Replication of a Chameleon's Tongue

P02 2021 Bhounsule Chameleons Tongue
Baneza Hernandez, Gregory Dachowski, Mohammad Ibrahim Raffay, Zach Williams
University of Illinois at Chicago, Chicago, IL, 60607

Abstract

Chameleon tongues are extremely rapid, stretchable, and compact. They have developed a specialized feeding system based on ballistic projection. When analyzing the kinematics of a chameleon it is observed that the tongue can accelerate from 0 m/s to 60 m/s in 0.1 seconds. Although speed is usually corresponding to size it was observed that the speed of the tongue is not relative to the size of the chameleon, nonetheless the length of the outstretched tongue is proportional to the size of the chameleon. While humans have yet to recreate the ballistic nature of the chameleon's tongue, we are trying to use common mechanisms to replicate the motion and speed that is generally observed when studying chameleons. Through vast research on the mechanics of chameleon tongues we have a general idea on how to mimic the motion of nature. With the help of industry applications, we can narrow our design requirements to a specific purpose, so the final design serves a purpose other than replicating nature. Our preliminary designs mainly focus on using spring forces to shoot the gripper out and other energy sources to bring the gripper back to the firing position. These designs seem simple in theory and although chameleons shoot out there tongue effortlessly to grab prey it can be difficult to demonstrate the trajectory accurately when considering of mechanics. Through trial and error, we will decide on a final design and continually improve on it until our design meets all of our sponsors' needs and the needs, we set for it based on our industry application.

I. Table of Contents

Cover Page	I
Introduction	
Problem Statement	1
Sponsor Background	1
Literature Survey	1-2
Design Requirements	2
Technical Content	
Assumptions	3
Proposed Solution	3
Prototype 1	3-5
Codes and Standards	6
Prototype 2	5
Preliminary Testing	5
Retraction Mechanism	6
Gear Ratios and Output	7
Parts List	7
Countershaft and Reel Design	8
Retraction Prototype 1	9
Retraction Final Prototype	9-11
Prototype 3	12-13
Final Prototype Testing	13-14
Preliminary Conclusions	
Future Work	14
Conclusion	14-15
Acknowledgments	15
Appendix	
Gant Chart	16
Fishbone Diagram	17
QFD Diagram	18
References	19

II. Introduction

Problem Statement

This project will show how the kinematics of a chameleon's tongue can be used as inspiration to develop a mechanism which can imitate the movements of the tongue. Chameleons can shoot their tongue from 0 m/s to 60 m/s in 0.1 seconds, this acceleration is most important to our design, but we are not going to overlook the recoil action that allows the chameleon to eat its prey. Designs for a high-speed snatching contraption that is inspired by a chameleon tongue will be considered to meet our sponsor's needs. Our sponsor professor Pranav Bhounsule runs a robotics lab at the University of Illinois at Chicago, he is interested in replicating nature with technology, the designed snatching mechanism can be used in engineering facilities where machinery can be programmed to remove a designated object from a conveyor belt.

Sponsor Background

Our project sponsor Professor Bhounsule is part of the mechanical engineering department at the University of Illinois at Chicago he develops robotic prototypes and control algorithms that push the current systems used in industry. Professor Bhounsule continuously works with both undergrad and graduate students interested in creating robots for a wide range of purposes. For our project professor Bhounsule is looking to replicate nature with technology currently available to the public, in our case it is replicating the acceleration, speed, and snatching ability of a chameleon's tongue. Finding a way to recreate this movement has the possibility of eliminating the limitation that large and bulky robotic arms have in manufacturing. Professor Bhounsule has no specific industry purpose in mind, but he sees many potential applications for such a high-speed snatching mechanism. Although there is no specific industry application, we are designing we will strive to have our design follow the size and speed of a chameleon that occurs in nature.

Literature Survey

When trying to replicate the movement of a chameleon's tongue the muscular structure is the initial component to understanding what is needed to replicate its ballistic projection. In the research article from Debray[1] she writes about the internal design of the chameleon's tongue and how it can be replicated using string, a coil gun, and a recoil motor. The first portion of the article goes in depth on the forces acting in the tongue during flight and the cross-section to further understand how nature is able to shoot and recoil with great acceleration and velocity. A chameleon is able to coil its tongue up similar to compressing a spring and then uses its body weight to thrust forward and release all of the generated energy toward its prey. This generation of energy will be our main goal in our design to best replicate the speed a chameleon tongue achieves. The recoil action of a chameleon's tongue seems to be solely based on the relaxed state of its muscles. Since their tongue's natural state is coiled in their mouth the tongue will always want to go back to the way it was, so based on the muscle memory the chameleon is able to retract its tongue back. The important thing to consider about the recoil of a chameleon's tongue is that it is much slower than the shooting action, this is not only because of the less forceful muscle memory but also because the tongue usually recoils with prey adding weight to the system. The main takeaway we have from this article is the forces acting inside the tongue and its cross-section, these two components will allow us to better understand what is going on inside the chameleon so we can better represent that in our final design.

To achieve the acceleration outlined by our sponsor and viewed in nature a lot of energy generation is needed. The needed forces are generated by the tongue's muscles, interior features, and body momentum. We know that a chameleon's tongue can go from 0 m/s to 60 m/s in 0.1 seconds, but we do not know the exact forces created by the chameleon. This can easily be calculated when it is simple horizontal motion and the weight of the tongue is known, but in our case, it is more important to know what forces the chameleon generates to better represent the tongue itself rather than accomplishing a task. Muller's publication[4] talks about the force that animals generate to escape predators along with the forces predators need to generate to catch their prey. He mentions the fastest accelerating animal is the spittlebugs which can accelerate at 408g, g is a unit of acceleration, their acceleration is 8 times as fast as a chameleon's tongue which shows how fast these little bugs can be, to put into perspective humans jump with a force that is around 2-3g's. While creating a scale of bug acceleration he ventures into the amount of force required by the accelerator muscle to make up the 51gs of acceleration. Through extensive testing Muller found that the accelerator muscle needs to generate 3000 watts per kilogram of muscle. This unit of force is based on a simplified model of the tongue but is very beneficial to how we complete our design. Knowing the force generated by the tongue will simplify the list of what mechanisms we can use to shoot our gripper and to what amplitude they need to be. Though this article focuses less on the chameleon itself it provided us with a unit of force our power source will have to generate to be close to the acceleration of a chameleon's tongue.

