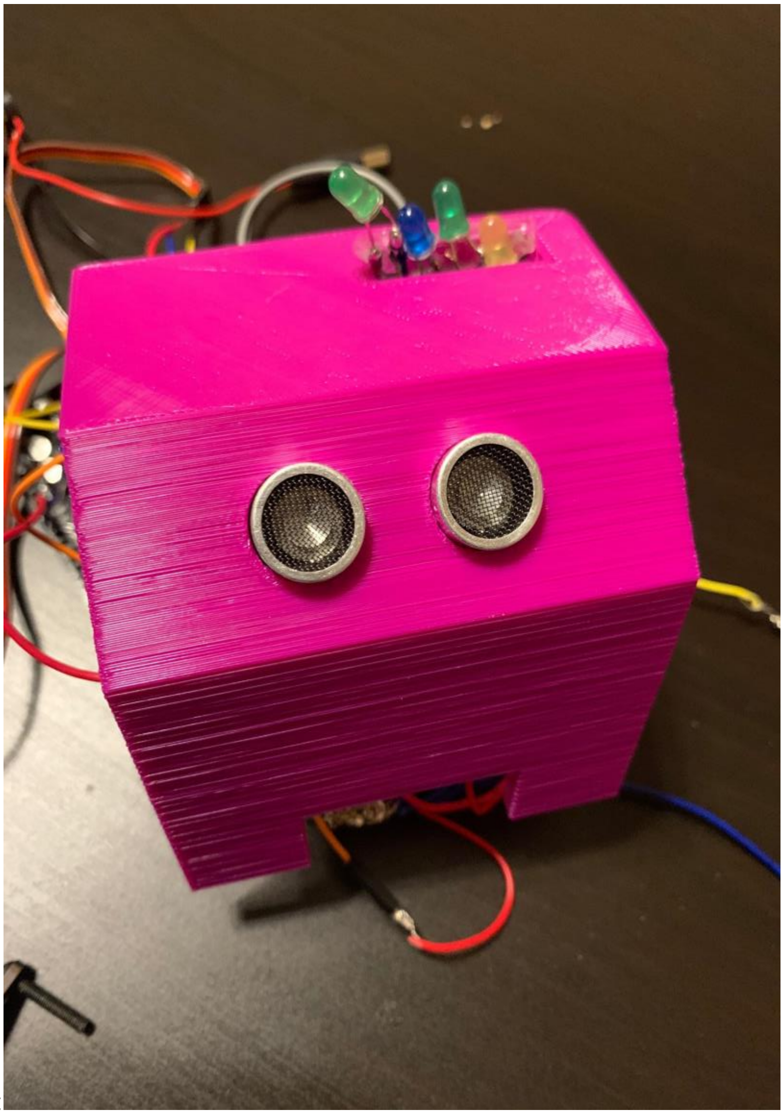
:

Figure 39 Fully Assembled

After all the assembly was completed, the actual sample test was entered. The team fixed the entire box above the toilet flush button, and the horn of the servo motor could just push the button. The team can use waterproof tape or double-sided tape for fixing. During the test, performed a test outside the range to detect the accuracy, performed a test within the range, and divided it into two cases: meeting the time requirement and not meeting the time requirement, and checking whether the indicator was operating normally. Finally, tested whether the toilet lid was closed, and the two state test indicators were not closed. When the lid was closed, the servo motor normally pushed the toilet flush button. After many rounds of testing, the samples could basically complete the required tasks. The team posted the video link in the appendix, and here is the web-link that can watch the video.

https://www.bilibili.com/video/BV1pZ4y1T7Zk

Figure 40 Fully Assembled

5 Conclusion

For the beginning of the design, the team's goal was to design a set of instructions that can realize non-contact sensory to the toilet and identify whether the toilet lid is closed or not. Based on whether the toilet lid is closed or not, the team executed instructions if the toilet should be flushed automatically. It took nearly three months for the team to create the initial rough idea, finally the team designed a plan and implemented the realization. The design theory took two months from a fuzzy general concept to a step-by-step reasonable design. It took about a month to modify the program, modify the design components, and to realize the functions. In the process, the design separated the entire logic into three relatively separated sections and implemented them one by one.

When realizing the motion sensor part, the result of the design was basically in perfect agreement with the design goal and the required functions could be realized. The main difficulty in this part lied in the theory of program design, the circuit was relatively simple, and there was no need to consider too many mechanical design concerns. For the sensor selection, Ultrasonic can basically complete the required commands, but in actual testing, if some small changes appeared in the Ultrasonic contact part, it was better to extend the hand with the five fingers open, which would cause the signal within the range to be received, but an out-of-range signal was received immediately. This situation would cause the test to fail, or extend the time required for hand sensing.

For the detection lid part, Micro-switch could basically complete the program logic instructions perfectly, and there were not too many difficulties in the process of soldering the circuit. Fixing the Micro-switch and the Micro-switch holder was a difficult point. The Switch cannot be properly jammed and have to be fixed with strong glue. In addition, it was relatively difficult to connect the ground wire at the bottom of the Micro-switch, which required careful operation. The design of touching the Micro-switch trigger mechanism failed for the first time because it did not consider in detail how to fix the lid parts and did not consider that the inner ring of the toilet lid is not flat. The last modified version was to extend the length of the trigger switch by remodeling to place it on the upper side of the lid. Can meet the design and overall function.

For the design of the motor part, initially the team wanted to use a DC-gear motor in theory, after theoretical speculation, program verification, and actual torque measurement. In the end it did not materialize. Regarding the servo motor part, the failure of the first servo motor attempt was mainly due to two aspects; the first one did not consider whether the plastic horn carried by the servo motor could bear the force and cause deformation. The precise torque size was not considered. The second point was that for the auxiliary four-bar linkage, after the theoretical test was completed, the model printing had a deviation in the actual test, the shape was not particularly ideal, and the influence of various friction forces was not considered, the servo motor could not provide enough to provide the required torque. The final solution was to replace the aluminum horn with a newly purchased servo motor on the side to directly push the toilet flush button. After the program is debugged and tested, the required functions can be completed. The difficulty in the realization of the motor part lied in: how to convert the rotation into a linear transmission and the design of the structure when the budget is limited; the actual rotation range of the actual purchase of the servo motor, the use of analogWrite required to find the movable range and adjust the required angle number.

For the overall design, each part of the sensor can be implemented with other sensors through the program. For the design of the waterproof box, it needed to be stably fixed in the toilet and needs to be realized with strong glue or a large amount of double-sided tape. The holder part also needs to be firmly fixed. If it was used for a long time, there was no guarantee that it would not fall off. The function was basically fully realized.

6 Recommendation

After three months of study, based on theoretical verification, the actual design and implementation have realized the function of the sample. The overall process is full of various difficulties, some of which come from conditions, some from information issues, and some from actual manufacturing. The following are some recommendations of this project. Provide technical and theoretical assistance to the group or individual of the project and combine some of the failure experience of this group to avoid as much as possible in future implementation.

