Group 23 Midterm Report: Automated Environment for Antibacterial Wipe Testing

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This paper documents the process to design an automated environment to wipe antibacterial wipes on surfaces for personal care company Kimberly-Clark. Design requirements, challenges, and methods are discussed. Several design concepts are presented, with their merits and drawbacks discussed. A final design is presented with justification, along with details for construction.

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I. Introduction

Professor Pranav Bhounsule, a professor at the University of Illinois Chicago and the head of the Robotics and Motion Laboratory, was approached by Kimberly-Clark, a personal care company. Kimberly-Clark seeks to improve their antibacterial wipes, and is in need of an automated system to rapidly and consistently test a large volume of antibacterial wipes. Professor Bhounsule then contacted Sebastian Mihulet, Mikhail Clayton, Umar Siddiqui, Amer Khalil, and Sulieman Sarmad, who are all students at UIC, and asked them to tackle this problem for their Senior Design project.

A. Problem Statement

Robotic automation has sped up the volume of production for nearly every industry in developed countries, yet has made very little change in the world of research. Many rote processes are still done by hand, introducing variability, researcher fatigue, and additional overhead. Automation allows for much larger sample sizes to be created, which is of particular importance for research. Larger sample sizes nearly always correlate with more meaningful and accurate results. Thus, any way to make research processes more streamlined, consistent, and efficient ensures a greater return on manufacturers investment many-fold.

This project focuses on creating an automated environment that can wipe antibacterial wipes on surfaces. Cleanliness is of utmost importance to researchers to minimize the risk of cross-contamination in their samples, and antibacterial wipes are essential in this pursuit. Thus, any increase in their efficacy is highly valuable, and must start from the ability to quickly test a large number of wipes in a consistent manner.

The problem posed by Kimberly-Clark is thus: how can an automated environment be designed in order to test the residue left by their antibacterial wipes? This question can be further divided into 4 other questions:

1.) How can dry wipes be combined with liquid solution to make antibacterial wipes?
2.) How can the antibacterial wipes be then wiped across a surface consistently?
3.) How can the newly-wiped surface be dried, then abused/abraded to leave a realistic film?
4.) How can the film be then tested to understand its properties?

This project excludes Questions 3 and 4. Question 1 is also optional, but highly preferred. The focus of the group, then, is to design an automated environment that combines dry wipes with antibacterial solution, then applies the wipes to a surface.

B. Sponsor Background

The primary sponsor for this project is Professor Pranav Bhounsule. Professor Bhounsule is collaborating with Professor Megaridis and a small team of researchers from Argonne National Laboratories to obtain an NDA with the personal care consumer product company Kimberly-Clark.

Professor Bhounsule received his Bachelors in Mechanical Engineering from Goa Engineering College from 2000-2004, his masters from Indian Institute of Technology Madras from 2004-2006, and his Ph.D. from Cornell University from 2006-2012. He is currently the Automation and Robotics professor at UIC. He came to UIC last school year after spending 6 years as a professor at UCTA. Additional to his career in academia, Bhounsule's robotics experience stems from a background doing post-doctoral research for Disney Pittsburgh for 2 years beginning in 2012.

At UIC, he is also the head of the Robotics and Motion Laboratory. This lab specializes in legged locomotion, robotics, and optimal control. The lab is a new addition to UIC's laboratories. This lab is interested in developing robotic prototypes and practical control algorithms that would push the state-of-the-art of current systems. It uses prototyping tools such as 3D printers and simulations and tools in system identification, optimization, feedback control, and learning to achieve these goals. His interest in our project is in the challenge that is presented in designing an environment to overcome the shortcomings of modern robotics to automate an industrial process.

The group's connection with Professor Bhounsule began in January of 2020 when one member of the team approached him for a student research opportunity. Through this relationship, Professor Bhounsule reached out to the student to recruit a group to work on an upcoming project he was excited to assign to a small team of students. This project is a collaboration with Kimberly-Clark.

Kimberly Clark is an American personal care paper-based consumer goods manufacturer. One of their products is the renowned Kleenex wet wipes. Kimberly Clark currently outsources the manufacturing of these wipes which is an expensive and time-consuming process. Thus, their motivation for initiating this project is twofold. The first motivation is the in-house manufacturing of these wipes to cut costs of production. The second motivation is the testing of the wipes. Kimberly Clark aims to test the material properties of the film left behind from the wipes after being used to clean a surface. Our goal to automate this process will save Kimberly Clark time and money in the long run.

C. Codes and Standards

This automated environment will be operating around humans, and around potentially hazardous chemicals. As such, there are a number of OSHA standards that must be complied with, and that must be taken into account when designing the system. The relevant codes are shown in Table 1.

Table 1: Codes and Standards

1. OSHA (5)(a)(1)	General Duty Clause
2. OSHA 1910.219	Mechanical Power Transmission Apparatus
3. OSHA 1910.212	General Requirements for All Machines
4. OSHA 29 CFR 1910.147	Control of Hazardous Energy (Lockout/Tagout)
5. NFPA 79 2015	Electrical Standard for Industrial Machinery

The purpose of all of these codes is to protect human researchers who will be working within close proximity to automated machinery. Of particular importance is OSHA 1910.212: General Requirements for All Machines. This Code states that “machine guarding shall be provided to protect the operator… from hazards… created by point of operation….[2]” Each potential design must consider what potential hazards might be created by the environment, and how those hazards could be mitigated.

D. Literature Survey

Advancement in robotics has created an opportunity to integrate robotic labor with the workforce. Robotic assistance is incorporated in many large manufacturing groups including car manufacturing, distribution centers, medical research facilities etc. for the purpose of establishing a faster and more reliable production process. Robots come in any shape and size to adhere to work requirements set by the manufacturers. While the market includes a myriad of robotic designs, the majority of the manufacturers adopted a robotic arm as the primary design for production. The robotic arms are superior to other methods due to their maneuverability and their interchangeable parts. Incorporating this kind of technology in the work field enables the owner to continuously manufacture products without the needs that an average worker would require. The increase in reliability and daily production rate makes robotic labor a more efficient option for manufacturing operations.

The senior design project uses a robotic arm to fully automate a sanitation testing process for a large manufacturer. The project requires the design of the environment as well as the automation process to demonstrate the robot’s capabilities. The automation process requires a sanitation solution to be applied to a dry tissue, where the robotic arm will then wipe the tissue on a surface for an analysis on the solution's residue. To establish a full understanding on how to design and create such a system, research was performed on various variables to ensure the most optimal system. Variables including materials, equipment placement, equipment design, etc. were compared and drawn in prototype designs to establish a visual concept for the project.

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[2] “Occupational Health and Safety Administration: Standard Number 1910.212.” United States Department of Labor. Accessed December 5, 2020. https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212

The Kinova Gen3 Lite robotic arm was chosen to conduct the fully automated process. The robotic arm features six degrees of freedom that allow the arm to rotate 360 degrees as shown in Figure 1. Based on the Kinova Gen3 Lite Robot user guide, the arm can extend up to 760 millimeters (Fig.2). With these limitations, the base design must include equipment within the range to allow the arm to reach the desired components. The components that the arm will lift are saturated tissues that are within the 500g payload range, making this robotic arm an acceptable option.