In order to mimic the motion of the chameleon's tongue it is necessary to understand the kinematics. Designing a device that will achieve the required acceleration will need a power source, a means to transfer power to mechanical energy, and necessary mechanism to achieve retraction. Understanding the kinematics of a chameleon's tongue will allow for greater input into the future design. In the research paper done by the Department of Ecology and Evolutionary Biology at the University of California[2], researchers used high speed cinematography to calculate the acceleration, velocity, and angles of motion of the chameleon's tongue. The researchers Peter C. Wainwright, David M. Kraklau, and Albert F. Bennett were able to find the effects the distance of the chameleon's prey had on the kinematics of the projection and retraction. This will help narrow down a set distance across which we want to achieve our project goal.

The second portion of Debray's[1] article focused on replicating the motion using a coil gun that shoots its gripper attached to a string which then is recoiled on to a spool back to the initial position. The experiment that is shown could be used to drive our initial design, but we would consider using a different shooting mechanism due to the complexity of coding and implementing a coil guy. This proved to be a great design to reach the needed acceleration that is in our design requirements but using this design in industry may have disruptive results. While the coil gun design meets a lot of our design requirements, we are looking to be a little more creative on our end in coming up with a more simple and effective way of achieving the acceleration set by our sponsor.

In a research paper done by Dong-Jun Lee and Gwang-Pil Jung[3], they were able to replicate the motion of a chameleon's tongue using a steel tapeline, a forward feeder, a back feeder, and an active clutch to engage the feeders. This design also contained a sensor at the front of the device to measure the distance of the item it was trying to grab. While this design was able to achieve close to the necessary acceleration, the design doesn't have the rigidity necessary for large industry applications. We will be looking for ways to improve on this design or ways to implement components into other designs.

Design Requirements

When replicating a chameleon's tongue, the sponsor is giving us creative freedom on how our design looks, what mechanics we use, and even what industrial application we choose to base our design on. While we have a lot of creative freedom there are some things the sponsor requires out of our design. The most important design requirement set for this project is the speed and acceleration seen in smaller chameleons which is 0 m/s to 60 m/s in 0.1 seconds. While the acceleration of our design is the most important criteria, our design must also retract back to its original position, it must be able to grip its prey in some manner, it must be close to the size of a chameleon, and lastly extend similar to the extension of chameleon's tongue. The design criteria mentioned were taken from the sponsor, but they leave a lot to be determined. Since our group needs a little more guidance to complete our design, we have decided to take an industry application and further limit the design based on size, reach, weight, and launch timing.

For the quality function deployment (QFD) chart that is shown in the appendix we had to identify the customer needs and compare them to Debray's[1] design. Once we differentiated the ideas in each design we identified how the team could make upgrades in regard to fulfilling the customer requirements. Debray's[1] design gives a good explanation on what is needed to understand how to replicate the ballistic projection of the chameleon's tongue. Debray's[1] design has been a great help on getting us started on identifying what our design needs to portray an ideal design that will replicate a chameleon's tongue. In the QFD chart you will see how our the rankings for each competitor relates to our requirements for customer needs. You will see that our design still has room for improvement which is how we will set our standards for modification in our final design. Our goal for this design is to make enough modifications so that our design is reduced in complexity in comparison to Debray's[1] design.

III. **Technical Content**

Assumptions

Our goal was to develop a design that may feasibly be applied in industry applications. When analyzing the kinematics of the chameleon's tongue it was concluded that the design will need certain assumptions to design a mechanism that will replicate nature with technology. As a group we made the assumptions that in order to design a proper contraption a spring and motor will be incorporated along with the idea that the mechanism will reach and grab an item from a stationary platform.

Proposed Solution

Our proposed solution is a simple spring-loaded cylinder with a gripper projectile attached by a string. This design is similar to a bow and arrow used for fishing. These bows are outfitted with a fishing reel to reel back the arrow after being shot, this design will be our first step at finding what works and what doesn't, this will make it be easy to produce and easy to modify. Debray[1] did something similar with their experiment but relied on a coil gun to generate the 3000 watts per kilogram, we would like to use a spring which will be more controlled and have a more repeatable action. Using a spring will allow us to interchange the spring for different springs with different coefficients resulting in different forces, this variability may not be an advantage for our sponsor's research, but it will benefit our general industry use. To achieve the retrieving aspect of the design a motor will be attached to spool up the string attached to the projectile bringing it all the way back to the initial position, using a motor will allow the design to automatically reload for firing by using the motor to compress the spring. It is not confirmed that the motor will be able to compress the forces needed for our acceleration but assuming we can find one that does it will allow for our design to be more independent of human adjustments. We have not yet made a diagram or technical drawings for this design. We are currently working toward getting all of our ideas down on paper before continuing to the drawing board.

Another design option which we did not follow through with would be to take a clutch activated tapeline feeder system that was used in Lee and Jungs[3] paper and find ways to improve its design rigidity and acceleration. This design would use a steel tapeline and use a feeder clutch system to project and retract the line. A DC motor would drive the projection and retraction motion of the spooled tapeline. A clutch would engage a forward feeder and the motor would drive the tapeline to retrieve the object. Once the object is reached, the clutch will engage the back feeder and the tapeline will retract. A higher response clutch system would need to be designed to achieve the goal acceleration as well as implementing a higher output DC motor. This manipulator design would also need to be more compact to increase rigidity and improve its application for industry purposes. We are not sure as to the size and weight of the object this design will be able to retrieve.

Prototype 1

Our proposed solution is comprised of three main components: the spring body, spring, and projectile. The spring will be hidden inside the body of the design and will shoot the catching projectile at the target using an electronic actuator. The following diagrams are a simple version of our proposed design. It incorporates all three parts but doesn't include the exact recoil method our final design will implement. Since we are not currently going through the prototyping process it is hard to tell where the recoil motor will need to be to generate the forces needed to reload the spring and projectile.

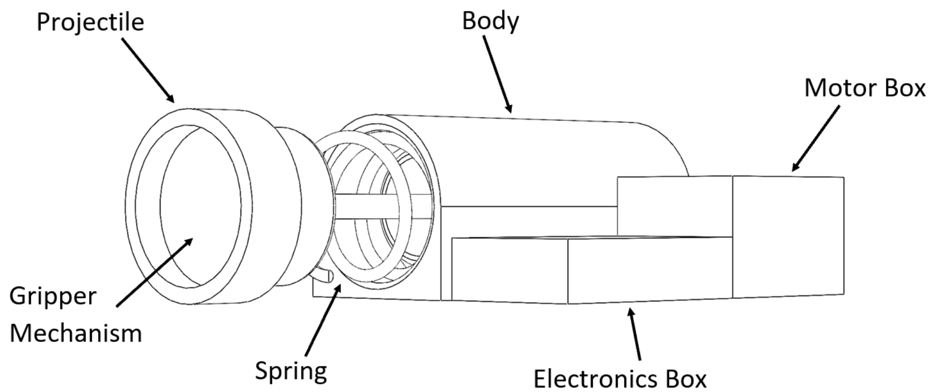


Figure 1: Prototype of snatch and recoil design made of ABS plastic

The design works linearly within the body but will be able to move in all directions given the string attachment between the motor box and projectile outside of the body. Given that the design will eventually move in all directions we currently only have access to linear motion study. The below diagrams show the linear motion of the launcher. The spring will compress inside the body by the projectile and when the electronics tell the trigger to open the projectile will shoot out, catch its prey and recoil back by the motor. This initial design was drawn to show the moving components and how they will interact physically. In the future this design will need to be modified to adapt to the selected springs, motor retrieval, loading mechanism, and projectile gripper. These designs will be worked on simultaneously with the selection of the correct spring and body material.

