Automated Bioanalytical Chemistry Sample Tube Uncapping Device

The University of Wisconsin-Madison
Biomedical Engineering Department
BME Design 200/300

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Client: Prof. Robert G Radwin
Advisor: Prof. Thomas Yen
Team Members: Samuel Perez-Tamayo - spereztamayo@wisc.edu (Leader)
Jake Jaeger - jjaeger4@wisc.edu (Communicator)
Jonathan Evans - jevans6@wisc.edu (BWIG)
David Fiflis - fiflis@wisc.edu (BPAG)
Alec Onesti - onesti@wisc.edu (BSAC)

Abstract

Capping and uncapping test tubes is not only a time consuming task, but can also pose a risk of injury to the people that do this task in the form of carpal tunnel syndrome. The current practice in labs around the world is to have a clinician manually open and close test tubes in high volumes of up to 700 test tubes a day. Our client experiences this volume in their lab and wants to improve their daily workflow by implementing a new automatic or mechanical device that can do this task. Ideally, time of the lab clinicians will be saved and the risk of developing carpal tunnel syndrome will be heavily reduced. Though several products exist today that accomplish this goal, none are in current use by the client, primarily because of the lab's unique workflow. There are many different mechanical and ergonomical decisions to be made regarding the production of the device, especially in terms of whether it can work on multiple test tubes at once or just one individual. The client requests that the team pursues multiple design ideas, as different devices may have certain advantages/disadvantages based on the application in which they desire. The final prototype consists of a semi-automatic rotary motor capable of removing any diameter of test tube cap.

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Introduction

Millions of samples around the globe go through some form of bioanalytical testing for a large variety of reasons. These samples are normally transported and worked with in some form of a laboratory test tube, and subsequently disposed of. Laboratory technicians responsible for processing these samples must undergo the repetitive task of opening and closing these test tubes each time the sample needs to be accessed. With new lab tests constantly being invented and developed, the demand for technicians is strong, and expected to continue to grow. The Bureau of Labor Statistics projects a growth of 18 percent from 2014 to 2024 in terms of employment opportunities, adding 29,000 professionals to the 163,400 already in the field (as of 2014).[1] With this given increase in the job market and importance for technicians, it is crucial to make their job as ergonomic as possible.

The repetitive uncapping and capping of twist-top test tubes is taking a physical toll on the lab technicians at a local Madison laboratory. Our team has set out to construct a device capable of reducing some of this physical stress. Whether manual or automatic, the device should be able to remove the top from the test tube, hold it until the work on the contents of the test tube is completed, then securely screw the top back on in a more efficient manner than the current process. This would ideally minimize the risk of injury as well as the maximize time for more important work.

Several products already exist on the market that accomplish the task of automatically capping and uncapping screw-top test tubes similar to those provided by the Madison laboratory. Each approaches the problem with a unique mechanism, yet all share many baseline characteristics. The three products most applicable to the problem statement are the Capit-All Screw Cap Tube Capper/Decapper [2], the PaR Capper [3], and the LabElite DeCapper [4]. In each of the designs, a tray of test tubes is placed/inserted in the area designated for the uncapping to occur. The test tubes used by these machines have specific tops in which a hexagonal/octagonal hole is cut out for the screw/arm of the device to reach down and insert into. This allows the top to either be screwed off or screwed onto the tube. The Capit-All design can handle 24-, 48-, and 96-spot racks and simultaneously caps, or uncaps, them all at once. The machine is capable of recognizing different tray types and sizes, so until the exact same tray is placed back into the device, the machine will not re-place the tops on the test tube. The LabElite DeCapper is very similar to the Capit-All, except the LabElite only works on one row at a time as to minimize time where the contents of the test tube are exposed, thus lessening the risk of contamination. The PaR Capper is the most different of the three in terms of size, machinery, and functionality. While the Capit-All and LabElite are roughly the size of a desktop printer, the PaR Capper is significantly larger. The user interface, a computer monitor located outside the machine's case, is used to select which test tubes are to be worked on. Subsequently, a robotic arm maneuvers its way around the interior, uncapping and capping specified test tubes one at a time.

Background

About one-third of all occupational injuries and illnesses stem from over exertion and/or repetitive motion, one of the most common being carpal tunnel syndrome. The median nerve is a nerve in humans that runs down the forearm, through the palm, and into several of the fingers. It controls sensations to the thumb and fingers and sends impulses to small muscles in the hand that allow for movement. The carpal tunnel is the narrow passageway made of ligaments and bones which holds the nerve and related tendons. When muscles and tendons surrounding the passageway get inflamed, the median nerve gets pinched, causing tingling, numbness, weakness, and pain in the hand and the wrist that radiates up the arm. This problem is called carpal tunnel syndrome, and can be caused by a variety of things including obesity, pregnancy, rheumatoid arthritis, and repetitive wrist work. Since the prevention of obesity, pregnancy, and arthritis are out of the scope of this project, the repetitive wrist work is focused on instead. Some of the movements that cause this inflammation include repeated wrist flexion/extension, radial/ulnar deviation, and forearm supination/pronation, all of which combine to produce the motion of screwing small caps on and off test tubes. [5]

CTS is becoming increasingly prevalent among laboratory workers due to the high volume of work without ergonomically-favorable tools. One of such processes causing significant stress on the wrists and hands of technicians across the world is pipetting. Another is the repetitive uncapping and capping of test tubes. Even more manual effort is required to remove the top of screw-on/threaded test tube as compared to a non-threaded, stoppered test tube, making the technicians at this specific Madison laboratory all the more susceptible to hand injury.