6.1 The need for a good design

The design of the product played the most important role in the realization of the entire project. Good design can not only save time and reduce costs, but also make the product stand up to testing and practical considerations. In combination with this project, the team's first suggestion was to split the overall project into smaller parts that are relatively easy to implement. This process can be complicated or simplify and concretize concepts that are not suitable for understanding. There can be sufficient discussions and ideas in this process.

The second suggestion is to discuss each of the small parts that have been broken down in detail and get a variety of methods or designs that can be achieved and list them. For example, the overall project can be divided into four parts ABCD, and on this basis, the four parts of ABCD are given a variety of achievable solutions for each part, listed as A-1, A-2, B-1, B- 2. This process can concretize how each small node is completed and can compare different schemes to obtain a relatively optimal solution.

The third suggestion is based on the completion of the first step and the second part, after discussion and analysis, the highest priority solution for each step is obtained, and they are integrated into a preliminary plan. Enumerated as A-1, B-3, C-2, D-1. This can make the logic of the whole program clear and relatively correct. Even if there is a problem, the cause of the problem can be found from each small node to facilitate improvement.

The fourth suggestion is to analyze the possible risks in practice and the design that needs attention. This is a part that requires careful thinking. Good analysis or design can make the process of realization relatively easy.

6.2 The need for careful material selection

For the selection of experimental materials, the factors that need to be considered are: First, whether the purchased materials or parts meet the requirements of theoretical design. For example, the sensor's rated voltage, rated current, or the rotation speed of the motor. If the material does not have the functions of the theoretical design, including overload or does not perform all the functions of the components, this will lead to safety issues first, causing unnecessary damage, and secondly, the actual product may not have the output or input of the theoretical concept. Second, the design requires the influence of a variety of additional factors, including humidity, contact friction, and errors caused by 3D printers. This process is where experimental failures are most likely to occur. Some components are not very suitable for manufacturing or require high requirements, which will lead to failures in practice according to theory and need to be improved through practice. This also brings up the third problem. Materials need to be purchased in advance. If any step is involved, it will delay a considerable amount of time. Ideally, after completing the design and analyzing the risks, you should directly purchase the required Material to save time and facilitate subsequent improvements. The third point is the need to consider how to fix the completed design with the experimental object. This is also a process that can easily lead to failure. For this experiment, liquid, humidity and other factors will make the fixing of parts extremely difficult and difficult to have the possibility of long-term use; or the ultra-high friction on the side wall of the flush button causes the motor to fail to provide the required torque. The solution to this method needs to be considered in the experimental design stage. When purchasing materials, you need to carefully consider whether the design is reasonable and avoid repetitive and unnecessary purchases.

6.3 The need for intermediate testing

The process is to practice the theoretical part through the purchased materials. This process is very important to ensure the double check process before realization. There is no need to solder the circuit, just test whether each small step can complete the required function, and whether the required function can be realized after combining all the components. After this is completed, the realization can be carried out. If realization is carried out directly, if an irreversible error occurs, it will greatly extend the time required for completion.

6.4 The need for mindful realization process

After the test of this project, it is also recommended to list the general realization process before implementation, such as which step needs to be done first, and will not conflict with the following steps, and if there is a problem in the step, is there any Replacement method. You need to pay attention to safety when welding the circuit, wear glasses and pay attention to the temperature of the soldering gun. After completion, you need to double check whether each part is fixed, and the line is connected. Make sure that there are no errors in the experiment.

6.5 Possible alternations

In general, for the products designed this time, it is recommended that the detection of the motion sensor part can be achieved through IR sensors with higher accuracy in the future. If design uses Micro-Switch to detect whether the lid is covered, designers need to consider how to fix it and whether the fixed position is reasonable. For the motor part, it needs to be considered separately, including the internal structure of the toilet pumping tank, the pumping volume, and the way of flushing the button. On this basis, design a reasonable automatic operation. It is also necessary to consider the safety hazards caused by the high torque of the motor. For example, the entire box can be covered with the flush button to prevent the horn from harming children. For fixing devices, future improvements can consider possible hooks, splints, and the like at the beginning of the design and avoid fixing with irreversible glue or unsightly tape.

Appendix

Code resource

Motion sensor

```
//motion sensor part function
// defines variables
const int trigPin = 9; //ultrsonice trigger pin
const int echoPin = 10;//ultrsonice ecoPin pin

unsigned long begintime=0;//time setup for get begintime
unsigned long stopTime=0;//time setup for get endtime
unsigned long timedifferent;//time setup for get time difference
int led1 = 13; //blue
int led2 = 12;//yellow
int led3 = 8;//green
long duration;//to record time change from ultrasonic sensor
int distance;//to record distance calculated
int condition1;//counter 1
int condition2;//counter 2
int condition3;//counter 3

void setup() {

pinMode(led1,OUTPUT);//set the led1 as output
pinMode(led2,OUTPUT);//set the led2 as output
pinMode(led3,OUTPUT);//set the led3 as output
pinMode(trigPin, OUTPUT); //Sets the trigPin as an output
pinMode(echoPin, INPUT); //Sets the echoPin as an input
Serial.begin(9600); //Starts the serial communication
condition1=0;//the begin value is 0
condition2=0;//the begin value is 0
condition3=0;//the begin value is 0
}


void loop() {
// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
//Sets the trigPin on HIGH state for 10 microseconds
```

```
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
//Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);
//Calculating the distance
//Speed of sound = 343 m/s at 20 oC = 0.0343 cm/us
distance = duration * 0.0343 / 2;



if(distance<50)//detect the distance if in the specific range
{
digitalWrite(led1,HIGH);//give signal to bright
if(condition2==0){//condition is to check the begintime
   begintime=millis();//record the first begin time
   condition2=condition2 + 1;//change the condition in order to not calculate again in one time
use
}
condition1=condition1 + 1;//check the state to "just give hands" mode so easy to get stoptime in
later
}

else if(distance>50 && condition1>1)//check just give hands and distance changed
{
   if(condition3==0){ //check the condition to get the first stop time record
      stopTime=millis();
      condition3=condition3 + 1;//prevent calculated again
   }
   digitalWrite(led1,LOW);//turn off the led1
   digitalWrite(led2,HIGH);//turn on the led2
   delay(1000);
   timedifferent=stopTime-begintime;//calculate the change difference

   if(timedifferent>2000){
   digitalWrite(led3,HIGH);//turn on the led 3
   delay(2000);
   digitalWrite(led3,LOW);//turn off the led3
}

   condition2=0;//reset all condition
   condition1=0;//reset all condition
   condition3=0;//reset all condition
   digitalWrite(led3,LOW);
```

```
      }
      else{
        digitalWrite(led1,LOW);
        digitalWrite(led2,LOW);
        }


//rest mode
Serial.print("condition value is :");Serial.println(condition1);
Serial.print("time differnt is:");Serial.println(timedifferent);
Serial.print("the distance is :");Serial.println(distance);

}
```