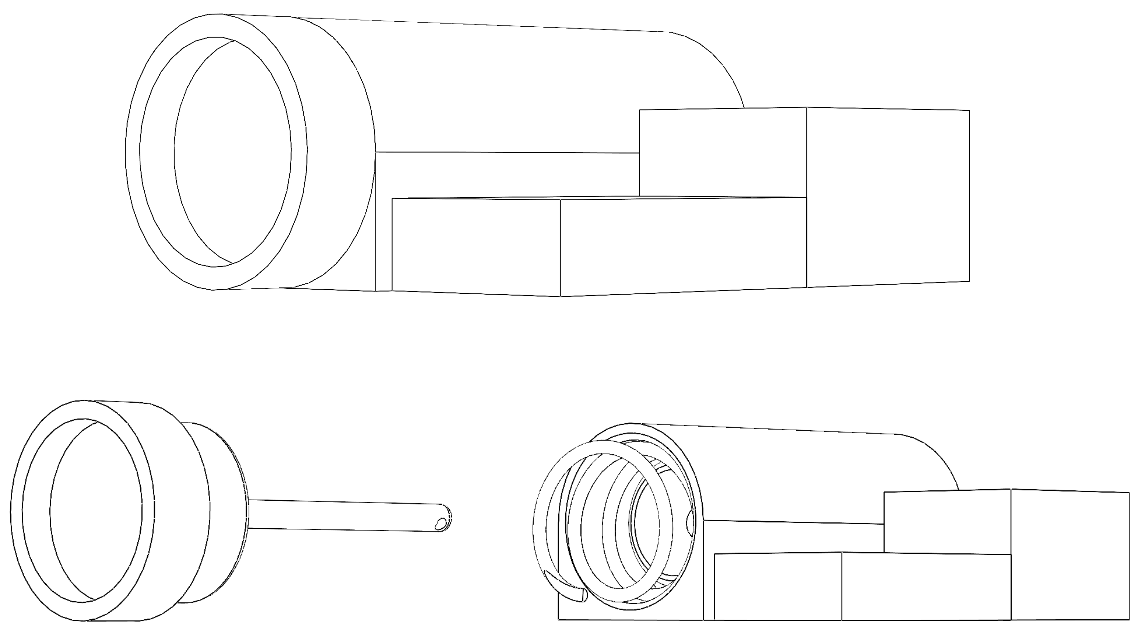


Figure 2: Depiction of the trajectory of the prototype.

A Fishbone diagram as shown in the appendix was made for our prototype to have a visual look at the identified possible problems that could occur based on its environments and human interactions. As a group we collectively decided that the best material to be used will be a metal for the final production, but for the prototype stage we will be using ABS plastic because of its cost-effectiveness. It is not known to what extent this material will hold force, but it is assumed that it is not strong enough to last for multiple experiments. Our method to determine the speed of our prototype will be to video record the high-speed motion of the spring when it propels the projectile, in the background there will be a measuring device to help capture the full visual of the projectile's motion. When evaluating how we can meet our sponsors requirements we kept in mind that our design would also be considered as something that could be used in an assembly line or production line. There are similar apparatuses that push object out of line but none that can return the object with sufficient speed. When having considered all possible outcomes for recreating the mechanics of a chameleon's tongue, we were able to choose the best possible features to achieve the result.

Prototype 2

The prototype in figure 1 will be made of ABS plastic to determine if our model will work, once we understand the path of trajectory and production tolerances, we will make modifications to fit certain springs and complete the required moving parts. The initial prototype showed that the design and tolerances will work with the FDM printer used. The initial springs order consisted of two spring diameters, one with a diameter of 1 inch and the second with a diameter of 0.97 inches. Eventually there will be many iterations of the design based on spring diameters and lengths but for the initial testing the two diameters listed will have designs. Figure 3 below shows a simplified view of just the body and launcher with subtle changes to make a working prototype. The addition of a simple peg trigger was used for fast prototyping to see how the first springs would perform.

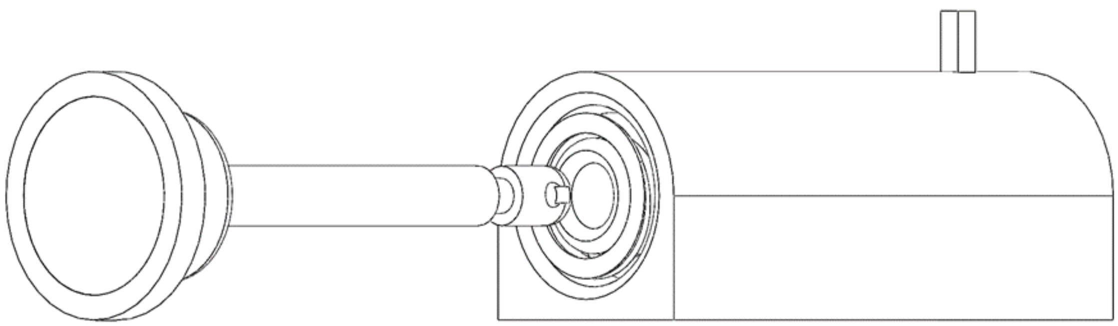


Figure 3: Prototype design 2 with peg trigger and correct spring dimensions.