According to the U.S. Department of Labor Occupational Safety & Health Administration, of all work-related repetitive injuries, CTS results in more days away from work than any other workplace injury. Ergonomic injuries including these cost the industry roughly $15-20 billion in workers' compensation costs annually, which is clearly unfavorable for the employers. The employees, as well, are harmed by such injuries, as they have to follow through with physical therapy and/or surgical repair and risk permanent disability in the wrist in severe cases. [6]

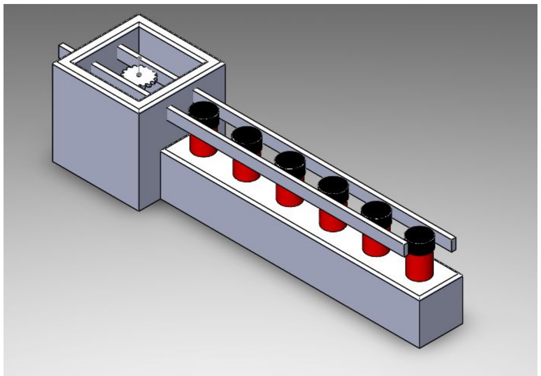
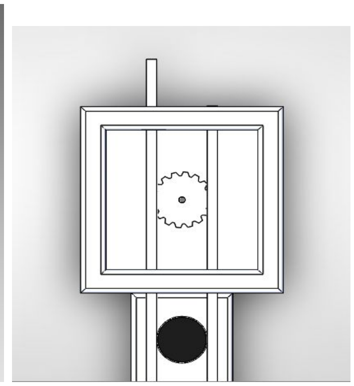
Professor Robert Radwin of the University of Wisconsin-Madison is serving as a liaison for the local company. The lab wants to lessen the manual labor required to open and close a high volume of test tubes by having our team design a device to automatically do this task, or at least lessen the labor of this task with a mechanical device. This improvement to their lab would allow their trained clinicians to spend more time on tasks that require their training and less time opening and closing test tubes by hand.

The design of this device is intended to reduce the cost, labor, and time in comparison to the current manual individual capping and uncapping method. In order to achieve these goals, the device must be able to cap and uncap at least 10,000 test tubes per month, and be available at cost cheaper than what it would take to pay a lab technician to perform the same job. Furthermore, the product must be easy to use in an attempt to minimize training time. The design should be small enough to fit onto the workbench so as to not interfere with the current workflow. Finally, the product must be sterilizable as it comes into contact with a variety of unknown substances, therefore we need to either avoid small parts or make the product autoclavable. The full list of product design specifications can be found in Appendix A.

Preliminary Designs

Design Idea 1: Parallel Bars

This design involves the anti-parallel motion of two bars in order to remove the caps of twist-top test tubes. The bars are powered by a single gear-driven motor, and they can act on an entire row of test tubes at one time. The job of the clinician is to line up the test tubes in the correct orientation relative to the parallel bars, and then power on the device, which results in the uncapping of the test tubes.

Figures 1 & 2: An overview of the parallel bars design with test tube rack inserted (Figure 1, left). A top view of the mechanism that would move the parallel bars (Figure 2, right).

Design Idea 2: Single-Grab

This design is a small, hand-held, mechanical device that can remove and replace the cap of a single test tube. In order to operate, it involves a motion similar to that as operating scissors. A spring loaded head is rotated when the two handles are squeezed together, and when released, it springs back into its original orientation. The head is placed on the cap of a single test tube, the handles are squeezed, and the rotation of the head twists off the cap and is held inside the head of the device. The clinician can then perform their work with the opened test tube, and then return the cap to the test tube by aligning the cap with the tube and releasing the handles, which rotates the head in the opposite of the original direction and recaps the test tube.

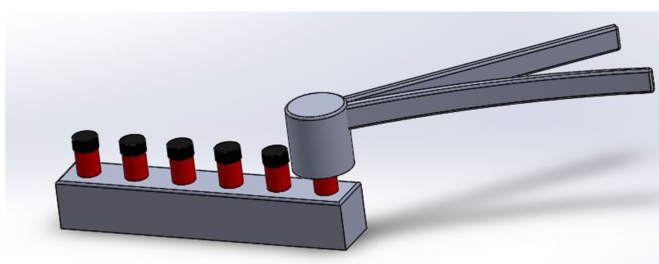
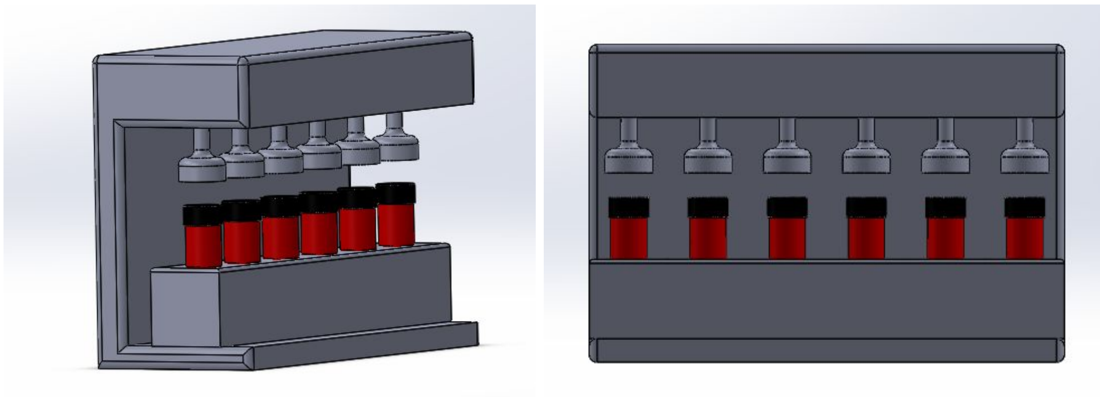


Figure 3: Model of the single-grab design uncapping a test tube.