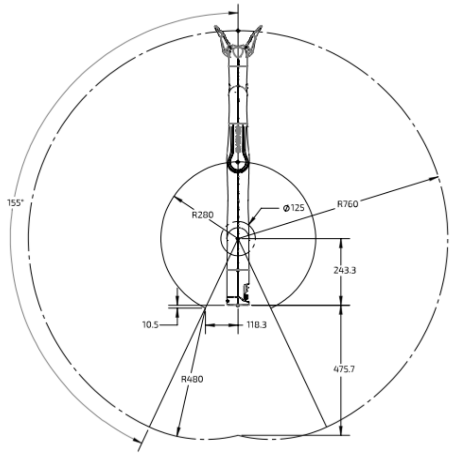


Fig. 1: Top View of Robotic Arm Horizontal Rotation

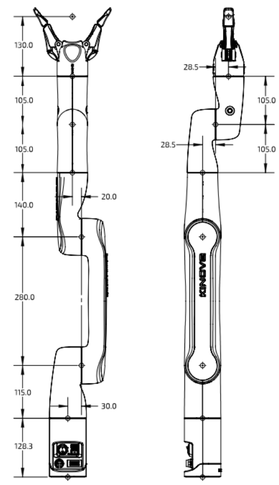


Fig. 2: Side View of Robotic Arm

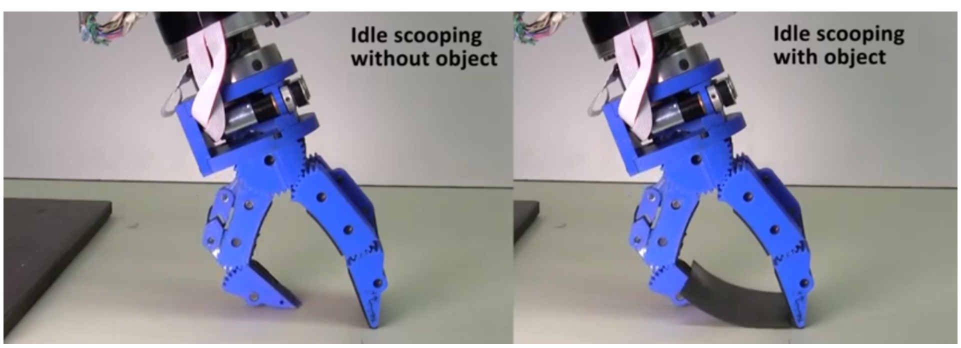
The surface design of the workspace on which the experiment is conducted plays a critical role in determining the outcome of the project. This project requires a durable surface that can withstand the 5.4 kg robot together with other equipment without undergoing deformation. To achieve this requirement, a metal finish between stainless steel and aluminum was considered depending on the application that it would be used for. According to Continental Metal Products, "Along with being stronger than aluminum, stainless steel is far more durable. It holds up in corrosive environments and is less likely to scratch." and "It is not likely to bend under pressure. Stainless Steel withstands stress, shock, pressure, and impact, in a manner that aluminum cannot."[3]. Stainless steel offers more benefits than an aluminum surface but falls short when it comes to weight. Dr. Vaghani and Dr. Desai gave a deeper analysis by introducing some of the benefits of stainless steel structures compared to other materials in their research "Stainless Steel As A Structural Material: State of Review". Aluminum on the other hand includes lightweight properties as well as durability. As stated by an industry article from Kaempf and Harris sheet metal, "… aluminum is almost one-third of the weight of steel."[4]. Depending on the series of aluminum that is used, the durability can be matched to that of steel. The Aluminum Association includes details that allow users to review the materials properties. Each materials property plays a role in deciding the material of the surface that best satisfies the project requirements. Together with the surface structure, the frame that supports the robotic arm and all the equipment must be able to withstand the loads applied including any additional equipment in the future. Companies such as 80/20 Inc. and Ventition allow the creation of environments through custom building software. The companies allow the user to custom create systems based on their needs as well as allow the user to include custom materials, machines, and accessories. These options allow for faster environment construction as well as ensure that the design will be fabricated accurately.

[3] "Aluminum vs. Stainless Steel in Hospital Applications - Pass thru Window." Continental Metal Products manufactures high quality stainless steel healthcare equipment for hospitals. Accessed November 5, 2020. http://continentalmetal.com/2018/01/aluminum-vs-stainless-steel-in-hospital-applications/.

[4] Harris, Kaempf &. "How Do Aluminum And Stainless Steel Differ?" Accessed November 5, 2020. https://www.kaempfandharris.com/industry-news/how-do-aluminum-and-stainless-steel-differ.

A method for securing the equipment to the workstation was discussed to prevent any shifting of the equipment during operations. Techniques such as designated cutouts were proposed which would satisfy the requirements of stabilizing the equipment, but it would limit the number of furnishings that would be compatible with the design. Other designs that were introduced was a clip system that locks the system component to the workspace. This technique was implemented on bicycle handlebars to keep a phone secure by Quad Lock. The company currently has multiple patents including a utility patent US 8,830,663 B2[5] and US 9,243,739 B2[6]. This style of securing is more complex and would require multiple components to be secured to both the workbench and the equipment. Other ideas proposed were the use of dog holes on the surface of the table. This technique is used across every industry to secure tools and equipment as displayed on the project ADA website. The pegboard system will allow equipment to be placed anywhere on the workspace to reduce the amount of restriction in designing. The pegs will secure the instruments with friction as the equipment is placed on the pegboard. Additional securing measures would need to be considered for fast-moving or heavy machinery. This problem is resolved with an additional clamp that is protected by patent no. US 8,403,314 B2[7]. The patent covers an “F " shaped peg that inserts directly next to the equipment on the pegboard with the extended end compressed against the equipment. Ensuring that all the components maintain the correct orientation allows the robotic arm to efficiently perform its tasks.

Since the project mandates that the robotic arm has to transfer the contaminated tissue to a testing surface, the arm has to be able to obtain the tissue without compromising the integrity of the solution nor the tissue. Many ideas arose that would allow the arm to transfer the solution. Since the tissue is extremely thin and fragile, a standard gripper would not be able to lift it up without creating damage. Alternative designs such as the one created by the Robotics Laboratories of Laval University demonstrate a three-fingered gripper that utilizes the thumb joint to get beneath the thin surface like a spatula as shown in Figure 3. This design mimics human movement that would allow the robotic arm to pick up the tissue and wipe it on a surface in a single motion. Other designs included suction as the primary method of raising the tissue. Millibar Robotics offers foam vacuum grippers that are available in a variety of shapes, materials, weights, and dimensions to pick up the tissue using vacuum pressure as displayed in figure 4. A similar demonstration could be seen in the “Pick and place of tissue paper with vacuum pump and suction cup – Piab” video uploaded by Piab Vacuum Automation. This option could create potential complications as it would introduce airflow to the solution, in result prematurely drying out the tissue before it establishes contact with the testing surface. These designs are currently implemented in manufacturing processes making them ideal candidates for this project.



[5] Erick Child, Whitney Clayton, Stephen B. Gates, Brent E. Barberis. Apparatus, system, and method for attaching peripheral items to devices. U.S. Patent 8,830,663 filed August 25, 2011 and issued September 9, 2014.