Preliminary Testing

The initial trails have been conducted and shown that we will need to select a different spring to produce the desired acceleration. For our first round of testing two springs were purchased form McMaster Carr with the following part numbers and spring rates: 9657K21 (152.995 lbs/in) and 9657K32 (46.04 lbs/in). The initial testing was complete with 0.5 inches of spring compression resulting in 76.5 lbs of force from the stronger spring and 23 lbs of force from the weaker spring. After a round of trial sessions, we realized that to obtain the desired speed of 0-60 m/s in 0.1 sec these springs will not be strong enough to produce the desired acceleration output. The weaker spring yielded a speed of 4.5 m/s which is well short of our desired goal and the stronger spring was too stiff to compress a full half inch. With the current design and manufacturing process we believe that the body will not hold up to the spring force required to achieve the outline exit velocity. This will eventually lead us to a milled design either out of metal or stronger polymers. Although we can produce the launching part of the design, it has been it was recommended by our advisor that we will need two other mechanisms, one to recoil the projectile to the end of the body and the second to load the projectile into launching position. Our goal now is to simultaneously get the gripper mechanism to have a smooth return and produce the correct exit velocity. As a group we will investigate a design for recoil motor that will provide a smooth return and a second recoil system that can compress a spring able to achieve the outlined acceleration. The current recoil design mechanisms with consist of a simple geared motor to get the projectile into position and the second design will be a slotted screw that provides enough torque to compress the high spring force. These designs have not yet been implemented into the assembly as they are much more complicated in design than out launcher body and projectile.

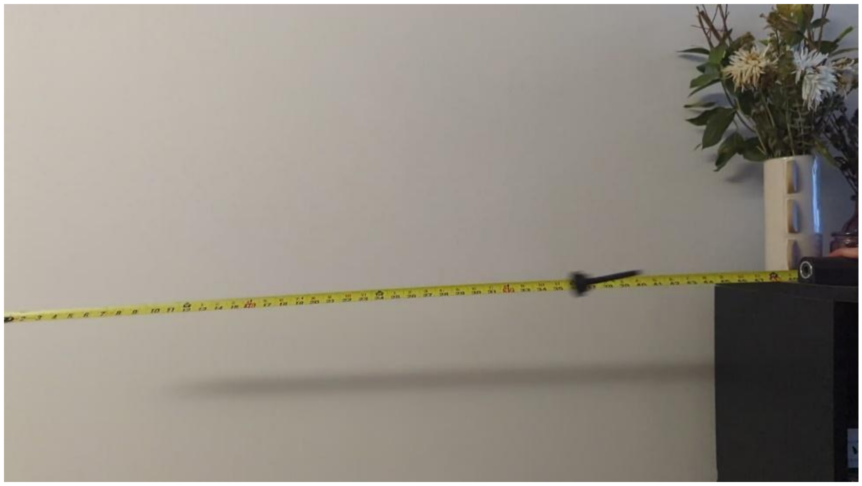


Figure 4: Screen capture from the projectile motion to determine the speed at which it is moving.

Codes and Standards

During design, prototyping, and construction of the device, we will follow the codes and standards set by the American Society of Mechanical Engineers (ASME). We will follow ethics and guidelines for proper design tolerances and safety protocols. For spring tolerances, we will follow ASME guidelines as defined by their standards for mechanical spring representation [7]. Any electrical sensors or data analysis devices will follow the ASME standards for data acquisition systems [6]. All powered electric devices such as motors will follow codes and standards set by the International Electrotechnical Commission (IEC) [8]. The design will have applications for manufacturing purposes which ASME and IEC has the codes and standards needed for a large-scale build. As design begins to scale towards industry applications, other codes and standards pertaining to safe operation and maintenance of the device will be applied.

While the initial testing resulted in 4.5 meters per second with a spring compression of 0.5 inches the next experimental step is to determine how the springs compressive load translates to exit velocity. The projectile determines the amount of spring compression with its protruding cylinder opposite of the magnetic gripper. The distance of that cylinder directly correlates to the spring compression, so the cylinder has been extended to 1 inch and 1.5 inches. The second round of testing will determine the relationship between spring compression and exit velocity but graphing the experimental progress. Based on the experimental results it can be determined if the relationship is linear or exponential and the next spring choice can better estimate the outlined exit velocity.

In our search to find a trigger apparatus that can be added to our design it was found in Jurriaan's[4] research on chameleon's tongue, muscular work is present in the tongue before projection and the accelerator muscle that is active elongates and is therefore likely to produce work. With this information we found that to achieve the recoil effect that is most like that of a chameleon we will have to add an additional part such as a trigger attached to a gear that can produce a force so that when the gripper mechanism is able to shoot out and return in a linear pattern.

Retraction Mechanism

For the projectile retraction system, we would need to design a mechanism that would be able to achieve high torque and maintain a high acceleration. The proposed solution for this problem would be to design a high speed, high torque gear box. The gearbox would convert the torque and acceleration of a DC motor to meet the necessary design requirements. The proposed design would also consist of a reel connected to the other end of the gearbox. The reel will be used to wind and upwind the cord used for the projectile launcher. This gearbox is designed for a

775 high torque DC motor with a speed range of 9000-12,000 RPM and a torque rating of 0.2 N.m. The initial prototyping will use 3D printing with PLA printing material for the gears, and either PVC board or plywood to construct the housing. The purpose of this prototype will be to make sure gear spacing is ideal to prevent binding and to test gear designs to see if we have met the acceleration goals. The initial stages of the design consisted of calculating gear ratios and output speed for multiple gear train designs.

Gear Ratios and Outputs

Input Speed (RPM)	9000								
Number of Gears	**Gear 1**	**Gear 2**	**Gear 3**	**Gear 4**	**Gear 5**	**Gear 6**	**Gear 7**	**Gear Ratio**	**Output Speed (RPM)**
3	15	65	30	-	-	-	-	0.50	4500.00
4	24	45	72	35	-	-	-	0.69	6171.43
5	28	42*	72*	100	35	-	-	1.37	12342.86
6	28	42*	72*	100*	64*	15	-	2.05	18432.00
7	28	45*	72*	80*	96*	100	24	2.24	20160.00
*Indicates gears that are compound gears.									

Table 1: Calculated gear ratios and output speeds for varying gear train designs.

The final gear train design selected uses seven gears including two compound gears that gives a final gear ratio of 2.24:1 and an output speed of 20,160 RPM. The specific gears were selected using the McMaster-Carr online catalog in order to find gears that had compatible teeth, widths, gear pitches, and pressure angles. Based on availability a list of compatible gears was compiled and the online Solidworks files were used in order to construct a working gear train. During the design construction two counter shafts were designed to meet the necessary design requirements and a final gear drive with the string reel attached to it directly. The countershafts were designed using the CAD models from McMaster-Carr, and a design for a countershaft sleeve to attached combined gears. The reel was created using the final gear CAD model from McMaster-Carr and a design for a retraction reel that were combined together.

Parts List

Part	Part Number	Number of Teeth	Shaft Diameter (mm)	Pressure Angle (degrees)	Face Width (mm)
Gear 1	2662N337	28	5	20	6
Gear 2	2662N42	45	8	20	6
Gear 3	2664N372	72	10	20	10
Gear 4	2662N439	80	10	20	10
Gear 5	2664N375	96	10	20	10
Gear 6	2662N414	100	10	20	10
Gear 7	2662N421	24	8	20	10

Table 2: Gear parts list with part numbers and gear specifications.