Design Idea 3: Multi-Grab Design

This design involves six motor-operated, rotating heads that twist off, and then back on again, the caps of six test tubes. The clinician lifts the row of test tubes up to the rotating heads, uncaps the test tubes, does the work with the uncapped test tubes, and then return the row of test tubes to the caps, which have been held in the rotating heads, to be recapped. This design can be redesigned with any amount of rotating heads that are desired by the client.



Figures 4 & 5: An overview of the multi-grab design with a test tube rack inserted (Figure 4, left). A front view of the device showing the heads lining up with the tube caps (Figure 5, right).

Preliminary Design Evaluation

A plethora of criteria are included in the preliminary design evaluation because of the extensive design specifications from the client. These design criteria and evaluations can be seen in design matrix below (Table 1). A total of nine design criteria were chosen and each criterion was given a value of importance in the final project. The reduction of manual effort is one of the most heavily weighted because it is very important to the client as employees are at risk of long term ailments from the repetitive task of uncapping tubes. The speed and success rate of the uncapping device is also very important for the client to efficiently process a large amount of samples each day. Many variations of test tubes are used by the client so the versatility of a design to uncap and cap different test tubes will also be important in the final design. Ease of fabrication is important given the timeframe of the project. The client noted the device needed to be very durable to last in the laboratory environment and not fail after uncapping thousands of tubes. Cost and safety have importance in any laboratory device. Finally, the lab technicians have limited bench space so size of the device is also part of the design matrix.

Design Criteria (Weight)	Parallel Bars		Single-Grab		Multi-Grab	
Reduction of Manual effort (20)	4/5	16	2/5	8	4/5	16
Speed (20)	5/5	20	1/5	4	4/5	16
Success rate (15)	4/5	12	3/5	9	3/5	9
Versatility (15)	1/5	3	5/5	15	2/5	6
Ease of fabrication (10)	2/5	4	4/5	8	2/5	4
Durability/longevity (5)	3/5	3	5/5	4	4/5	4
Cost (5)	3/5	3	5/5	5	3/5	3
Safety (5)	5/5	5	5/5	5	5/5	5
Size (5)	3/5	3	5/5	5	3/5	3
Total (100)	69		63		66	

Table 1: The design matrix used to evaluate the three preliminary designs.

Proposed Final Designs

The final design matrix shows the three designs being rated relatively similar scores from the proposed criteria. The main difference in scoring between the designs is whether the device can uncap many tubes at a time versus if that design is versatile in uncapping many varieties of tubes. However, all three ideas were discussed with our advisor and client, and it was ultimately decided that a different approach should be taken. Our client's workflow emphasized versatility in uncapping different tubes, inexpensive construction, and simplicity in design to optimize cleanliness and maintenance, preferred single versus multiple tube uncapping, Discussion will focus instead on the final design.

Proposed Final Design After Client Visit

After visiting the client's lab where the device is being designed, and also meeting the technician who will be using the device, the ranking of our PDS criteria was substantially changed, and a new design to be made that met this combination of the reorganized criteria of the updated PDS. This final design was chosen for prototype construction.

Design Idea 4: The Uncapper

This design is a condensed version of the multi-grab design described in design idea 3. It involves a motor-powered, rotating head that uncaps a single test tube at a time. The clinician takes a single test tube and uncaps it before placing the test tube in the correct rack.

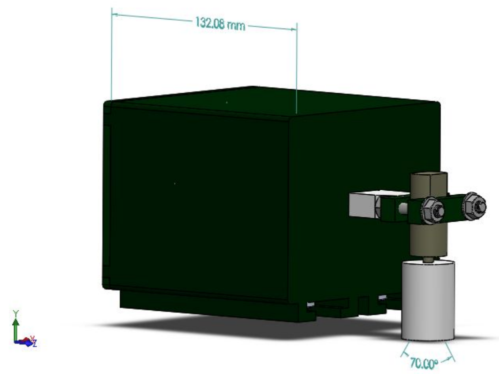


Figure 6: The Uncapper. A single rotary motor powers the uncapping capability of this design

Evaluation of the design:

The Uncapper scored high in many of the categories previously used to evaluate the other three preliminary designs.
It scored maximum scores in success rate,
versatility, ease of fabrication, cost, and safety.
This design is very simple and intuitive, so its probability of success are very high. Its design allows it to uncap any size test tube, making it versatile. It involves only one motor and casing, making it relatively easy to fabricate. It has a small amount of necessary components, keeping the cost down. Finally, it only has one moving part to clean, making this design very safe and easy to maintain.

The Uncapper		Design Criteria (Weight)
4/5	16	Reduction of Manual effort (20)
3/5	12	Speed (20)
5/5	15	Success rate (15)
5/5	15	Versatility (15)
5/5	10	Ease of fabrication (10)
4/5	5	Durability/ longevity (5)
5/5	5	Cost (5)
5/5	5	Safety (5)
4/5	4	Size (5)
	87	

Table 2: Design matrix evaluation of The Uncapper

Fabrication/Developmental Process

Materials

High density polyethylene (HDPE) was used for fabricating the cone and lever arm due to its machinability, strength and cost effectiveness. Several iterations of the cone were created so ease of fabrication was crucial in material choice. The material is also tough and lightweight so it was a good choice for the lever arm mechanism holding the motor in place.