Micro-Switch sensor

```
//lid detection part
int led4 = 2;//set up led to 2 in arduino
int Switch = 7;//set up Micro-Switch to 7 in arduino


void setup() {
  pinMode(7,INPUT);//set the Switch as input
  pinMode(2,OUTPUT);//set the led1 as output


}

void loop() {
//to check the Switch trigger is pushed or not
 if(digitalRead(7)==LOW){
  digitalWrite(led4,HIGH);//let led4 trun on

 }else{
     digitalWrite(led4,LOW);//let led4 trun off
 }

}
```

Servo motor

```
int Servo_motor=11;
```

```
void setup() {

Serial.begin(9600);

pinMode(Servo_motor,OUTPUT);

}


void loop() {


for(int angle=0;angle<255;angle +=1){
    analogWrite(Servo_motor,angle);
     delay(1000);
     Serial.print("condition degree is :");Serial.println(angle);
}



analogWrite(Servo_motor,60);
delay(400);
analogWrite(Servo_motor,160);
delay(400);
analogWrite(Servo_motor,60);
delay(2000);



}
```

MatLab

```
clear
Ax=0;
Ay=3.833;
Bx=1.53;
By=4.8;
Cx=3.472;
Cy=3.591;
theta1=270;
theta4=90;
theta2=33.90;
```

```
r2=((Bx-Ax)^2+(By-Ay)^2)^0.5;
disp(r2);

r3=((Cx-Bx)^2 +(Cy-By)^2)^0.5;
disp(r3);

CA=((Cx-Ax)^2 +(Cy-Ay)^2)^0.5;
disp(CA);



for i=-1:-1:-45

r4=CA;
lengthofAC = sqrt((Cx-Ax)^2+(Cy-Ay)^2);
r1 = sqrt(lengthofAC^2-r4^2);



A1=2*r4*(cosd(theta1)*cosd(theta4)+sind(theta1)*sind(theta4));
A2=2*r2*(cosd(theta1)*cosd(theta2+i)+sind(theta1)*sind(theta2+i));
A=A1-A2;

B1=r2*r2+r4*r4-r3*r3;
B2=2*r2*r4*(cosd(theta2+i)*cosd(theta4)+sind(theta2+i)*sind(theta4));
B=B1-B2;

if(((A*A-4*B)^0.5)<0)
    fprintf("there is no intersection of slop");
else
    r1a=(-A+(A*A-4*B)^0.5)/2;
    r1b=(-A-(A*A-4*B)^0.5)/2;

end

D_X_1=r1a*cosd(theta1)+Ax;
D_y_1=r1a*sind(theta1)+Ay;

D_X_2=r1b*cosd(theta1)+Ax;
D_y_2=r1b*sind(theta1)+Ay;

C_X_1=r4*cosd(theta4)+D_X_1;
C_y_1=r4*sind(theta4)+D_y_1;
```

```
C_X_2=r4*cosd(theta4)+D_X_2;
C_y_2=r4*sind(theta4)+D_y_2;

change1=((C_X_1-Cx)^2+(C_y_1-Cy)^2)^2;
change2=((C_X_2-Cx)^2+(C_y_2-Cy)^2)^2;

if(change1<change2)
    Cx1=C_X_1;
    Cy1=C_y_1;
    Dx1=D_X_1;
    Dy1=D_y_1;
else
    Cx1=C_X_2;
    Cy1=C_y_2;
    Dx1=D_X_2;
    Dy1=D_y_2;
end

fprintf("the new point of Cx is %f\n",Cx1);

fprintf("the new point of Cy is %f\n",Cy1);

fprintf("the new point of Dx is %f\n",Dx1);

fprintf("the new point of Dy is %f\n",Dy1);

B_X=r2*cosd(theta2+i)+Ax;
B_y=r2*sind(theta2+i)+Ay;

fprintf("the new point of Bx is %f\n",B_X);

fprintf("the new point of By is %f\n",B_y);

Cx=Cx1;
Cy=Cy1;


part1=r1*sind(theta1)+r4*sind(theta4)-r2*sind(theta2);
part2=r1*cosd(theta1)+r4*cosd(theta4)-r2*cosd(theta2);

theta3=atand(part1/part2);


%velocity
```

```
V_matrix1=[cosd(theta1),r3*sind(theta3);sind(theta1),-r3*cosd(theta3)];

V_matrix2=[-r2*1*sind(theta2+i);r2*1*cosd(theta2+i)];

result1=linsolve(V_matrix1,V_matrix2);

R1V=result1(1,1);
Vtheta3=result1(2,1);


% velocity B/A
VBA1=r2*-sind(theta2+i)*1;
VBA2=r2*-cosd(theta2+i)*1;
%velocity of point B
VB1=0+VBA1;
VB2=0+VBA2;


%for point C
VCB1=r3*-sind(theta3)*Vtheta3;
VCB2=r3*-cosd(theta3)*Vtheta3;

VC1=VCB1+VB1;
VC2=VCB2+VB2;

end
```

Final code

```
//final edtion of MQP sensor code
//here are all variables define
const int trigPin = 9;//ultrsonice trigger pin
const int echoPin = 10;//ultrsonice echo pin
unsigned long begintime=0; //set up of begin time variable
unsigned long stopTime=0;//set up of stop time variable
unsigned long timedifferent;//set up of time difference variable
int led1 = 13; //blue
int led2 = 12;//yellow
int led3 = 8;//green
int led4 = 2;//green
int Switch = 7; //Micro-switch
long duration;//in order to catch the back time from echo pin
```

```
int distance;//variable for distance
int condition1;//counter condition1
int condition2;//counter condition2
int condition3;//counter condition3
int condition4;//counter condition4
int Servo_motor=11;//pin for servo motor



//for the first time setup and with what kinds of funcrtion Arduino should give
void setup() {
pinMode(led1,OUTPUT);//led as output
pinMode(led2,OUTPUT);//led as output
pinMode(led3,OUTPUT);//led as output
pinMode(trigPin, OUTPUT); //Sets the trigPin as an output
pinMode(echoPin, INPUT); //Sets the echoPin as an input
Serial.begin(9600); //Starts the serial communication
pinMode(7,INPUT);//Micro-switch as in put
pinMode(2,OUTPUT);//led as output
pinMode(Servo_motor,OUTPUT);//servo motor as output
condition1=0;//let first time the counter values of condition1 as 0
condition2=0;//let first time the counter values of condition2 as 0
condition3=0;//let first time the counter values of condition3 as 0
condition4=0;//let first time the counter values of condition4 as 0
}


void loop() {
// Clears the trigPin
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
//Sets the trigPin on HIGH state for 10 microseconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);

//get the time the trigPin give and echo revieved
duration = pulseIn(echoPin, HIGH);

//Calculating the distance
//Speed of sound = 343 m/s at 20 oC = 0.0343 cm/us
distance = duration * 0.0343 / 2;
```

```
if(distance<50)//assume user hand is close to sensor which want to flush
{
digitalWrite(led1,HIGH);//give signal to user
//first time to get the time point
if(condition2==0){
  begintime=millis();
  condition2=condition2 + 1;//this is try to avoid of duplication
}

condition1=condition1 + 1;//set up a condition that need to get stoptime

}

else if(distance>50 && condition1>1)//this represent the first time hand close then leave the
sensor
{
 //this is in order to first time calculate the stop time after hand is leave
  if(condition3==0){
    stopTime=millis();
    condition3=condition3 + 1;//this is try to avoid of duplication
  }
  digitalWrite(led1,LOW);//turn off the led1
  digitalWrite(led2,HIGH);//turn on the led2 to show user the timedifferent calculation is begin
  delay(1000);
  timedifferent=stopTime-begintime;//to get the time different

  if(timedifferent>2000){//which satisfy the requestion is ready to detect lid
  digitalWrite(led3,HIGH);//led3 trun on
  delay(2000);
  digitalWrite(led3,LOW);//led turn off


if(digitalRead(7)==LOW){//the lid is closed
  digitalWrite(led4,HIGH);//turn led4 on let user know
  condition4 =condition4 +1;//this is try to avoid of duplication

//begin here is to give a flush command to servo motor
 if(condition4 >1){
analogWrite(Servo_motor,60);//output for motor
delay(400);
analogWrite(Servo_motor,180);//output for motor
delay(400);
analogWrite(Servo_motor,60);//output for motor
delay(2000);
```

```
condition4 = 0;//allset so need back to zero
 delay(1000);
  digitalWrite(led4,LOW);

}
  digitalWrite(led4,LOW);
 }
else{
  //reset all conditions
condition2=0;
condition1=0;
condition3=0;
condition4 = 0;
  digitalWrite(led4,LOW);

}
  }

    //reset all conditions
  condition2=0;
  condition1=0;
  condition3=0;
  digitalWrite(led3,LOW);
    }
    else{
      digitalWrite(led1,LOW);
      digitalWrite(led2,LOW);
      }
Serial.print("condition value is :");Serial.println(condition1);//for test
Serial.print("time differnt is:");Serial.println(timedifferent);//for test
Serial.print("the distance is :");Serial.println(distance);//for test
}
```