Countershaft and Reel Design

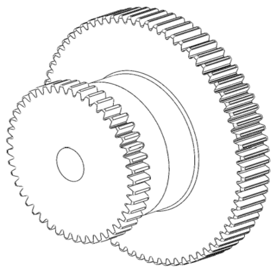


Figure 5: Countershaft 1 consisting of gears 2 and 3.

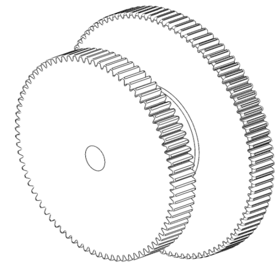


Figure 6: Countershaft 2 consisting of gears 4 and 5.

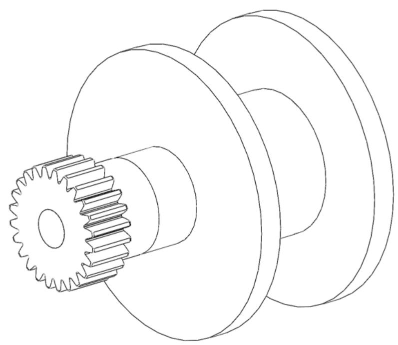


Figure 7: Final gear drive with attached reel retrieval.

The next step in the design process was assembling the gear train using the feasible gear parts from McMaster-Carr and the redesigned countershaft gears. The setup for the gear train was done in such a way as to maintain mechanical reliability and minimize the size. The gear train starts at the front which is where the DC motor will be mounted. The gear train is designed to maintain an angle of 16 degrees between the motor and the retraction reel so as to allow for a clear line of sight when firing the projectile. The next step for the retraction design will be to assemble an initial prototype for testing and to use as template for the final gear spacing. The body of the retraction mechanism will be constructed in a way as to allow for easy assimilation with the projectile launcher prototype.

Retraction Prototype 1

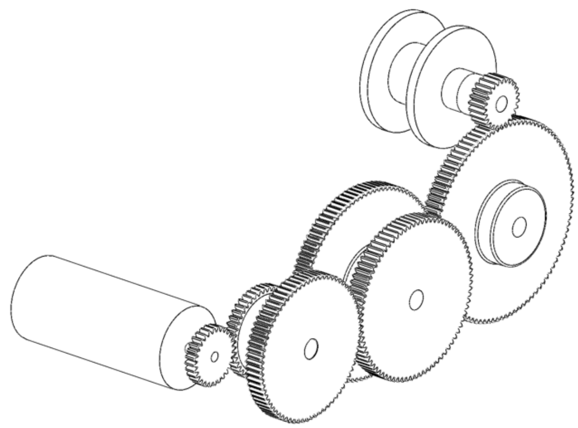


Figure 8: Final gear train design with projectile retraction reel.

Retraction Final Prototype

The final prototype for the retraction system was scaled down to a five gear train system. During preliminary testing it was found that the motor used was not powerful enough to drive the gear train continuously. This was not satisfactory for our design for the retraction speeds our design was attempting to achieve. Another issue that our design ran into was that there was excessive binding between the gears. This resulted in the gear teeth wearing down at an accelerated rate. For the final design the gear train used a five gear system with only one compound gear instead of two. When testing the final prototype we were able to achieve continuous motion along the gear train at a speed of 5 m/s. The prototype was also able to hold to the forces being delivered by the motor and resulted in substantially less wear and tear on the device. With this design, we were also able to maintain the speed we achieve while not losing a large amount of torque. This was crucial in order to retract the projectile back into the launch cylinder. When the projectile is released it exerts an amount of force that requires a larger amount of torque in the opposite direction in order to instantaneously pull it in the other direction. The gear train design was able to achieve that with minimal lag time. The final gearbox design was able to complete the second stage of the motion of the chameleon's tongue resulting in a complete and fluid motion in both directions. For the final prototype we also designed a gearbox housing that would allow us to assemble the gear train with minimal interference between the gear. The housing also had a base for the motor to sit into without causing any binding at the motor and give the design smooth and continuous motion. The final gearbox design with motor and housing can be seen in Figure 9. The figure contains a complete assembly drawing of the final design from three different viewpoints and a parts list containing all the necessary components for full functionality.