The material with the greatest impact on this project was the one which would line the inside of the cone and be in direct contact with hundreds of test tube caps every day. Not only did the material need to be durable and have enough friction to remove the caps with ease, but it also needed to prevent any contamination that could possibly occur during the use of the device. Dycem, a thin, lightweight material with an extremely high coefficient of friction, excelled in all three of these categories. This material is able to grip the caps of the tube to ensure they will be uncapped with the turning of the motor.

A 12 volt DC motor was chosen to provide to necessary torque to uncap the test tubes. The speed chosen was 81 RPM as a compromise between efficiency and ease of use. This speed also avoids contamination from potential tube content dispersion. The motor has a stall torque of over 1,400 N*mm which is large enough to take the caps off with ease.

The electronics of the device were designed to allow for flexibility in the timing and speed of the motor after final testing. An Arduino microcontroller was chosen as the logic controller of the device due to its functionality and easy reprogramming. Since the Arduino is not able to handle the voltage and amperage necessary to power the motor, a TIP41 NPN transistor circuit gates the voltage to the motor. A rocker switch was used to activate the 'always on' mode for the device and a microswitch was chosen to recognize the lever action of the cone under normal operation.

The housing of the device and motor holder was 3D printed in polylactic acid (PLA). 3D printing was chosen for the ability to easily customize the inner geometry of the housing to accommodate for the switches and other electronics (see Appendix D). This material is durable for the laboratory setting and optimal for prototyping.

Two rare earth neodymium magnets were used for their ability to hold the entire device down to the metal lab benches used by the laboratory. These magnets are strong enough to ensure the device stays stable under operation, while still allowing for the device to be moved around the labspace relatively easily.

Methods

The cone was made from 1.25" HDPE round stock on the lathe. First the outer diameter was turned down to ensure the part was axial with the rotation so the final cone would not wobble under operation. Next, a 0.25" hole was drilled into the stock to begin the cone geometry. Using a small boring bar and the compound carriage set to the desired angle, the inner cone geometry was created with small, slow passes. After completion of the inner cone, the center was drilled out to the diameter of the motor shaft. This step was done with the part still in the original position inside the collet to further ensure all drilling remained axial. The cone was then cut off at the final length and brought to the mill for further manipulation. A set screw hole was drilled and tapped along the motor shaft hole and an 8-32 set screw was used to mount the cone to the keyed motor shaft. The dycem was cut into four triangular strips then attached around the inner cone using a light layer of 3M super gel.

The electronic components and Arduino were first designed and tested using a solderless breadboard. Code was written for the Arduino with the option of delaying the motor turnoff as well as lowering the speed if necessary. Once breadboards were tested and approved, wires were soldered to the pins of the switches and the motor. The resistors and transistor were soldered to a blank circuit board followed by the correct wiring. Finally, a diode was soldered to the motor pins to eliminate potential kickback voltage.

The housing was designed using SolidWorks and contained inner geometry to attach the microswitch as well as a slot for the motor lever. The bottom of the housing designed contained slots for the magnets and a detachable back. The full housing was printed in PLA using a Sindoh 3Dwox printer. Next, the microswitch was glued into its position under the lever slot using the 3M SuperGel. The 12V plug and rocker switch were both glued into their respective places in back of the assembly as well.

The motor lever was fabricated from a 1" thick sheet of HDPE. The material was trimmed down using the bandsaw then milled to the precise final geometry. A slight contour was added to the proximal end of the lever to ensure that the microswitch would not accidentally trip without the lever actuation. The 3D printed motor holders were drilled to allow a 1/4"-32 bolt through on either side of the motor and clamped down using two nuts. The motor holder was attached to the distal end of the using two 8-32 screws.

Final assembly was completed by running the motor wires through the lever arm slot with the lever arm inserted. The circuit board was attached to the top of the housing and the arduino was placed inside. The back of the housing with the plug and the rocker switch was attached and the two magnets were inserted into the slots to finish the assembly.

Final Prototype

The final prototype is shown in the figures below. The final cone angle is 70° with four vertical strips of Dycem, covering roughly half of the inner geometry surface area. This final angle and amount of Dycem allows for more than sufficient friction force from the walls to provide the proper torque to open the caps while still being shallow enough for the caps to fall out of the cone after the process is complete. The magnets attach the device from the bottom to the metal workbenches at the laboratory. This allows the process to be completed with only one hand raising the tupe to the cone. The motor actuates once the cone and lever system is raised about 5 mm from rest. This allows the user to only have the motor be running when the device is actually being used.

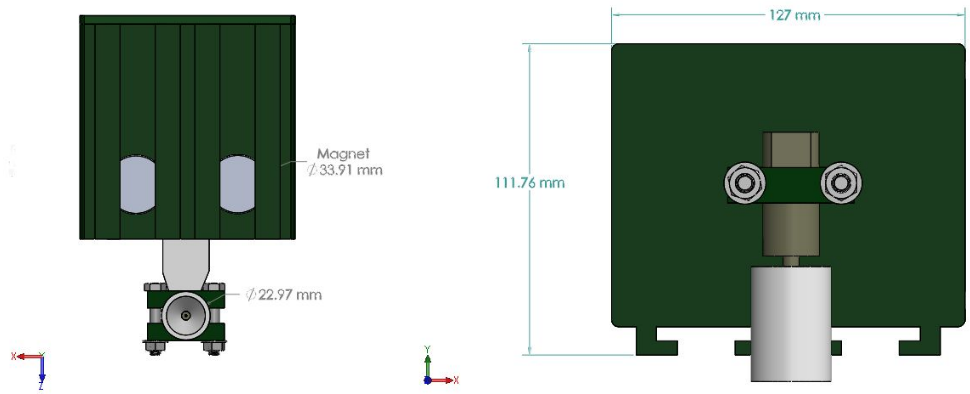


Figure 7: CAD drawings of the final design. The inner cone geometry can be seen from the bottom view (left) as well as a front view of the full design (right).