Water-protection box

There is a total of two versions of waterproof box are designed. In the first draft of designing, we built a triangular prism but with a curved surface. The design with thickness of 3mm each side, includes two holes located on the curved surface for our motion sensor's detectors sticking out, one motor holder inside the box, and a rectangular hole for the designed linkage poking out of the box to do the pushing job.

We then found out that this design is a decent design but currently unable to be realized with our 3D printer. Because our first draft involves thin walls and curved lines and surfaces. The mechanism of our school 3D printer does not allow us to do such a fiddly job. It is very easy to make errors when printing, but our prototype leaves little space for errors. 3mm is too thin to tolerate any mistakes -- any error happens in the printing process would create uncertainties to our entire shape of the design, and if anything wrong happens on our curved cap, it will both affect the installation of our motion sensor and flexibility of our designed linkage, which will then lead to negative impacts on the application and results. Besides, because our motion sensor is attached on a small piece of electric board and the board is flat, unnecessary inconvenience will appear when installing the sensor on the curved surface.

Although the box is to provide water protection, because of either the designed holes on the box or the 3D printing material itself, moistures and floating aerosols are inevitable. If there is not a strong connection between the sensor and the cap, it certainly will weaken its stability and hence influence its lifespan and the user experience. In addition, our prototype was made earlier of the project. By then we did not have all data measured out, therefore some details were ignored when making the model. For example, there isn't any space or holes drilled for wires going in and out because we simply didn't know how thick each of the wire was going to be and how many wires we need to install inside the box.

Consequently, we abandoned our first draft of our prototype and changed it into what it is now -- all sides are flat, walls are thicken, and holes are well-designed.

Micro-Switch Holder design

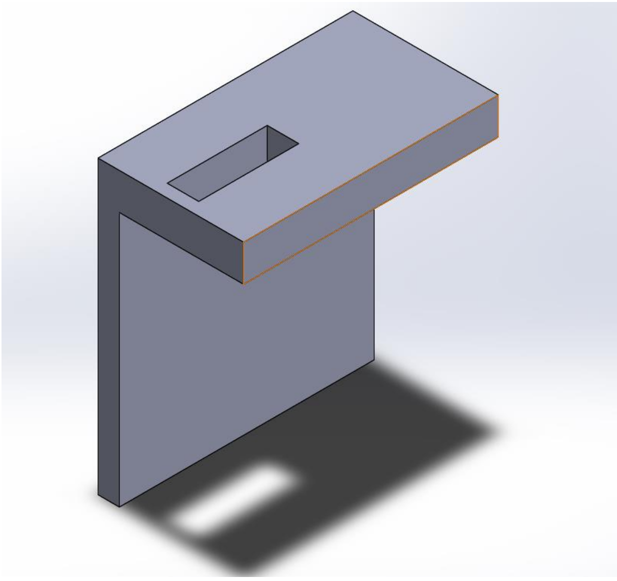


Figure 41 Old Holder

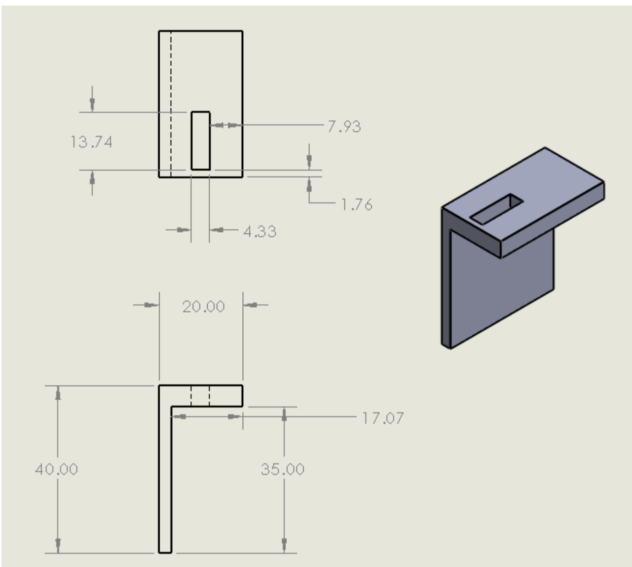


Figure 42 Old Holder Drawing

This first initial design for the micro-switch holder had two major issues. The group was worried that the holder would not mount well even if the double-sided mounting tape is flexible to the toilet bowl. Toilet bowls are curved on the sides and only near the top where the toilet seat sits it is flat. The flat longer side of the holder would have trouble being mounted upright on the side of the toilet bowl, so the group agreed that a redesign of that side needed to be done. The group agreed upon making that wall have a curvature which will allow the holder to remain upright when mounted on the side of the toilet. The second issue was that the switch would not be held in place without using tape. Since the platform on the top is flat and smooth, tape must be used to keep the switch from moving around even if it sits flat. The platform does not have any feature built in that can hold the switch without using tape. The platform had a cut into the upper platform to comfortably house the switch and make it, so tape does not need to be used. The group wanted the cut to go deeper so at least half the switch was submerged within the cut preventing the switch from falling out.