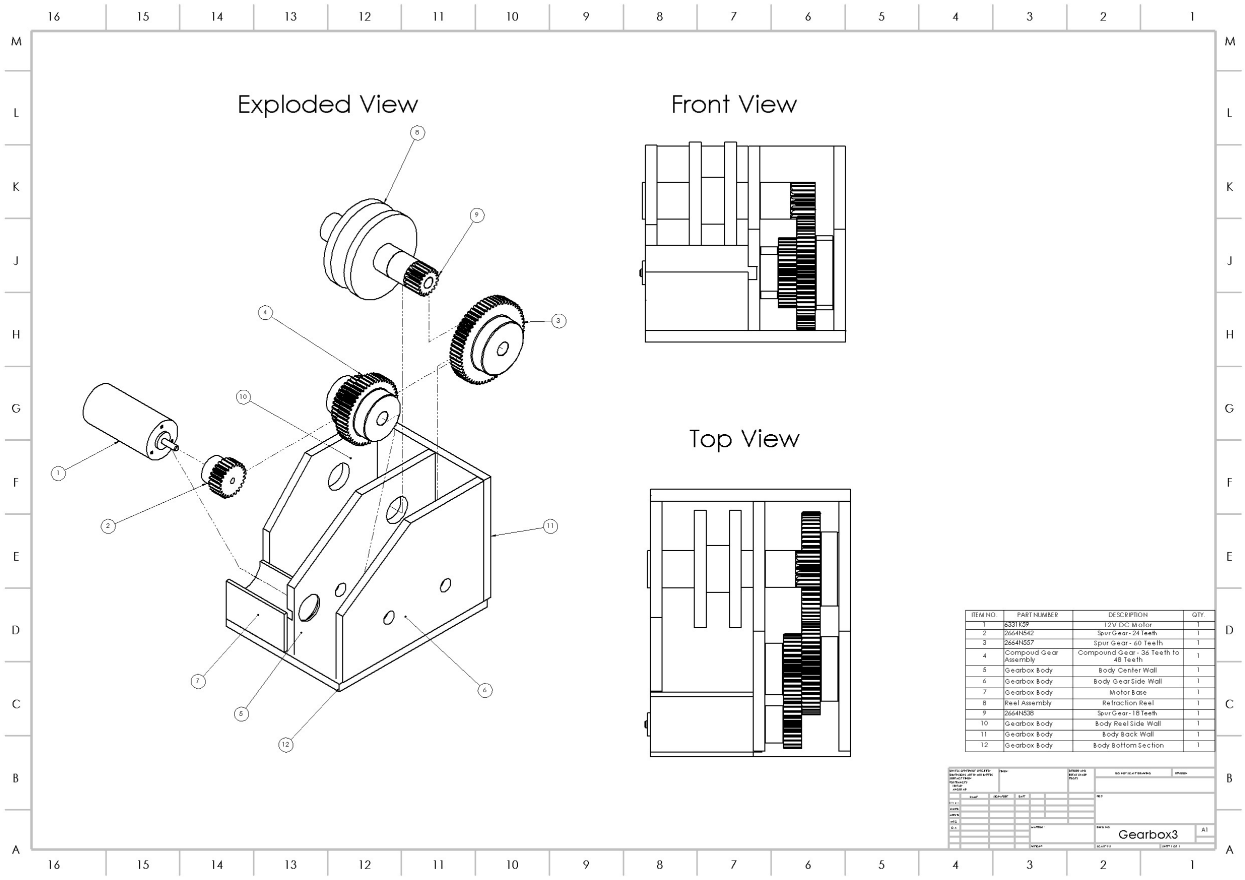


Figure 9: Final Design for the Retraction System

In order to operate the device we used an arduino microcontroller, an L298N motor controller with a dual h-bridge, a breadboard, 3 push button switches, a potentiometer switch, and a AC to DC power transformer that can be used with any wall outlet. The switches allow for clockwise and counterclockwise motion of the retraction system with another switch that deactivates the system. The potentiometer switch allows for speed control. The speed control allowed us to adjust the speed of the motor for testing purposes so that we could see how the gearbox functions at different speeds. The use of a L298N motor controller allowed us to power the DC motor using a 12 volt source and allowed us to send 5 volts power to the arduino microcontroller. The main power source used is from a 120 volt wall outlet and the transformer throttles the voltage down to 12 volts for use in our design. Finally we used the arduino microcontroller to process the functions required for our motor and gearbox system. The breadboard and microcontroller schematic is shown in Figure 10. There is also a full wiring diagram for the retraction system that can be seen in Figure 11.

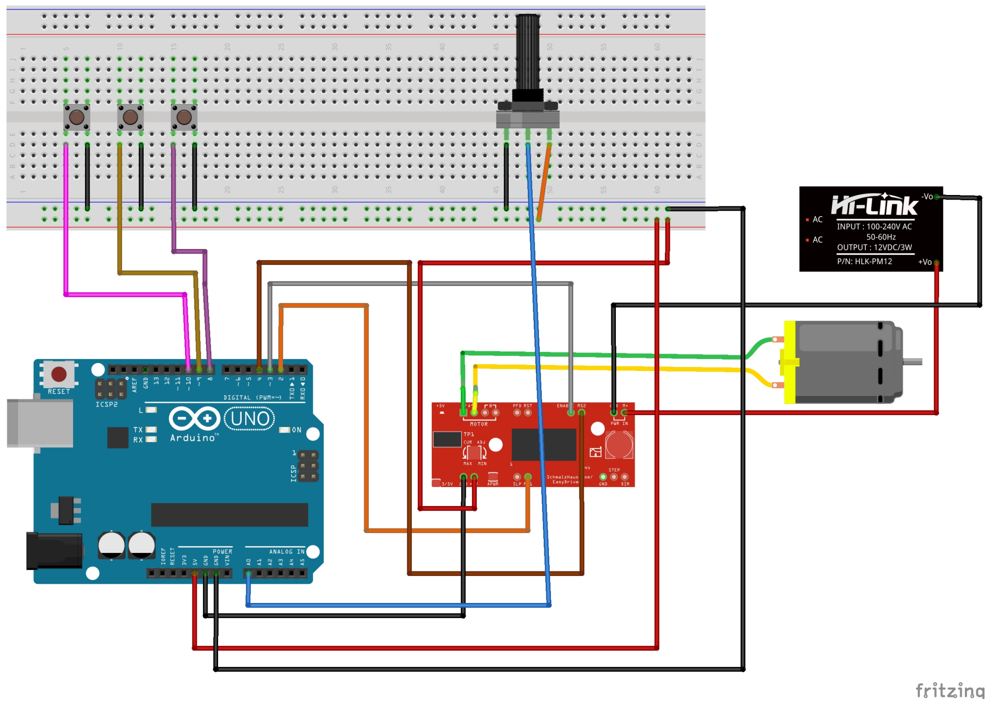


Figure 10: Arduino and Breadboard Schematic for Retraction System.

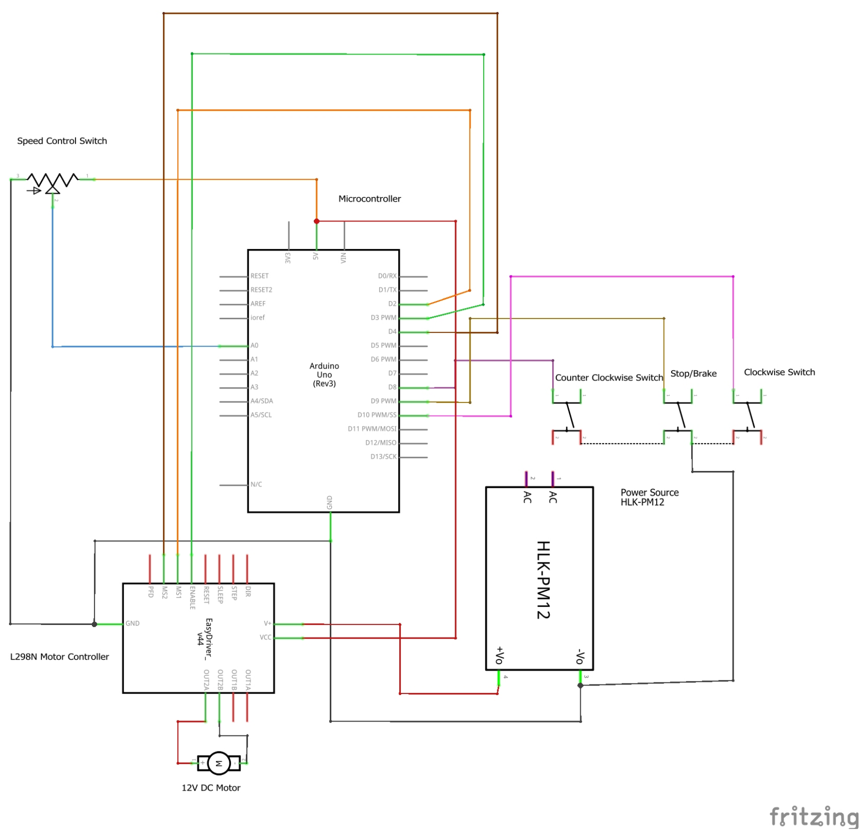
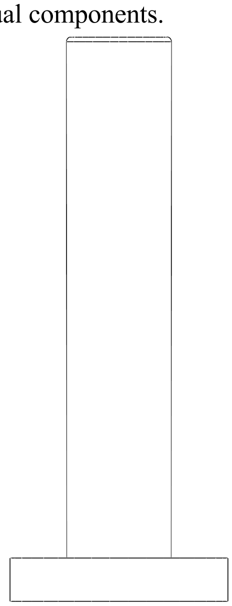