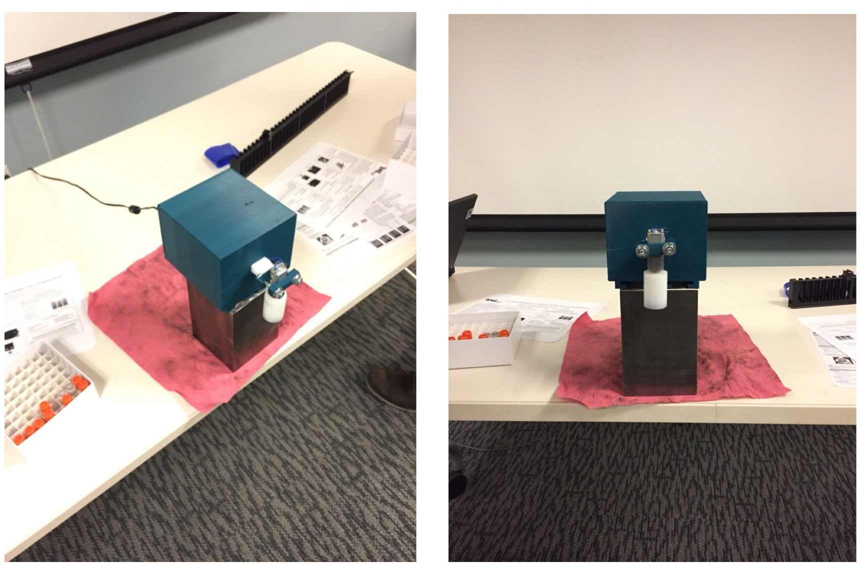


Figure 8: Photos of the final design.

The circuitry of the final prototype regulates the activation of the motor. The device is entirely powered with a 12V DC converter supply. Both the rocker switch and the microswitch are supplied 5V from the Arduino and have 10 kΩ pull down resistors on the side connected to their respective input pins. The 12V runs through the PNP transistor which is opened through an output arduino pin with a 1 kΩ current limiting resistor. A diode is attached across the motor to limit the kickback voltage after shutoff.

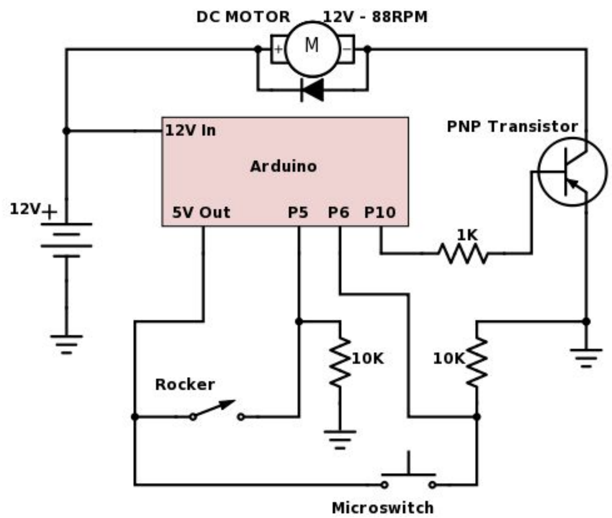


Figure 9: Schematic of the circuit used to power the motor.

The final Arduino code did not require consideration of delays or voltage regulation, and was consequently straightforward. The code actuates the motor when either of the input pins from the switches are turned on by sending 5V to the PNP transistor. The finalized Arduino code can be found in the appendix.

Testing

The torque required to open each test tube needed to be measured in order to conduct prototype tests and finally determine the parameters of a suitable motor to open the tubes. As torque gauges did not match the dimensions of the test tubes, more crude measurements had to be made. A 6-pound-test fishing line was attached tangentially to the test tube's cap at one end, and attached to a cup of known mass on the other. The test tube cap was screwed onto the tube body, and was attached horizontally over the edge of a table, allowing the cup to hang freely below. Calibration weights were added until enough torque was surmounted to twist the cap off the tracks. The mass of the weights in the cup, combined with the mass of the cup itself, necessary to uncap the test tube was recorded 10 times for each test tube type, and can be found in Table ???. Treating this system as a simplified pulley, the torque required to remove the cap can be calculated by multiplying the gravitational force created by the hanging mass by the radius of the test tube cap. However, when determining the equivalent amount of torque that a technician would use, the required value is divided in half as the technicians fingers exert a force couple on the cap.

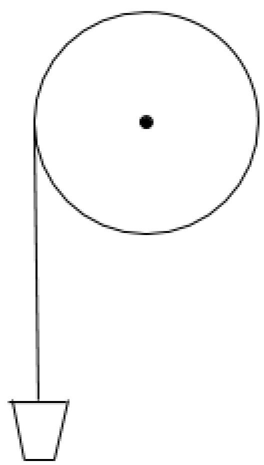


Figure 10: simplified diagram of torque testing. Cup with calibration weights hangs freely tangentially from the test tube cap (length of test tube runs in/out of page).