Motor selects

Regarding the motor part of the experiment, a total of three attempts were made and two failed. One failure was to use a DC-gear motor, and one failure was to use a servo motor.

For the initial experiment, the team's first decision was to use a DC gear motor as the motor to provide torque. The specific motor model purchased is High Torque Reversible Electric Geared Motor. Its characteristics are Pure copper wire core rotor, galvanized surface treatment, high-temperature resistance, high abrasion resistance, strong load capacity, sturdy and durable, effectively protecting the gear box motor body. The required rated voltage is 12V; the rated current is 0.37; The rotation speed under no load is 100RPM, and the maximum torque is 4KG/cm. There are four reasons why the DC gear motor cannot meet the requirements of this experiment. First, the rated voltage and current required by the DC gear motor are greater than the ideal voltage in the design. In the experiment, a 9V battery was used. Therefore, if new 9V batteries are not considered in series, the rated voltage cannot be reached in the test, which may reduce the power that the DC gear motor can actually provide, resulting in the inability to provide normal torque, and the experiment cannot be completed. Thinking from other perspectives, connecting two 9V batteries in series requires calculating some resistance in series, which will make the circuit more complicated and more likely to cause danger. The second point is that if you only rely on the program and DC gear motor, you cannot achieve small-angle control; if you buy a controller, it will increase the cost. The method of controlling the angle change that can be thought of during the experiment is to calculate the time required for a fixed angle number through the RPM, and then set the two transmission directions according to the time to realize the function. But in the actual experiment process, because the DC gear motor purchased is 100RPM, there is a relatively large error in capturing a very small time point, and it is not easy to return to the original position after execution. The third point is that the shaft shape of the DC gear motor is relatively round, and the 3D printing that needs to be matched has relatively high requirements for accuracy, which is prone to slippage and is not easy to stabilize when the torque increases. The fourth point is that although we have tried our best to purchase high-torque motors during the purchase process, DC gear motors generally still cannot provide the high torque we need when the rated voltage is relatively low (5V). This does not mean that the DC gear motor cannot achieve functions, but relatively speaking requires more data support and auxiliary components.

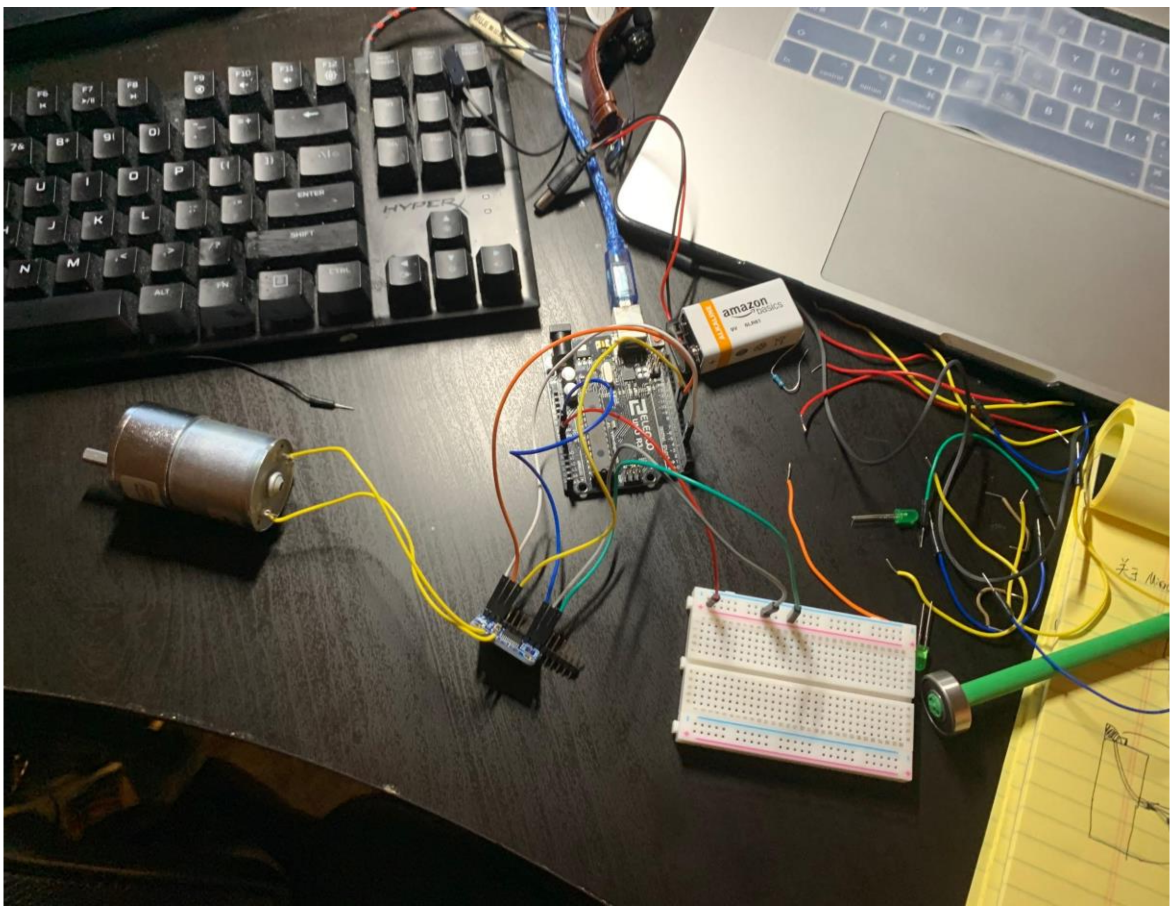


Figure 43 Test of Using DC-gear Motor

After experiencing the failure of the DC gear motor, the new design considered stepper motor and servo motor two alternatives. Compared with DC gear motors, both motors can control the degree of rotation required relatively accurately. The reason why stepper motor is not used in this experiment is that because its essence is driven by electromagnetic, its relative torque is very low, which is not enough to complete the experiment. Based on the above analysis, servo motor is finally used as the motor. At the beginning of the experiment, it was calculated that the theoretical thrust required was approximately 12N. Then use the formula t=f*s to select the motor that meets the conditions. After purchasing the motor, you need to test the actual effective rotation interval of the servo motor, and then select two points and corresponding values according to the available rotation interval. (The angle difference is about the degree of rotation required.) For the first time the servo motor is used, and the four-bar link is connected, it is found in the actual test that the toilet flush button cannot be pushed. (The reason for the four-bar linkage will be explained in the next chapter.) During the test, the side-mounted servo motor was used, and the built-in horn was used to push the toilet flush button. Although it can be pushed, it looks very difficult relative to the motor, and it will spin down and will not return, or it will directly cause the servo motor to lose control. In addition, the plastic horn that comes with the servo motor will deform to a certain extent during the process of pushing the bottom. This shows that this servo motor will not be the best choice, but it satisfies the needs procedurally and logically, so what needs to be improved is to buy a servo motor with a larger torque. One of the important factors leading to the failure of realization is the failure to consider the force changes brought about by friction.