[6] Christopher Peters, System and method for mounting a handheld electronic device. U.S. Patent 9,243,739 filed May 30, 2012 and issued January 26, 2016

[7] Brian Hyuk Joon Chung, Christopher Heflin, Jennifer Faith Uzumeu, Gregg Michael Mangialardi. Dog hole layout for a workbench system. U.S. Patent 8,403,314 filed September 7, 2007 and issued March 26, 2013

Fig. 3: Robotic Arm Gripper for Thin Objects

Fig. 4: Robotic Arm Suction Attachment

As talks with the sponsor and advisor continued throughout the course of the project, opportunities for new methods for picking up the wet wipe arose. As previously outlined, the main goal of this robotic machine is to perform a human-like automated wipe that does not compromise the integrity of the wipe nor the solution residue. The team previously conducted research on picking up the wipe using suction but was discarded with the idea that the introduction of flowing air would compromise the wipe by drying out the pre-applied solution. During the composition of the decision matrix, a group member suggested reinvesting some effort into the suction end effector as the primary method of picking up tissue. The end effector that was suggested was a robotic arm attachment that is developed by OnRobot. The attachment configures to any type of third-party robotic arm with an air regulation capability. The VG10 electric vacuum gripper utilizes four rotatable arms to pick up objects with the three adjustable suction cups located on the bottoms of each arm as shown in Fig. 4. This attachment would be considered a feasible solution because it could be adjusted to only use the farthest suction cup on each arm. This would allow the device to lift only the ends of the wet wipe. Since the middle of the wet wipe is not in contact with air and doesn't undergo any convection, the wet wipe could be applied to a surface for testing. Other improved designs include flexible arms on the vacuum module. A patent is currently being held by SCHUNK GmbH & Co. KG which is a multinational manufacturing company that specializes in robot manipulators and accessories. Their design consists of a patent DE102014223118A1[8] that includes a gripping device with adjustable jointed arms (fingers) that are equipped with two suction cups at each finger as seen in Fig. 6 and 7. A design similar to this vacuum gripper would also be an ideal choice since it has the ability to efficiently pick up the wet wipe without compromising neither the wipe of the solution. Since a patent is already granted to the company, the best choice would be to purchase a manipulator module from either OnRobot or SCHUNK to avoid any patent violations.

[8] Michael Drab, Ralf Becker, Jens Wolfarth, Flexible, Adjustable Electrical Vacuum Gripper. Germany Patent DE102014223118A1 filed December 11, 2014 and issued December 05, 2016

Fig. 5: VG10 - Flexible, Adjustable Electric Vacuum Gripper By OnRobot

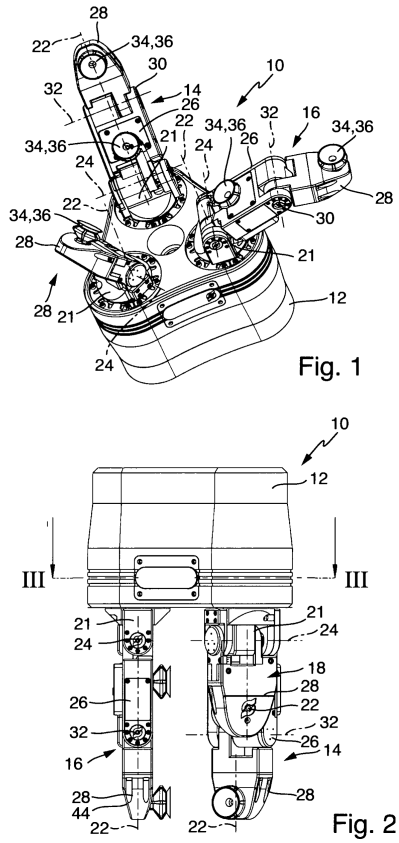


Fig. 6: Patent ID: DE102014223118A1 Design

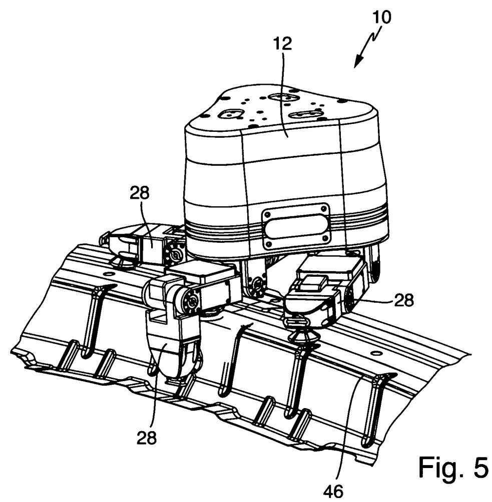


Fig. 7: Patent ID: DE102014223118A1 Arm Joint Capabilities

II. Design Criteria

A. Project Requirements

Design criteria are specific markers or milestones that any proposed solution must meet to be considered valid. These criteria are often given by the customer, and are divided into 'Needs' and 'Wants'. 'Needs' are those criteria that are essential for a prototype to be considered valid. 'Wants', on the other hand, are design criteria that are ancillary, and do not determine the validity of a solution. The criteria provided by Kimberly Clark are as follows:

Needs

1.) The environment can perform a wipe on a substrate.
2.) The wipe mimics how a human would wipe.

Wants

1.) the wipe will adhere to EPA guidelines
   a.) The robot can wipe a single substrate 4 times.
   b.) The robot can flip the napkin after every wipe.
2.) The loading and unloading of the wipe is faster than what a human researcher could do
3.) The wiping motion is fast.

B. Assumptions

With the design criteria defined by Kimberly-Clark, assumptions can be made about the scope of the project. These assumptions greatly help in limiting the scope of the project to a manageable size. Below are the key assumptions that the group has made:

The first assumption is that the wipes will be provided already saturated and wetting them will not be within the scope of the project. Second, the analysis of the residue left behind will also not be within the scope of the project. Finally it is assumed that human interaction will be minimized. Human interaction will only be implemented for operations that are impractical for a robot to complete.

C. Fishbone Diagram

With the team's assumptions outlined, the scope of the solution space should next be defined. A fishbone diagram, as shown in Fig. 8, is a useful visual aid that helps store concept requirements to efficiently create a finalized design concept. This diagram excelled in synthesizing the group's brainstorming and preliminary thoughts into an easy-to-follow graphical form.

To use the diagram, categories must first be defined. These are all of the unique design challenges or considerations that the group faced. These categories were decided upon by attempting to break down the question of "How will we wipe a wipe on a surface?" into as many sub-questions as possible. These questions, along with their corresponding category, have been expanded upon in Table 1.

Table 2: Fishbone Diagram Categories.

Sub-question	Category
What will the environment look like?	Design
What material will the environment be made of?	Material
What are the relevant measurements for a valid wipe?	Measurements
How will the wipe make contact with the surface?	Method
How will a human interact with this environment?	Human Interaction
What are the important environmental factors?	Environment

After defining categories, each category must be filled up with as many answers or potential solutions as possible. Realism and cost are not the focus of this stage. Rather, the goal is to find how wide or narrow the potential solution space is. In searching for these answers, discussion was sparked on how some of these answers might be implemented, or what the challenges might be of enacting a certain decision.

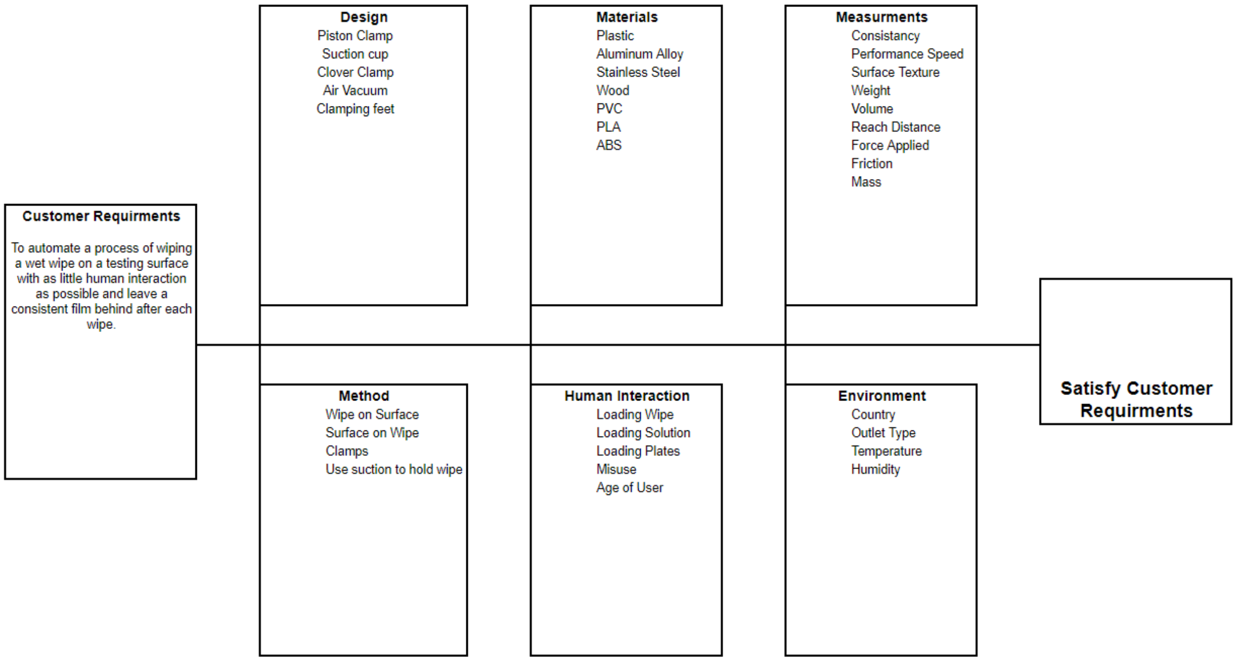
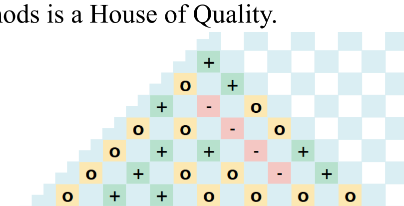