Testing was conducted in order to evaluate the effectiveness and durability of the device. To conduct the testing three sets of 350 tubes were uncapped, each set using a different test tube, and recorded the speed of uncapping as well as success rate. Using the torque values obtained earlier, the average torque of the three test tubes was applied to each cap during testing. To ensure that each tube was subjected to the same amount of force, the tubes all spent the exact same amount of time in the uncapper.

Results

Upon conducting our uncapping time comparison test between our device and by hand, we determined that there was no significant difference between the two methods. We compared the results of the two populations (total tubes uncapped with device, and total tubes uncapped by hand) via a pooled T-test. Nine test tubes were tested for each method. The average uncapping time for the uncapping device was 1.66 seconds/tube with a standard deviation of 0.14. This is in comparison to average manual uncapping time, which was 1.62 seconds/tube with a standard deviation of 0.03. These values yield a T-observed value of .858, and with a degree of freedom of 16 for the test, a p-value of 0.2 is obtained which is greater than the standard value for alpha of 0.05. Thus, there was no significant difference between uncapping methods.

Furthermore, all three types of test tube types were tested by the uncapper 350 times each in order to ensure reliability. There were no complications with the device during these trials, and the device uncapped test tubes at a 100% success rate.

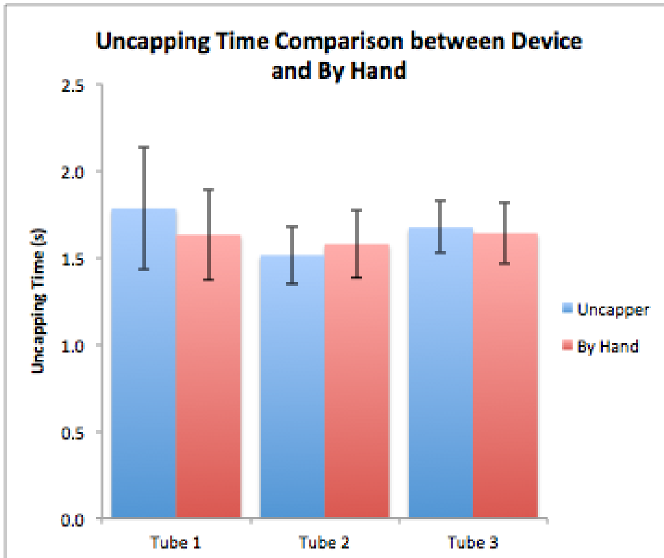


Figure 11: Uncapping times of the three tubes compared between the uncapper and by hand.

Test tubes 1, 2, and 3 were found to require torques of 12.3, 6.5, and 15.6 N*mm, respectively, to remove the cap. Images of each of the test tube numbers are listed in the appendix for identification purposes. The crude torque measurement made many assumptions/simplifications, so the exact values may not be accurate, but at the very least, they should give an idea of the relative torques to uncap the range of different tubes. Test tube 3 is the hardest of the tubes evaluated to open, followed by test tube 1, then test tube 2.

Discussion

The results of these tests demonstrate that there is no significant increase in time or reduction in effectiveness when employing the new device. Thus, there would be no disruption of workflow in the lab, or reduction in productivity.

Upon demonstration of no significant difference between manual and device assisted methods, it becomes a question of ethics to continue to put lab technicians at risk for carpal tunnel with traditional manual methods when this device performs the same job just as effectively without the risk of carpal tunnel syndrome. We conclude that it would be unethical to put workers at risk for this disorder when an inexpensive and safe alternative exists with this device.

No changes were made following our final tests of the device. However, in the future a second motor and uncapping head could be added in order to double the speed of uncapping. Also, the speed of the motor could be increased in order to reduce the speed of future uncapping, and make this device significantly faster than uncapping by hand.

As for sources of error, we conducted timing using a conventional stopwatch to measure capping time. This accounts for a degree of inaccuracy in the measurement of uncapping time. Also, device assisted uncapping was compared to manual uncapping by the engineering team. Experienced lab technicians may have speedier methods that were not replicated in these evaluations.

Conclusions

Lab technicians in the bioanalysis field have to uncap and recap thousands of tubes a week to perform their jobs effectively. Repetitive tasks such as unscrewing a test tube cap have been found to cause long term ailments such as carpal tunnel syndrome, which hurts both the employee and the company. The final design incorporates a motor and angled cone to remove test tube caps with minimal effort required by the user. The model works in both a pressure-sensitive mode as well as having complete on and off functionality. Magnets hidden underneath the device allow it to be secured to any metal lab bench and provide a counterweight while test tubes are being uncapped with an upward force. Taking advantage of these features, the uncapper allows lab technicians to uncap the same amount of test tubes in almost half the time while removing the risk of injury over time due to repetitive manual uncapping.

Future Work

The final prototype still has some possible changes that will overall enhance the quality of the device. The next major goal is to determine a method of having a second motor and cone in the same model. This configuration will allow a person to uncap two tubes simultaneously, one in each hand, and prevent clutter in the lab by having a second model with only one motor and cone manufactured. Our tests show that with only one uncapper the manual speed to uncap a test tube is matched and so with a second one the rate at which the technicians can uncap test tubes will be drastically increased. Further down the line adding the capability for the device to be hand-held could be an option, but if doing so does not add any substantial benefits in work ability or ease of use then it will not be a major goal unless it is specifically requested.