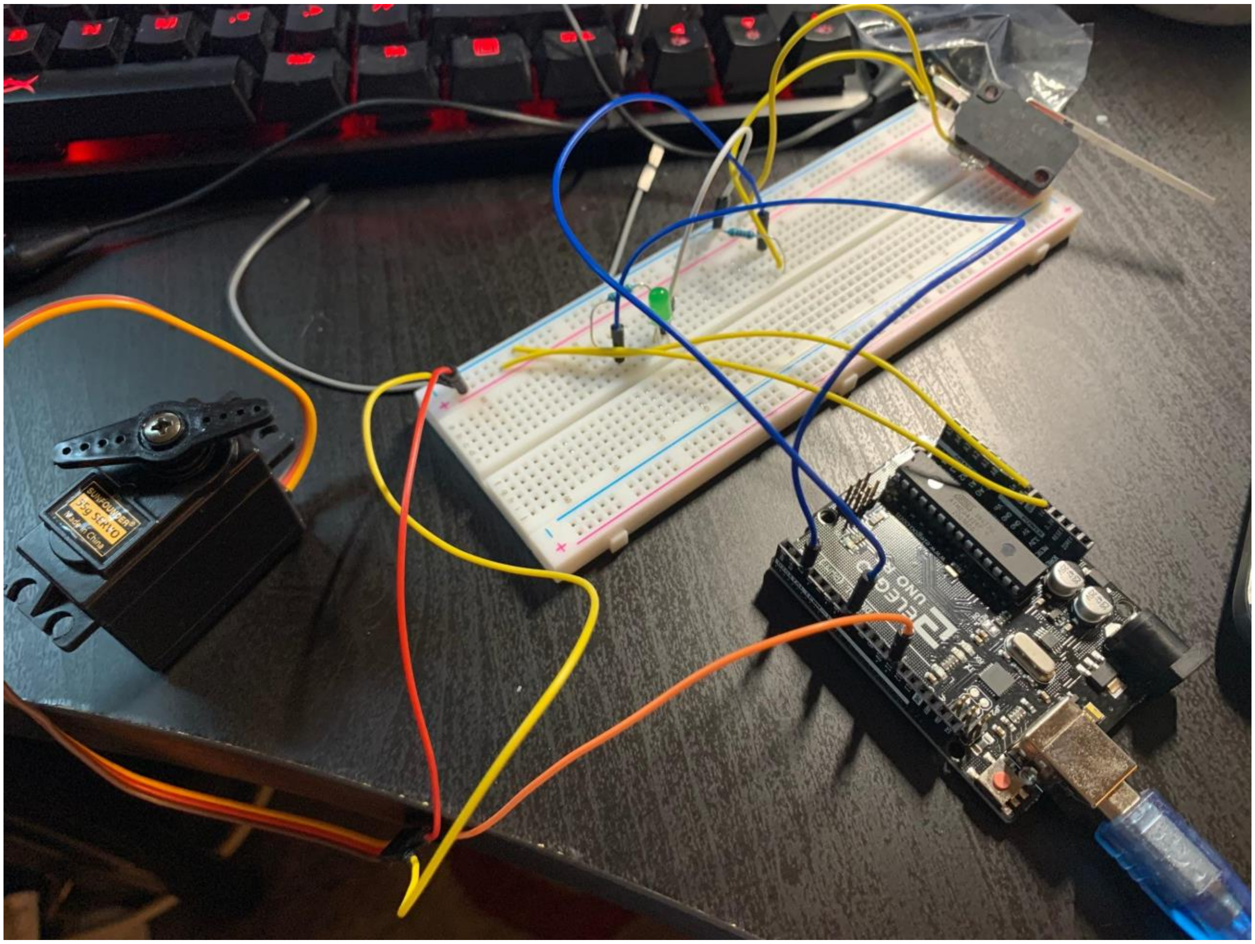


Figure 44 Testing of Servo Motor Change of Angle Change

Four-bar Linkage

Whether in the process of conceiving the use of Four-bar Linkage or completing Four-bar Linkage through software modeling, the degree was calculated by the program and finally 3D printing. In the whole project, a considerable amount of time and energy was spent. Finally, it was found in the realization that it could not be completed in accordance with the ideal situation. In the process of failure, it is necessary to summarize the reasons, which provides a reference angle for future designs.

For the model building part, there was a relatively big mistake. The reason was that the horn of the servo motor was not considered in the modeling punch and also existed in the entire motion structure as a linkage. In the ideal Four-bar Linkage designed, the last part needs to be transformed into vertical sliding friction. Because the horn was not considered, the first design resulted in a Five-bar Linkage, which led to the failure of the entire design. Because of the addition of a linkage, a deviation occurred from the distance and the movement of the entire linkage the trajectory has undergone a fundamental change.

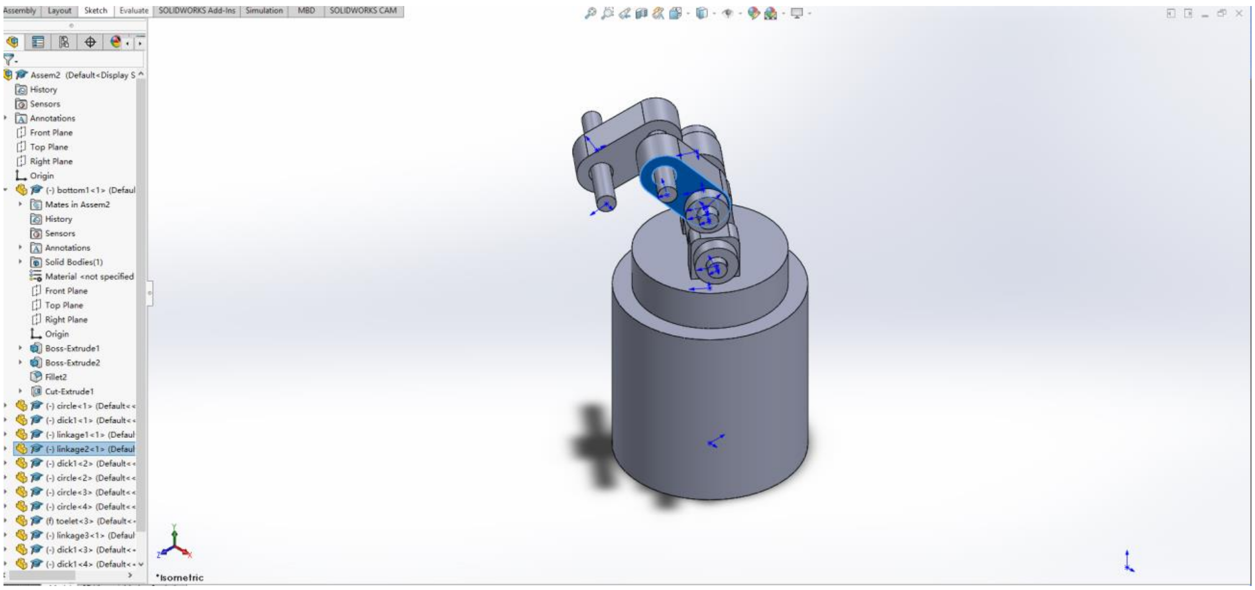


Figure 45 Design of Five Bar Linkage System

In addition, the link thickness of the first design is relatively thin, and it is not very reliable after printing. Secondly, due to the relatively small diameter of the designed pin, when the pin is connected to the linkage, the pin is quite prone to breakage. To avoid breaking here, the design makes the upper part of the sliding surface a fixed structure instead of a structure connected by pins, which increases the stability at one time.