Fig. 8: Fishbone Diagram

D. Metrics

In measuring the relevant metrics for an automated wiping system, visualization is vital for productive discussion. One of the most comprehensive methods is a House of Quality.



Row #	Relative Weight	Customer Importance (1-5)	Maximum Relationship	Customer Requirements (Explicit and Implicit) / Functional Requirements	Film dimensions	Cost	Materials used	Number of Parts	Degrees of Freedom	Force/suction	Repairability	Accuracy (%)
				Column #	1	2	3	4	5	6	7	8
				Direction of Improvement	◇	▼	▼	▲	▼	◇	▲	▲
1	14%	5	9	Consistency	●	○	○	○	▽	●	▽	●
2	14%	5	9	Picks up wipe	●	○	○	○	○	●	▽	●
3	11%	4	9	Wiping on specific surface	●	○	○	○	●	●	▽	●
4	8%	3	9	Cheap	●	●	●	●	●	●	●	○
5	3%	1	9	Compact	○	○	●	●	●	○	●	▽
6	11%	4	9	Speed	●	○	▽	○	○	○	▽	○
7	14%	5	9	Does not compromise wipe	▽	▽	▽	○	▽	●	▽	○
8	8%	3	9	Robustness	▽	●	●	●	○	▽	●	▽
9	3%	1	9	Aesthetics	○	●	●	○	○	▽	▽	▽
10	11%	4	9	Safe	▽	●	●	○	○	▽	○	○
11	5%	2	9	Accessability	●	○	○	●	○	▽	●	▽
12	0%											
13	0%											

Fig. 9: House of Quality

Correlations	
Positive	+
Negative	-
No Correlation	o

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Fig. 10: Legend

Firstly, the horizontal row named Functional Requirements includes measurable properties about the system. These are objects or concepts that can be assigned or associated with a numerical value by the group. The vertical column named Customer Requirements shows desired attributes that the customer would like to see in the final product. The symbol present at the intersection of each Customer and Functional requirement shows whether those two requirements are strongly, moderately, or weakly related to each other.

The row directly above the Functional Requirements shows, for each Functional Requirement, whether it must be maximized, minimized, or brought as close as possible to a target value. The triangle above the Direction of Improvement shows the directional relationship between each Functional Requirement. For example, the Cost and Materials Used of a system have a positive relationship: as one increases, so does the other. Finally, the weights column next to the Customer Requirements show the relative importance of each Customer Requirement.

The usefulness of the House of Quality is its ability to, at a glance, allow the users to understand the relationships between the many different facets of a system. As one aspect of a system is optimized or increased, a House of Quality shows how the other aspects of the system would respond.

With the House of Quality created, the group was then free to break down the environment into subsections that can be solved individually. The first of these subsections that the group chose to investigate was how to pick up and manipulate the wipe. The House of Quality represents the applicable metrics for the environment in its entirety. The focus of the group was on how to pick up and manipulate the wipe. To this end, the following metrics were identified as the most relevant to the manipulation of the wipe:

Table 3: Metrics for Proposed Designs.

Metric	Measurement method	Justification
Size	Floor space of the environment	Final solution, while under no stated space restrictions, must make proper use of its space and not be overly large.
Human intervention	Time a human operator must spend maintaining/setting up the environment	The priority is to make this environment as productive as possible - any human intervention time must be justified with a return on run time/testing time.
Degrees of Freedom	Using the specification documents of the manipulator to determine the degrees of freedom	Degrees of Freedom determine how restrictive/open the design can be. Higher degrees of freedom = more freedom in placement/design.
Testing rate	How many tests can be completed per hour	Rate gives a direct comparison between design solutions.
Cost	Money spent on a prototype	The prototype should not be excessively expensive.

E. Proposed Concepts

1. Quad-Lock

The first idea presented was for a method to attach separate modules to the environment, allowing the end-user to customize their environment to their own desires. Fig. 11 shows an interchangeable clip in which you could attach various toolsets, devices, and etc. For example, the group could use a table with a shape cut out with a toolset having a similar cut as shown in Figure 5.

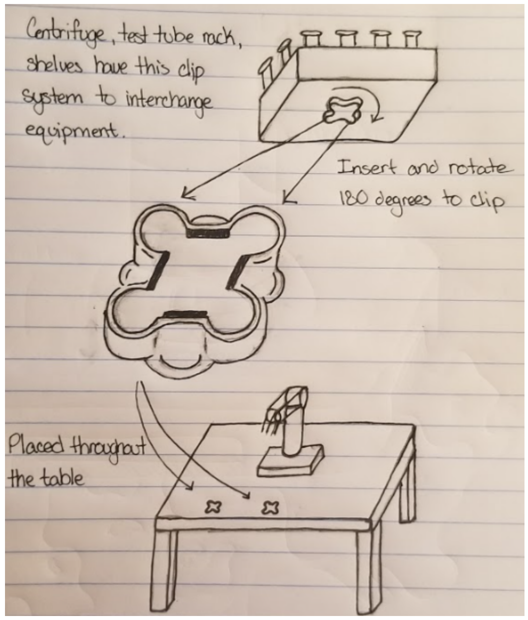


Fig. 11. Quad Lock© Interchangeable Mechanism

2. Gripper Feet

This solution sought to pinch a wipe between two textured, rubber feet. At rest, they would be at a steep angle with the horizontal, so as to allow the feet to get under a wipe. As the gripper closes, the feet would then make contact with each other. First, the bottom edges would contact. This forces the feet to come together vertically, thus holding the wipe in place.