While the production of a device capable of uncapping test tubes is complete, it was only one half of our overall goal for the project. Creating a device that is able to cap all of the test tubes after they complete their testing in lab is still of high priority. Possible mechanisms capable of doing so have already been proposed, so the team now just has to shift its focus from uncapping to capping. The current model also has the potential to be adjusted to be able to function as both a capping and uncapping device, but much work is to be done prior to that becoming a reality.

Simplification of the electronics and circuit inside the device is another area of possible future work. Most labs are limited in the amount of space they have and the decision to allot enough space will have to be made prior to investing in the uncapper. Minimizing the work space lost with the introduction of the device is necessary if the uncapping device is to be utilized throughout the laboratories of similar clients.

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Appendices

Appendix A: Product Design Specifications

Function: A device that can, with or without automation, efficiently uncap test tubes with twist tops and save our client from finger joint damage and from wasting valuable time manually capping 500-700 test tubes each day.

Client Requirements: The device must be stand alone, easy to use, and more efficient than manually uncapping test tubes. It must also be compatible with multiple sizes of test tubes. It should be a simple design that is easy to use, reliable, and fits into a lab setting where bench space is limited. The device must average the capping and uncapping of 10,000 test tubes per month, making this a fairly robust design. It must work every time, and the design needs to be low cost and low maintenance.

Design Requirements:

1. **Physical and Operational Characteristics**
    a. *Performance Requirements:*
    Device has to be able to withstand high use without failure; must work every time with an average of 10,000 samples uncapped per month. Efficiency is also of great interest, as minimizing down-time while the device is in use is important.
    b. *Safety:*
    Must fit into a regulated work environment and pass all of its sterility checks. It should not pose a risk of injury for anyone using or near the device.
    c. *Accuracy and Reliability:*
    Must work every time with an average of 10,000 samples uncapped per month.
    d. *Life in Service:*
    Design should be able to be used for many years of heavy use. If the product has an element that is prone to breaking down, there should be a simple procedure for replacement/correction of that part.
    e. *Shelf Life:*
    This design is being made for a specific client, so no shelf life is expected for the product. However, the device should be able to sit on a shelf indefinitely and still be functional should it be used by laboratories across the world.

f. *Operating Environment:*

   A laboratory where bench space is limited. For that reason, the device should take up as little workspace as possible. Sterility is of great importance in a setting like this, so ideally the product will be able to be cleaned after previous usage.

g. *Ergonomics:*

   Must be capable of withstanding heavy use from multiple technicians. The device should be easy to use and have a very small learning curve, as technicians should be able to teach other technicians how to use it. The device should not create any discomfort in the fingers/hand/wrist during use.

h. *Size:*

   Should fit into a lab setting with limited bench space; no larger than a desktop printer.

i. *Weight:*

   No restriction on weight for the design.

j. *Materials:*

   Must be able to be cleaned and sterilized without the risk of damaging the device.

k. *Aesthetics, Appearance, and Finish:*

   Device should not stick out from the other devices and machines of the lab, so a look similar to those devices is desired. As this product is centered around efficiency, aesthetics are a lower priority as compared to functionality.

2. Production Characteristics

a. *Quantity:*

   One device for our client for now, however its construction would ideally be easy enough to mass produce the product.

b. *Target Product Cost:*

   Cost will be decided based on materials/parts used in construction as well as the client's thoughts on the usefulness of the design.

3. Miscellaneous

a. *Standards and Specifications:*

   The device should not break any of the sterility standards of the laboratory. We must be sure that there is no cross contamination between the samples during the process, as that would greatly interfere with the technicians' results.

b. *Customer:*

   Professor Robert G. Radwin and a research lab in the Madison area.

c. *Patient-related Concerns:*

   Lab technician did not seem nearly as concerned about risks of repetitive wrist motion as their supervisors did.

d. *Competition:*

There are several products already on the market that serve the role of capping and uncapping test tubes. These include the Capit-All™ Screw Cap Tube Capper/Decapper, the PaR Capper, and the LabElite DeCapper. All three are capable of accomplishing the same task, yet involve different mechanisms/processes. The biggest difference between the three is the number of test tubes capped/decapped at once. The Capit-All can simultaneously work with up to 96 test tubes at once, the PaR capper individually uncaps/caps, and the LabElite uncaps/caps one row at a time.

***Appendix B*: Expenses**

Item:	Supplier:	Purpose:	Price:	Quantity:	Subtotal:
12 V Motor	ServoCity	Mechanism for uncapping device	$9.99	1	$9.99
Microswitch	SparkFun	For push-to-run function of the design	$1.50	2	$3.00
1.25" HDPE Rod	Amazon	For creating the uncapping cone	$15.64	1 ft	$12.79
Transistors	Amazon	For circuit	$6.54	1	$6.54
Rare Earth Magnets	Amazon	Mounting Device	$19.40	4	$19.40
12 V 3 Amp Power supply	Amazon	Powering the unit	$10.68	1	$10.68
Arduino Microcontroller	Amazon	Logic Unit	$19.99	1	$19.99
Dycem	Prof. Yen	Provide friction to uncap tubes	$0.00	N/A	$0.00
				Total:	$82.39