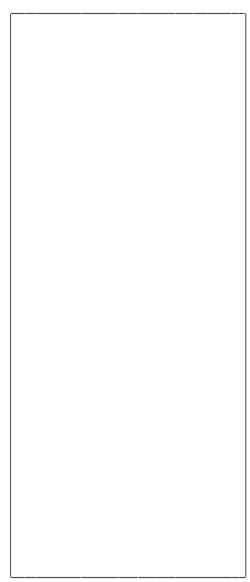
Figure 11: Wiring diagram for Retraction System

Prototype 3

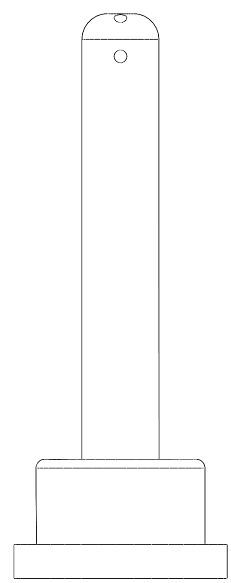
Prototype three came with some major design changes to better the producibility of the overall design and to accommodate the new larger and more powerful spring. Given that the new chosen spring has a length of 6 inches and a diameter of 2 inches our body had to be changed to fit that spring so that was the initial design change to our body. After we made everything fit the new spring we came together as a team to evaluate the design on how to effectively print it and if it would hold up to the increased forces we are now using to get a larger exit velocity. After deliberation we decided to make the design easily producible on a lath so the body and projectile could be made out of one solid piece of material to reduce the chances of it breaking. This design choice led to the removal of the flat bottom of the body and different hole shapes to the connection point on the projectile. Prototype three also better represented a size that matched the size of the design gear box and motor system, this was also important to do to make sure that the string could be attached to both mechanisms and not be too much friction for a smaller projectile to overcome. The other aspect our team thought could have been further developed was the ease of putting everything together. Prototype one and two consisted of the body as one piece where the spring had to be glued to the bottom face of the inner cylinder cut out, the process of getting glue all the way to that face was extremely hard and caused glue to be rubbed on the cylinder walls. This increased the amount of friction on the whole design and needed a better way to put everything together. This led our group to design a two-piece body with four guide rods so everything lined up perfectly. While the number of pieces did increase, we believe that the new design will be better adjusted to complete the full motion with less post processing and a low coefficient of friction. Below shows the CAD design of our third prototype and the individual components.



The above part is inner cylinder of the body

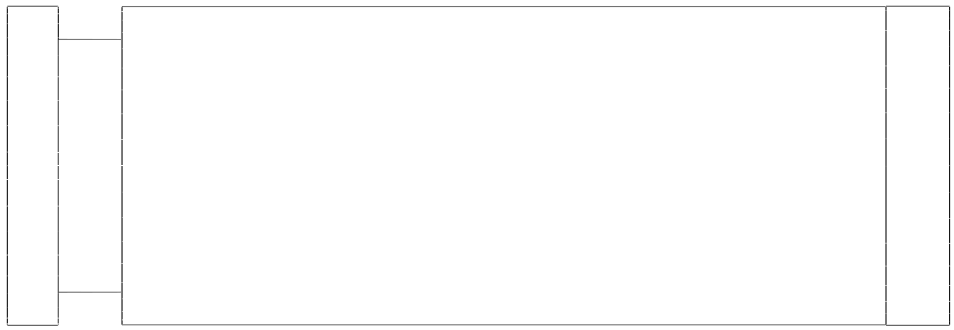


The above part is outer cylinder of the body



The above part is the projectile with 1 inch of compression

This three-piece design allowed us to print the prototype in pieces resulting in an overall faster production time and also allowed us to reprint given printer errors in the first print. What isn't shown in the above images are the four centering pins that align the two pieces of the body so the projectile compression cylinder can be centered when the whole prototype is put together. The next image is all three pieces put together to show the overall shape factor of the design.



The projectile weighs significantly more in this design, compared to prototypes one and two, due to the increase in size. This was taken into account when choosing the spring for this design. The spring for this design was chosen for its increased size and ease of compression. Since we did not have a mechanical advantage mechanism to reload the launcher, we relied on own force to compress the spring which limited us to about 150 pounds of force. This limitation led us to choose a spring with a 50 ponds per inch spring rate to allow our own force to compress the spring almost 3 inches.

Final Prototype Testing

Given the new spring and heavier design we used our previous testing to assume the final exit velocity and the overall motion of the new launcher. Given all of our calculation and assumptions our final design with the chosen spring could achieve an exit velocity between 5 m/s at 1 inch of compression and 30 m/s at 3 inches of compression. While the theoretical results still do not align with the outlined exit velocity our prototypes were design to achieve a variety of exit velocities depending on the application it is being used for. The experimental results for one inch of compression proved our calculations were correct, at one inch of compression we achieve a recorded speed of 5 m/s. An exit velocity of 5 m/s is definitely not the speed of a chameleon's tongue, so we increased the compression cylinder on the projectile just like in our second prototype and were able to achieve 10 m/s with two inches of compression. Given that our design could easily be changed to achieve different exit velocity outcomes we used one inch of compression to prove the whole motion of our design. The chameleon's tongue does not only extend with a high velocity it also retracts with an increased velocity. The two velocities are not to the same magnitude, but we focused on achieving a quick retraction using our gearbox and motor design that we completed earlier. When attaching the two mechanisms the projectile extended at a rate of 5 meters per second and then retracted to the initial launching position with a rate of 2.5 meters per second. The retraction velocity of our design was controlled by a dial to adjust the retraction speed similarly to how we designed the projectile to achieve different exit velocities.