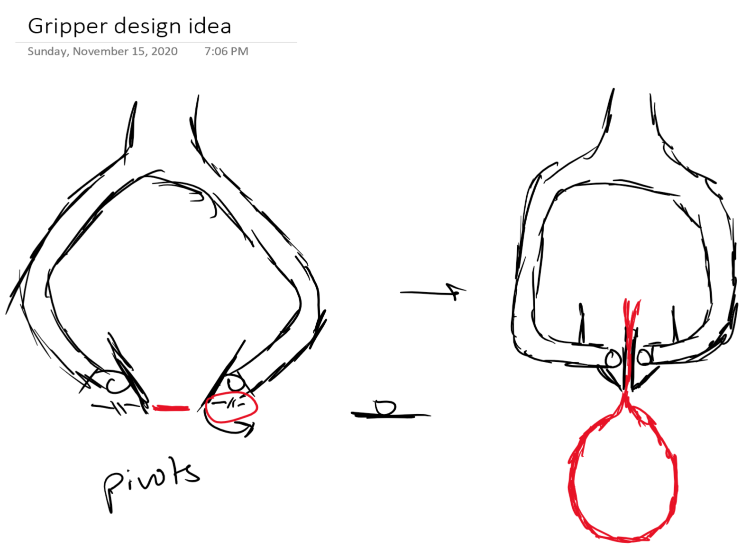


Fig. 12: Gripper feet conceptual design

3. Pinwheel Concept

This solution’s primary focus is to transfer the testing surfaces to a static wet wipe. The suggested structure includes a four-bladed windmill that utilizes hydraulic pistons with vacuum suction cups as a method of transferring surfaces to the test wipes.

The proposed solution includes many components that allow the system to perform efficiently. In the design, an electric motor spins the pinwheel. Connected to the motor are four evenly spaced hydraulic rods that are allowed to extend and retract at specialized locations. Connected to the ends of the hydraulic rods are ordinary vacuum suction cups that are around two inches in diameter. Other major equipment includes clean and contaminated surface sample storage units. The housings are identical to each other in design and size to appropriately enclose the surface samples. These structures use a spring-loaded backboard that drives the surface samples to one custom cut side. These structures would be ideally placed at the 90-degree and 180-degree positions respectively for the clean surface housing and contaminated surface housing with the custom cut sides facing towards the pinwheel motor. Just below the motor around 270-degrees is a conveyor belt that is approximately two feet in length. The conveyor belt is driven in a clockwise direction by an additional motor that is synchronized with the primary pinwheel motor to allow a consistent force to be applied on the conveyor belt in the same spot every cycle. Based on the direction of the belt’s rotation, a disposal container is utilized at the end of the belt as the primary method of discarding contaminated waste. On the opposite end, a wet wipe dispenser is proposed to issue single pre-applicated wipes. The dispenser maintains two tasks which include properly separating a single wipe from a stack and accurately dispensing it on the conveyor belt. Incorporating these components in the conceptual design demonstrates a proof of concept that would efficiently achieve the goal of performing an automated wipe process.

Using the equipment, the overall process behind the conceptual design is less complicated than the equipment required. Based on the design as shown in Figure 13 the initial operation begins at 270 degrees, where the hydraulic piston pushes the suction cup into the hole in the clean surface housing. With the force from the position and the reaction force from the spring-loaded backboard, the suction cup is allowed to create solid contact with the smooth texture of the clean surface. Once a vacuum-tight seal is made, the motor continues to rotate the system in a counterclockwise direction. During this process, the dispenser that is located on one end of the conveyor belt as previously stated separates a single wet wipe from a stack and distributes it onto the belt. This process should ideally occur at the same rate as the pinwheel's rotation. The idea behind having the dispenser and conveyor belt operate synchronically with the rotation of the motor is to allow the tissue and the clean surface to be in contact at the 270-degree location every time a clean surface reaches this location. When the wet wipe and the clean surface come in contact, the clean surface performs a whipping simulation that leaves behind the wet wipe solution residue. Having acquired a residue sample, the now contaminated sample surface continues rotating until it reaches the 90-degree spot. As the contaminated surface sample is making its 180-degree journey, the conveyor belt continues to move the used wet wipes to the opposite end of the dispenser. Reaching the end of the belt, the used wet wipe falls off the end of the conveyor belt into a strategically placed waste bin at the end of the belt length. When the contaminated surface reaches its final destination at the 90-degree position, the contaminated surface sample is inserted into the contaminated surface storage container. Once the surface is tightly inserted in the slot, the suction cup releases the contaminated surface to begin the cycle again.

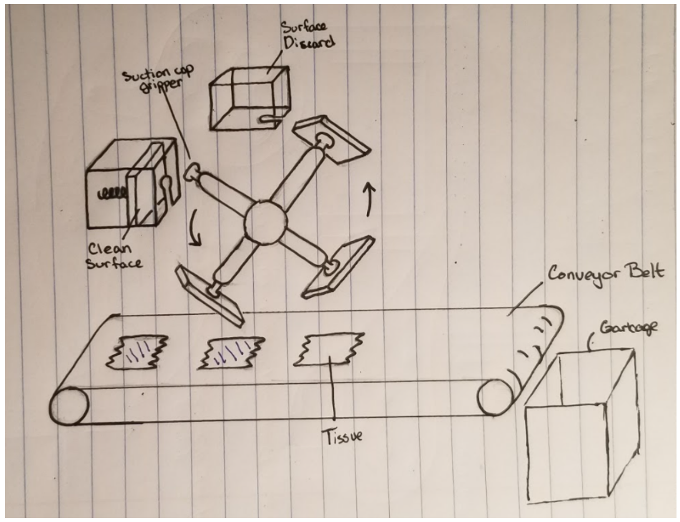


Fig. 13: Pinwheel conceptual design

4. Vacuum concept

The Onrobot VG10 electric vacuum gripper is an end effector that holds materials via suction. The goal of wiping the surface with this End-Effector is achieved by four equidistant configurable suction cups with a Styrofoam attached at the center of the gripper to provide a flat solid surface to which the wipe will be attached. The gripper has two vacuum channels out of which one will be used for the suction cups and the other for Styrofoam. As the intensity of both the vacuum channels are adjustable, we can have a higher vacuum intensity for Styrofoam and a lower vacuum intensity for suction cups. The reason for having two different vacuum intensities is because if we have a higher vacuum intensity for suction cups it will compromise the solution of the wipe. Once the gripper holds the wipe with the suction cup the robot manipulator will move in a circular motion to wipe the desired surface.

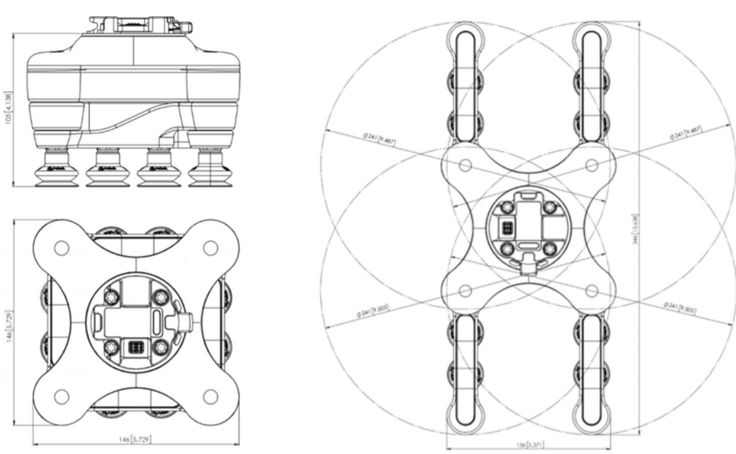


Fig. 14: Schematics for vacuum conceptual design

5. Clamp Concept

This concept uses an attachment to an end effector that will push into the napkin and close as force is applied. As the attachment pushes onto the napkin, the napkin will wrap around the attachment until it has reached the spring-loaded hooks placed in each corner. Once the hooks have grabbed onto the napkin, They will begin to close, wrapping the napkin around the attachment. As more force is applied, the attachment will be pushed toward the backboard. Once the attachment reaches the backboard, the attachment will lock into place, securing the napkin.

The remainder of the steps are similar to those proposed earlier. The wiping surface will be brought on a conveyor belt type system. The system will have the surfaces in a known position that the manipulator will reach out to and perform its wipe. After the wipe is completed, the surface will be moved to a storage location and the manipulator will be ready to discard the wipe and repeat the process. To discard the wipe, the manipulator will produce a force normal to the surface of the attachment, similar to when it picked up the napkin, in order to release the napkin into the proper waste container.