Figure 46 First 3D Printed Parts and Broken Pin.

After the above failures, the Four-bar Linkage needs to be redesigned, where the horn needs to be considered as a pin, and the length of the horn needs to be considered. Since the center of the horn is connected to the servo's 25T gear, the actual length of the horn needs to be divided by two. In addition, it is also necessary to consider the drilling holes with many M3 screws on the horn, so it is necessary to consider the effective distance from the hole to the center of the servo motor gear. In the design, the thickness of the link and the diameter of the pin should be appropriately increased without collisions to ensure that it will not be damaged in actual operation. Due to the errors in 3D printing, for the holes and lengths that need to be printed, some extra distances will be added to ensure that the printed parts can be used normally. Here is the view of the object in SolidWorks

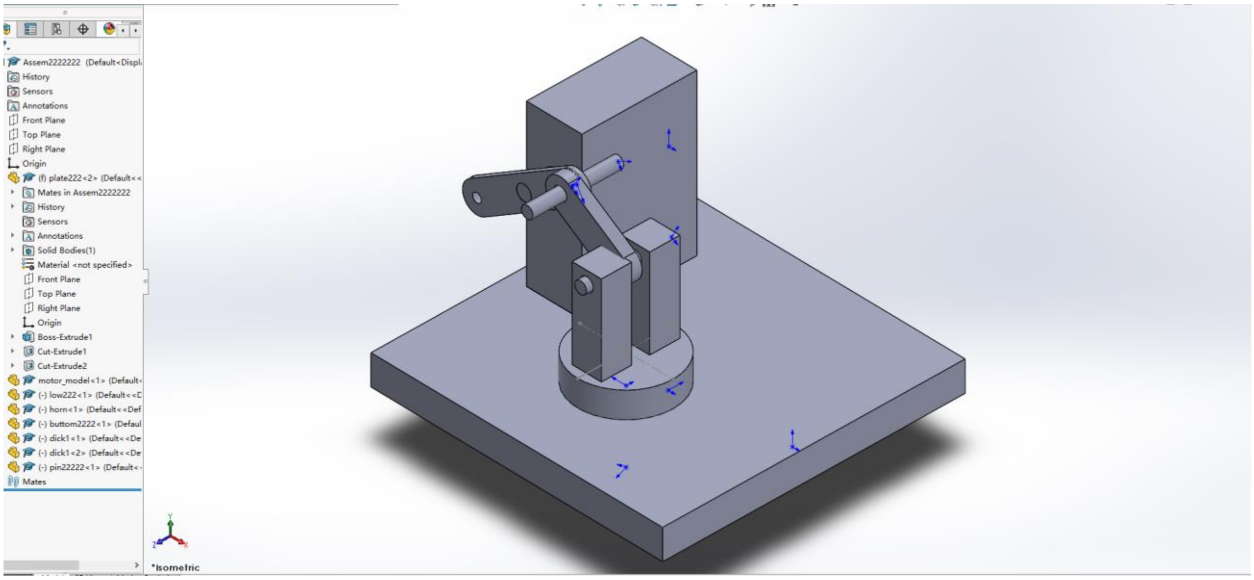


Figure 47 Four-bar Linkage

After completing the 3D modeling, the parts need to be printed. For the printed parts, the servo motor was assembled. Places that need to be fixed are fixed with M3 type 20mm screws. In actual implementation, although more space has been reserved at the opening, the diameter of the cylindrical pin is still relatively small, resulting in the printed pin not being a cylinder but more like a cuboid. This causes the pin to enter the socket not smoothly, and greatly increases the frictional influence caused by the surface area of the hole, making the entire pushing process require far more force than normal. Secondly, when the bottom of the printed contact surface touches the toilet flush button, its side also has too much contact with the wall of the toilet flush button. In a sense, this makes the design of the four bar linkage fail, because the contact area is relatively large and the contact surface is quite rough in this process, which leads to a large friction coefficient of the contact surface, despite the power brought by the high torque. , Pushing the button is quite unrealistic. The reason for this problem comes from the over-idealized estimation in the design process. Because the friction is not considered when using SolidWork, and the printed shape is too idealized during printing, the actual product cannot be successfully formed.