***Appendix C*: Arduino Code**

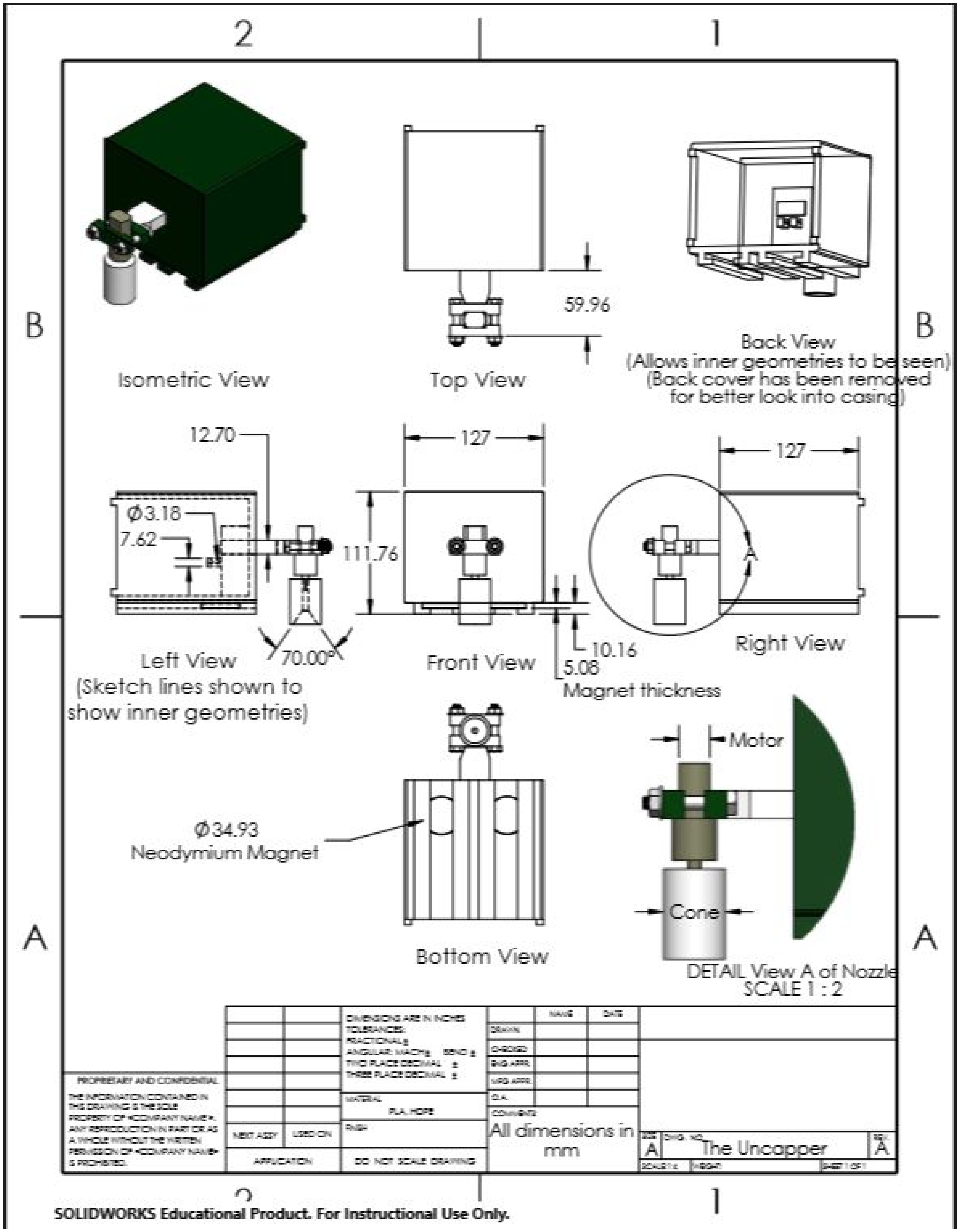
```
int touchOnPin = 6; //connect to microswith
int alwaysOnPin = 5; //connect to rocker switch
int motorPin = 10; //connect to gate of transistor
int alwaysOnPinState = LOW;
int touchOnPinState = LOW;

void setup() {
  pinMode(touchOnPin, INPUT); //set microswitch pin to input
  pinMode(alwaysOnPin, INPUT); //set rocker switch pin to input
  pinMode(motorPin, OUTPUT); //set transistor pin to output
}

void loop() {
  //read pin states
  alwaysOnPinState = digitalRead(alwaysOnPin);
  touchOnPinState = digitalRead(touchOnPin);

  if(alwaysOnPinState == HIGH){
    digitalWrite(motorPin, HIGH); //on if rocker is on
  }
  else if(touchOnPinState == HIGH && alwaysOnPinState == LOW){
    digitalWrite(motorPin, HIGH); //on if microswitch is on
  }
  else {
    digitalWrite(motorPin, LOW); //otherwise off
  }
}
```

***Appendix D*: **CAD Drawing of The Uncapper



***Appendix E*: Torque testing raw data**

Test Tube Type	**Trial #**	**Mass required to uncap test tube (g)**
1	1	370.4
1	2	360.9
1	3	353.4
1	4	378.4
1	5	381.9
1	6	375.4
1	7	372.9
1	8	358.9
1	9	341.4
1	10	342.9
2	1	190.4
2	2	200.4
2	3	185.9
2	4	195.9
2	5	193.9
2	6	195.4
2	7	191.4
2	8	201.9
2	9	198.4
2	10	187.9
3	1	508.9
3	2	485.4
3	3	495.9
3	4	501.9
3	5	489.9
3	6	502.4
3	7	507.9
3	8	476.4
3	9	503.4
3	10	498.4

***Appendix F*:** Test tube identification

Figure 12: From left to right: Test Tube 1, Test Tube 2, Test Tube 3. Test tube on the right was not encountered in the lab enough for it to be considered as one of the main ones.