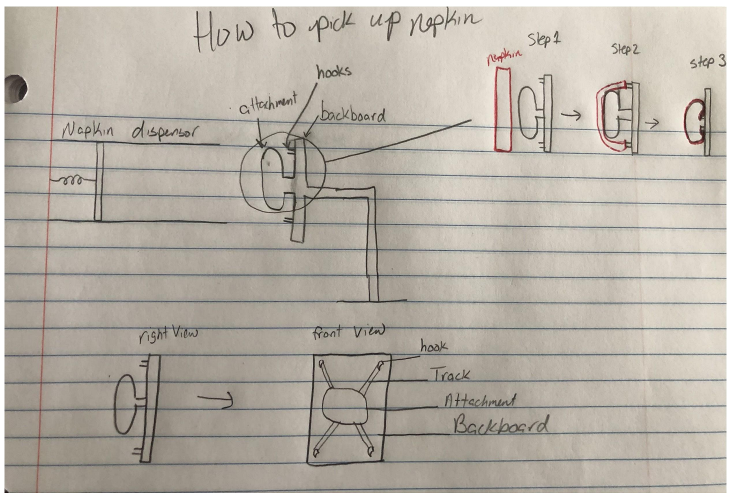


Fig. 15: Clamp conceptual design

6. Clover Clamp Concept

For the clove clamp concept, some of the assumptions are that the wipes will be individually dispensed allowing for a conveyor belt to bring the wipe into place to be picked up. An external flat surface attachment as seen in Fig. 16 will be gripped properly into place by a robotic gripper hand to allow for a concealed attachment. This device will then be placed upon the wipe with the use of sensors to guide the hand into place and allow all four corners of the wipe to be aligned with the flat surface attachment. The table itself will involve a series of motors that springs up a clover-shaped arm that will push the four corners of the wipe around the flat surface. The four corners of the flat surface have a clamping system that allows the wipe to be properly clamped down with the use of the clover hands keeping these corners in place (Shown in Fig. 17). As the wipe is properly clamped you will be free to code the wiping motion and possibly have a force sensor to detect the amount of force that is applied to the wipe itself. This concept is a work in progress as it has multiple complex systems in which overcomplicates the intention of this project.

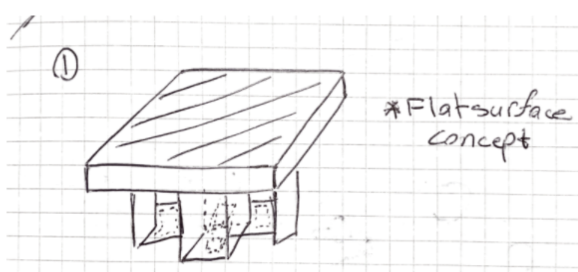


Fig. 16: Diagram showing mechanism used for flat surface concept

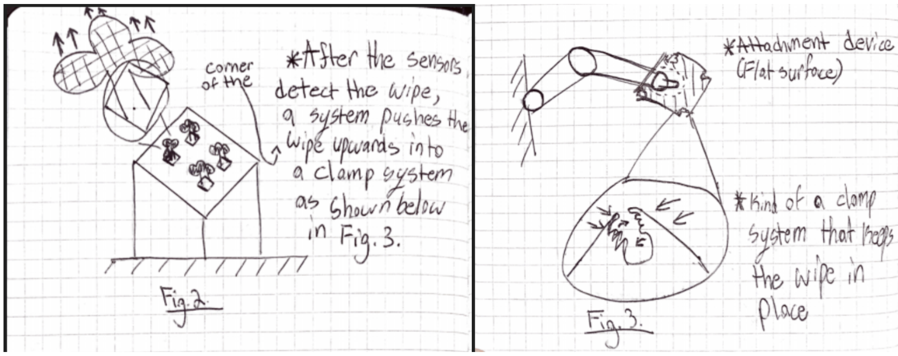


Fig. 17: Diagram showing mechanism used for the Clover Clamp concept

7. Selecting a Final Design

The concepts shown in sections 2 through 6 were compared with one another via a design matrix. The higher the score in each category, the better each design alternative performed. While the numbers assigned to each category are subjective, they nevertheless assisted the group in critiquing and evaluating each alternative.

Weights:	2	5	5	10	9	8	5	3	4	4	
	Design Complexity	User Complexity	Versatility	Pick-up ability	Compromise solution?	Tissue integrity	Robustness	Size	Cost	Potential Failiures	
Suleiman's Food Vacuum	4	6	7	8	9	8	8	6	1	5	380
Amer's Piston backboard	5	6	7	9	10	8	6	7	6	7	422
Mikhail's Suction cup Pinwheel	6	6	6	7	10	6	6	5	5	4	361
Umar's Clamping feet	9	7	4	9	10	5	5	9	9	8	413
Sebastian's Clover clamp	1	1	2	8.5	10	9	5	4	3	3	325

Figure 18: Design matrix

One use of a design matrix is to enact the highest scoring concept. From this interpretation, the Piston backboard would be the design alternative of choice. Another use for a design matrix, however, is to determine the most effective aspects of each project. In this interpretation, the true value of a design matrix lies in its ability to frame the strengths and weaknesses of each solution. The group could then more easily choose and combine the best aspects of each solution. This, along with discussions from Prof. Bhounsule, led to the groups' final design.

8. Final Design

The groups' final design will be a modified 3D printer. The group will buy a budget 3D printer, as the only components necessary from it are the well-tuned 3 DOF system. The group will then attach an additional motor, along with a gripper, to hold the wipe in place. Software is available publicly to allow for manual control of the 3D printer: one of these softwares would be used to program the wipe motion.

As for a gripper, the final design is most similar to the Gripper Feet concept, as detailed in Section II-2. A gripper will be designed in Solidworks, and rapidly prototyped via 3D printing. To open and close the gripper, a motor will be mounted where the extrusion nozzle of the printer usually sits.

To adjust the amount of force pressing on the wipe, a force sensor will be placed on the end of the gripper. This force reading will feed back into a control system, ensuring that the correct amount of force is always applied. If time permits, a GUI will be developed to allow the user to quickly change the amount of force applied. This will allow the effect of a stronger wipe to be more easily tested without modifying the source code.

To ensure rapid testing of the samples, a tray will be included that can be quickly loaded and unloaded. Samples can be placed into slots by human operators, then loaded into the environment to be tested. After testing, the operator can quickly unload the used tray and replace it with a tray containing new sample surfaces.

As the quickest and easiest option to create parts is via 3D printing, the group will print most of the custom designed parts. This will afford the group time and resources that would be spent in manufacturing that can be better spent testing and iterating. While a concept has certainly been finalized, the group expects a large amount of iteration throughout the testing process.

III. Methodology

A. Choosing a 3D Printer

Affordability was the chief concern when selecting a 3D printer. As this was intended to be a proof of concept, spending more than $1000 cannot be justified. Furthermore, the chosen printer must be compatible with publicly available software, as the internal controls will need to be overridden.

After researching, the two printers of interest to the team were the Creality Ender 3 Open-Source, and the Prusa i3 MKS3. The Creality printer was significantly cheaper than the Prusa, at $180 vs. $750 respectively. In addition, the Creality printer was assured to be compatible with public software, as its code is open source. Thus, the Creality was chosen.

Fig 19: Creality Ender 3 Open-Source Printer.