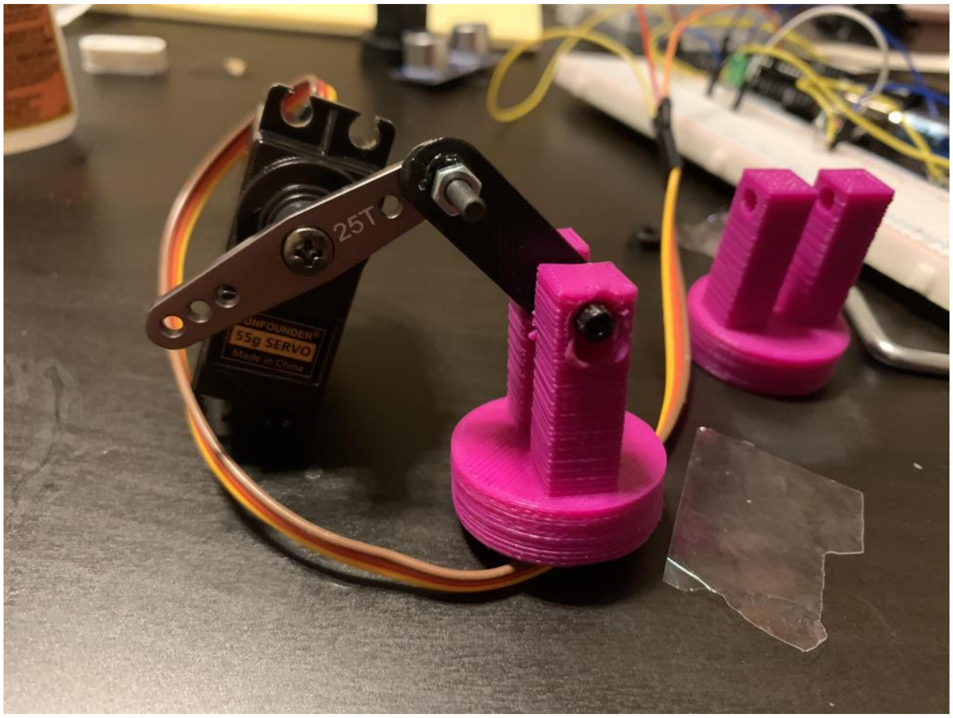


Figure 48 Test Servo Motor Combine with Four-bar Linkage made by 3D Printer

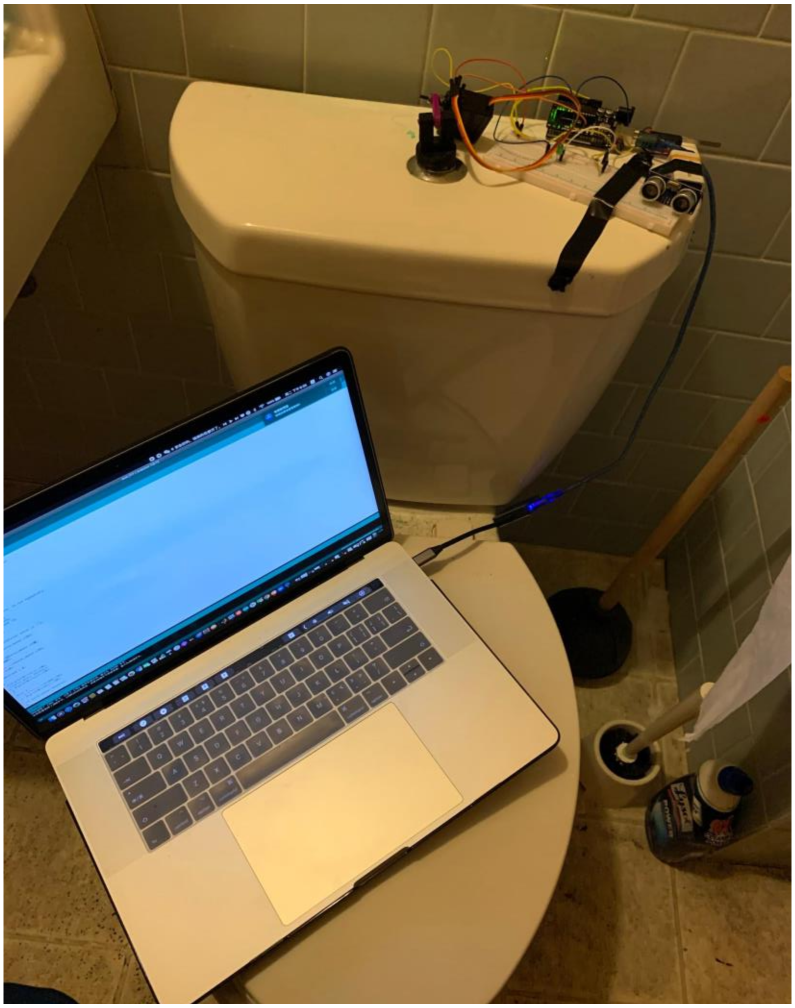


Figure 49 Test in Realization Process

Bibliography

Antibiotics can be lifesaving…. (2019, February 8). Centers for Disease Control and Prevention. https://www.cdc.gov/cdiff/index.html

C. Difficile: Symptoms and Treatments. (2017, April 28). WebMD. https://www.webmd.com/digestive-disorders/clostridium-difficile-colitis#1

Charles P. Gerba, Craig Wallis, and Joseph L. Melnick. "Microbiological hazards of household toilets: droplet production and the fate of residual organisms." *Appl. Environ.*

Coronavirus Cases. (2020, August 3). Coronavirus Cases. https://www.worldometers.info/coronavirus/

During the epidemic, why is it so important to close the toilet and flush again? (2020, February 15). Sohu.Com Inc. https://www.sohu.com/a/373382061_103374

E. (2020, September 2). Self-made automatic detection of lid flushing device (to prevent the spread of COVID-19). Bilibili. https://www.bilibili.com/video/BV1pZ4y1T7Zk?rt=V%2FymTlOu4ow%2Fy4xxNWPUZ%2Bu%2B1bvpD7hRSnsezHIzdYs%3D

Enterococcus faecium - microbewiki. (2012, January 29). Enterococcus Faecium. https://microbewiki.kenyon.edu/index.php/Enterococcus_faecium

Hartman, M. (2019, April 29). *What did America buy with the auto bailout, and was it worth it?* Marketplace. https://www.marketplace.org/2018/11/13/what-did-america-buy-auto-bailout-and-was-it-worth-it/

Legionnaires' disease - Symptoms and causes. (2019, September 17). Mayo Clinic. https://www.mayoclinic.org/diseases-conditions/legionnaires-disease/symptoms-causes/syc-20351747

Microbiol. 30.2 (1975): 229-237. (2020, February 15). Retrieved June 30, 2020, from https://www.sohu.com/a/373382061_103374

"New Cases of COVID-19 In World Countries." *Johns Hopkins Coronavirus Resource Center*, coronavirus.jhu.edu/data/new-cases.

Xiao, F., Sun, J., Xu, Y., Li, F., Huang, X., Li, H....Zhao, J. (2020). *Infectious SARS-CoV-2 in Feces of Patient with Severe COVID-19*. Emerging Infectious Diseases, 26(8), 1920-1922. https://dx.doi.org/10.3201/eid2608.200681

Osmosis. (2019, September 25). *Enterococcus - causes, symptoms, diagnosis, treatment, pathology*. YouTube. https://www.youtube.com/watch?v=4rZ_bMY_oPk

Q&A on coronaviruses (COVID-19). (2020, April 17). Q&A on Coronaviruses (COVID-19). https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/q-a-coronaviruses

Rettner, R. (2020, June 11). *Toilet Flushes May Spread Legionnaires' Disease*. Live Science. https://www.livescience.com/toilet-flushing-legionnaires-disease-spread.html

Sealy, M. J. C. A. |. (2019, July 8). *How Japan's music-playing, water-spraying TOTO toilets took over the world*. CNN. https://edition.cnn.com/style/article/toto-on-japan/index.html

Sheikh, K. (2020b, June 17). *Flushing the Toilet May Fling Coronavirus Aerosols All Over*. NY Times. https://www.nytimes.com/2020/06/16/health/coronavirus-toilets-flushing.html

TOTO Ltd. – World's largest toilet manufacturer. (2017, June 14). Japan Products - High Quality Products and Services. http://japan-product.com/ads/toto-ltd/

Watson, S. (2018, September 29). *Enterococcus Faecalis*. Healthline. https://www.healthline.com/health/enterococcus-faecalis

Wee, S. (2018, November 7). *In China, Bill Gates Encourages the World to Build a Better Toilet*. NY Times. https://www.nytimes.com/2018/11/06/business/bill-gates-reinvented-toilet.html

What Is Coronavirus? (2020, August 2). Johns Hopkins Medicine. https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus

What is Legionnaires Disease? (2016). Baidu. https://zhidao.baidu.com/question/1176112379214857939.html

Why America Is Losing The Toilet Race. (2020, February 25). NPR. https://choice.npr.org/index.html?origin=https://www.npr.org/sections/money/2020/02/25/808791622/why-america-is-losing-the-toilet-race