B. Gripper Design

The first iteration of the end effector involved a two finger concept that secured the napkin using a pinching motion. The design attempted to mimic a thumb and index finger configuration of a human hand. As shown below in figure 20, the design included two 50 mm long curved arms, or 'fingers,' that slid along the x-axis using the axial rotation of the stepper motor shaft. At the ends of the fingers were hooks that ensured that the napkin would maintain proper alignment during the wiping motion. Theoretically the gripper would pick up the napkin from the tray slots by pinching it between the arms. The napkin would be secured on the hooks by a human assistant and the gripper would perform its wipes.

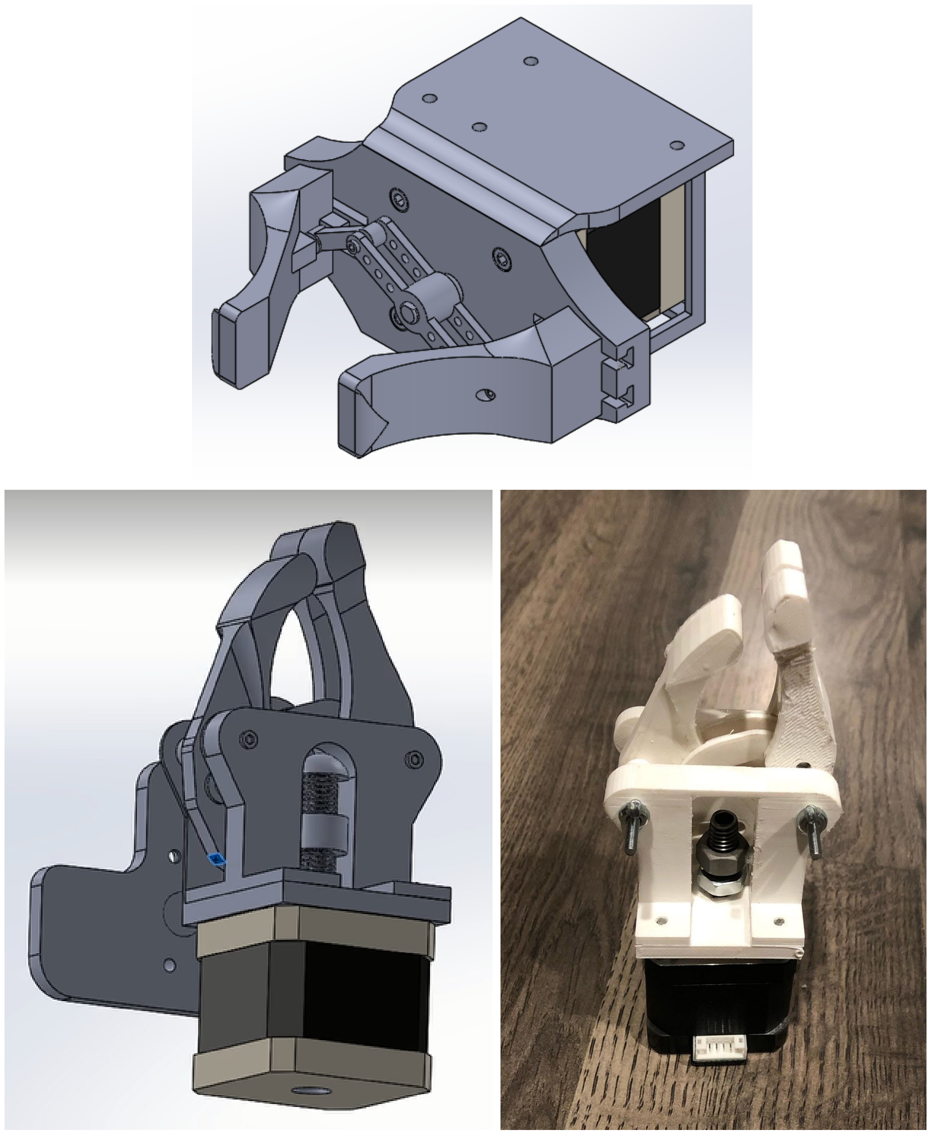


Fig 20: Finger-Gripper Design

However, issues were discovered with this design. The first iteration failed to demonstrate proper human grip due to the placement of the 'fingers.' When a human grips a wipe with their first three fingers, the thumb most often sits higher than the front two fingers, leaving a gap that does most of the wiping. This was not reflected in the first version, and was corrected in the second concept. The second concept was completely overhauled to properly mimic the gripping position of a human as closely as possible, which included finger redesigns and a more robust driving system. The new concept incorporated two appropriately spaced finger-like arms on one side and a thumb-like arm on the other as shown in figure 20. The new design's intended method of picking up the napkin was to use a pinching method like the previous concept. The driving mechanism for the arms was revamped to include a stepper motor that utilized a screw and nut to convert vertical to horizontal motion. This design was favored amongst advisors and sponsors due to its similarity to the human wiping form, structure, and versatility. The concept allowed for the implementation of pressure sensors and silicon finger molds to further mimic a hand structure and gripping forces. Since this design showed promise, future gripper iterations will be refinements of this second iteration, rather than complete overhauls. Since the gripper provided a proof of concept for the design, the second concept will be modified for better performance and greater efficiency.

C. Tray Design

The first iteration of the tray had a simple 4x4 16 cavity design. The tray was designed in such a manner that it was replaceable by having it placed on a tray holder which was attached to the base of the 3D printer with clips. It was done so to replace the trays faster and therefore resulting in more sample surfaces to be tested. The first iteration of the tray is shown in figure 21.

However, the number of sample slots in the first iteration were unnecessarily high and were cut back to a 3x4 cavity design . This space was put to more effective use with the addition of four vertical slots in our second iteration of the tray. These slots allowed for folded wipes to be placed by the operator, allowing the environment to automatically load and unload the wipes. Furthermore, the clips that were used to hold the tray holder with the base of the 3D printer were not sturdy enough so instead the tray holder was magnetized to the base of the 3D printer.

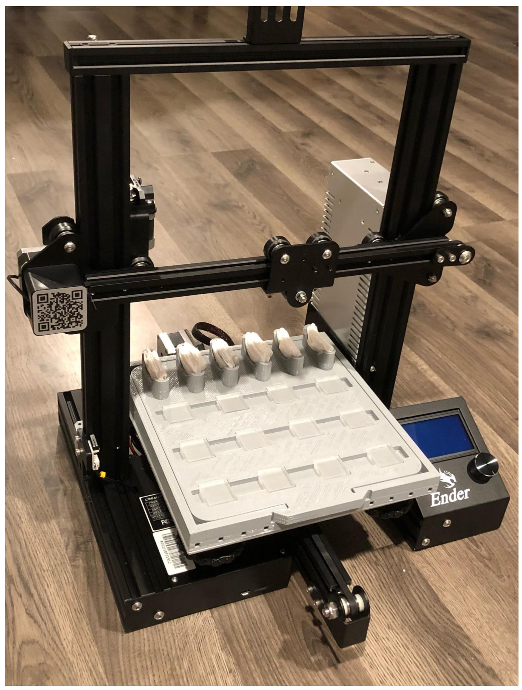


Fig 21: Tray assembly w/ 3D printer

D. Software

The final iteration of our design required software to manipulate the position of the printer and to open and close the gripper. The printer was required to perform a wiping motion. To accomplish this, commands written in G-Code are being sent to it to manipulate the position of the end effector. The wiping function is then sent to the 3D printer over serial using a python program. The program loops the wiping motion until it has wiped every sample surface on the tray. Another program was written in python and sent over serial to control the opening and closing of the gripper. This program manipulates the gripper by controlling the number of rotations completed by a stepper motor. Below is a software flowchart detailing the process required to successfully wipe the samples.

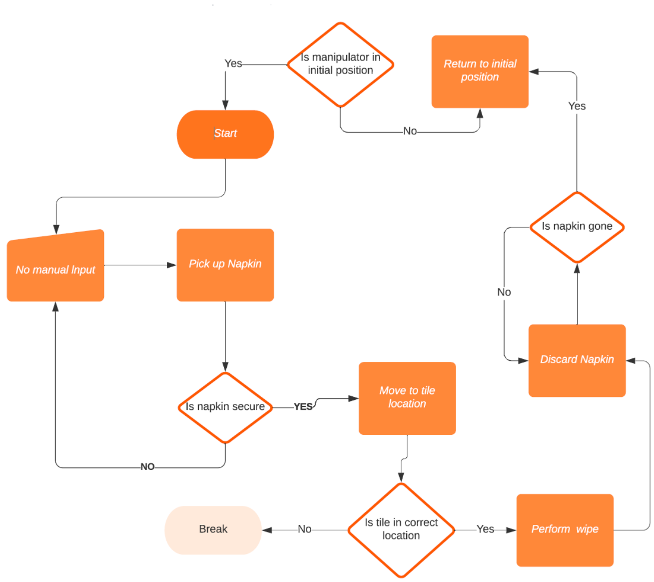


Fig 22: Software Flowchart

E. Testing

The group sponsors were heavily involved in the testing process for the environment, and their feedback drove the group's iterations. If the sponsors determined that the design was sufficient, then it had been deemed to pass, and no more iteration was done. The main testing focus for the sponsors, and by extension the group, was the gripper.

Initially, the gripper's ability to hold a wipe without human intervention was tested. Once the gripper could hold a folded wipe without dropping, it was presented to the sponsors. The sponsors then instructed the group to focus on making the gripper as close to a human grip as possible. This kicked off a series of redesigns to make the gripper closer to human fingers which included improvements in the figure texture, finger surface area, and finger resizement.

After a satisfactory design was achieved for the gripper, it was mounted on the 3D printer to allow for the whole system to be tested. To test the whole environment, it was tasked with completing a whole cycle on the samples without error. A cycle included picking up the napkin from the slot and wiping a row of four substrates before being discarded into a waste bin. This cycle was run with a new napkin during each cycle until all napkins were used. The environment passed this test on the first try, and was then presented to the sponsors for approval. Once they approved, the environment was deemed successful.

IV. Conclusions

This report detailed the process to develop an environment that automatically wipes napkins on test surfaces. After many design iterations and discussions, the most resource-efficient option determined was modifying an off-the-shelf 3D printer. The group purchased a Creality Ender 3 Open-Source printer, then custom designed a gripper to hold napkins, and a tray to hold substrate samples. The gripper was opened and closed with a stepper motor, driven by an A4988 stepper driver. The environment was controlled by a Raspberry Pi, running custom G Code to move the printer through the required wiping motions.

While the team successfully met the requirements of this project, more work must still be done to realize the full scope of this project. The next steps will be to hand off this environment to a future senior design team, who will add sensors and other feedback control systems to further improve the precision and accuracy of the wiping. The samples generated by the environment will also have to be further analyzed to determine their film properties.

V. Contributions

A. Mikhail Clayton

Throughout the senior design course, the group was challenged with various aspects of engineering that were based on real-world scenarios. With limited manufacturing experience and remote learning, each member relied on each other to complete different parts of the project. So to say that one person had only one part in the process would be far from the truth. From this, I learned about how crucial teamwork is, to ensure that all components are made on time and correctly. This was most evident during my process of creating the end effector in Solidworks. In this process, I relied on dimensional data and tolerance adjustments from my group members to make the necessary adjustments. I also learned how to properly document the design and manufacturing process for the system. By working on the Gantt chart, meeting minutes, and design sketches, I understood the importance of maintaining adequate documentation. Since our project changed multiple times throughout the semester, the progress charts kept me on track with deadlines while my proposed designs prevented me from repeating past mistakes. Through this, I as well as the entire group was able to complete our tasks and our project on time. The last major lesson that I learned was how to use SolidWorks to model a system. During my contribution to the gripper design and modeling, I used SolidWorks to modify and adjust the gripper to properly attach to the 3D printer. I was able to use my knowledge from class as well as outside resources to gain a better understanding of different techniques and systems that could be used to create designs. The senior design project created new learning opportunities and experiences that I would not have gotten in a classroom which made me understand what it is like to be a mechanical engineer.

B. Umar Siddiqui

This senior design project was an exercise in flexibility and teamwork. In addition to the challenges of collaborating virtually, the scope of the project was constantly in flux and evolving as new information was given from our sponsors. As such, when I reflect back on my work over the past year, I find myself much more flexible and able to deal with change. I am now able to evolve along with my clients needs, which will be an invaluable asset to me as I transition to industry.

Another lesson I learned was how important clear communication was, especially in an online format. At the beginning of the project, so much of our time was spent clarifying things that a person had said, or trying to understand the intent behind a design. In these endeavours, clear and concise communication would have helped our group immensely. As the project progressed, our communication skills became sharper and sharper, and our progress increased to match.

During ME 396, I contributed by offering design alternatives, keeping meeting minutes, writing reports, and assigning tasks to teammates. During ME 397, I continued my involvement with the group by providing feedback on the CAD designs as Mikhail, Sulieman, and Sebastian presented them. Furthermore, I did a majority of the report writing and other team documentation. I also helped Amer with the electronics, specifically when setting up and using the gripper motor.

C. Sebastian Mihulet

Originally, I was looking forward to working in person and collaborating with fellow classmates which took a turn as Covid created some restrictions as we all know. As a team we worked through the difficulties of this project and learned how adaptability is an important part of our society. Being able to have all the work done and put together while the primary of meetings was via Zoom or Discord. On top of not being face-to-face with the exception of twice, we went through hardships with having a base foundation for the project. The NDA not only backtracked us multiple times, but also limited any known constraints or requirements for the project. It was a struggle in all honesty to have any type of confirmation on what is needed other than to do X and Y in return still wasn't clear. This was the closest project to a real world issue I have come across throughout my educational career and was eye opening as there were people who helped each other accomplish a common goal. This is engineering at it's finest and I look forward to building on top of that experience. For the contributions of this project I primarily handled/assisted most of the presentation setups for meetings, the meeting times with our professors and team, any type of video editing/animation, and Solidworks design of the tray and system assembly.

D. Amer Khalil

The lessons I learned from this project are vast however the most important things I have learned was the importance of self learning. The code required by this project was not something we learned throughout the coursework at UIC, and as such required extensive research and self learning to be able to accomplish the task at hand.

My individual contributions to this project range from sponsor contact to software developer. I wrote all of the software required to make the robot move in the desired motions. I did the wiring of the raspberry pi and the gripper. I researched and implemented solutions to decrease the overall space requirement of the raspberry pi by utilizing a hat that sits directly on top of the pi as opposed to a driver on a breadboard off to the side. I assembled and tested the product as covid prevented the team from meeting up consistently.

E. Suleiman Sarmad

During the senior design project, we faced several challenges with regard to communication and collaboration amongst the members and sponsors. We were limited to collaborating virtually due to the COVID-19 pandemic. Over the course of the project, I developed more vital cooperative skills and learned how to adapt to any circumstance. Such skills are essential when it comes to working under pressure and will help me transition into the industry. Additionally, I learned that manufacturing parts using a 3D printer is based on a trial and error method where you do not always get the desired results. Therefore, the project yielded first-hand experience dealing with such inconveniences and subsequently taught me how to minimize errors and get optimal outputs. My contribution towards the project was mainly on the design and manufacturing aspect of it. I used Solidworks to design the first iteration of the tray and helped my teammates with the design of the end-effector. Furthermore, I was responsible for the parts to be made at the machine shop and makerspace. Additionally, I worked along with Mikhail to keep the Gantt chart up to date.

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VI. Appendix