The final prototype connects the two devices into one by taking the projectile launcher and attaching it to the reel of the retraction system using a white braided string. The string thickness was able to withstand the forces exerted by the system while being strong enough to completely pull the projectile back into the launcher. The way the device operates is that the projectile is loaded into the launcher. The projectile is then compressed down along with the spring by hand. The device uses a metal pin that is inserted at the top of the launcher cylinder into a prefabricated hole. Once the projectile is fully compressed in the launcher, it is held in place by the pin into a prefabricated hole inside the projectile itself. During this process, the retraction system is in the off position and the string is fully retracted onto the string reel. With the device being in full launch position, the pin is released and the projectile launches using the force of the spring to drive it forward at a speed of 10 m/s. When the projectile reaches the end of the string, which allows for a traveling distance of 1 meter, the switch on the retraction system is actuated. The speed of the retraction mechanism is at its maximum and when the device is activated, it retracts the projectile completely into the projectile launcher at a speed of 5 m/s. Once the projectile is fully retracted, the retraction system is deactivated. Reloading is done manually by hand using the pin to hold the projectile in stationary position. The complete prototype with projectile, launcher, and retraction system can be seen in Figure 12.

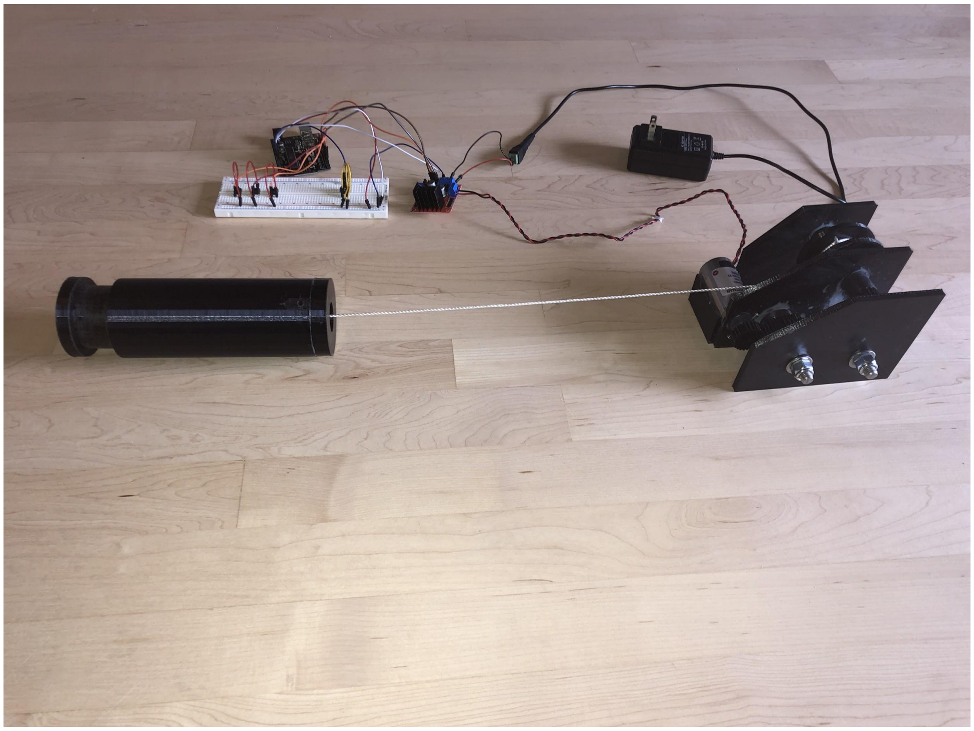


Figure 12: Final Prototype

IV. Preliminary Conclusions / Future Work

Conclusion

In the fall 2021 semester we have completed our preliminary research and narrowed down a couple design options. We have assigned report sections to team members and assigned dates for completion. Each member has been given an initial design option and tasked with improving, expanding, or implementing the design for real world implementation. By the end of the week the team will have completed the midterm report and have team members assigned to the necessary future work. There will be continued research conducted as we look to narrow down the final design. Everyone will present the research found and collectively we will discuss how we can implement those finding to better our design. During the research process we were able to find a large amount of information on chameleon biology and previous attempts to replicate its motion. We discussed how the trajectory of the chameleon's tongue could be modified in a way where we could design something similar that would be used in industry applications. The difficulty came when researching industry applications for such a device. For the design process we will have to find new and creative ways to integrate this type of technology to solve real world problems. The next steps in the design process will help us narrow down an application for the final device.

A meeting with our sponsor will need to be scheduled to present our design and our plans to execute. Once we get approval from our sponsor, we will need to research the cost of the materials that we will need to execute the design. As a group we will set up dates where we will meet to discuss codes that we will need to achieve the movement of the spring recoiling. We will also need to determine how we will get our design to capture an object at the end point. Once we can get the fundamentals of the design process, we will start the building process and our experimental trials along with keeping our sponsor informed on our progress.

In the span of winter break and the beginning of spring 2021 semester we have printed a 3D print design and ordered springs to start our prototype trials. In the process of trial and error we have realized that the initial McMaster Carr springs will not be sufficient to get the desired speed of 0-60 sec in 0.1 seconds. With the 3D print able to shoot out, we will need to research ideas on how to get the recoil affect. Based on the theoretical forces the body will eventually be machined out of a solid block of material, yet to be determine, so that the spring doesn't destroy our design. We will go to maker space and design a body and maybe a projectile on the Mill machine and do trial and error in hopes of achieving the outlined velocity after the gripper shoots out. We have scheduled meetings with our sponsor and advisor who have given input on ideas on how we can achieve the recoil affect, which at the moment is where we are trying to decide what design to go with. The simpler design of initial recoil back to the end of the body is in progress but the more complicated reloading design has yet to be put into action.

During the final few weeks of our second semester our team focused on proving the whole motion of our prototype while keeping in mind the final exit velocity. Our third prototype was our final prototype of the course and provided us with the conclusion that our design and design process allowed us to show the complete motion of a chameleon's tongue while allowing the power and exit velocity to be changed easily to achieve different outcomes. This was our main goal going into the project, so we consider it a success. When comparing our final success to our initial project charter there is only one section, we fell short in. The final exit velocity of the project outline was 60 m/s while this was a lofty goal it was one, we kept in mind the whole design process. Even though our design did not reach the 60 m/s we created a design that could achieve that exit velocity with small changes and additions. The main issue we continually ran into during this project was the amount of compression required to achieve 60 m/s it ended up being a total force required of 300 pounds for prototype tow and 650 pounds for prototype three. This amount of force is not readily accessible through human strength or simple mechanism, so we did not have the required time or funds to design and implement a reloading mechanism that could create the forces required. Overall we believe that our final prototype shows that we succeed in achieving the overall motion of a chameleon's tongue, which was our main goal and the main goal of our project sponsor.

V. Acknowledgments

The team would like to extend its gratitude to Pranav Bhounsule, Assistant Professor at Department of Mechanical and Industrial Engineering for being the sponsor and providing guidance in this project. Along with being flexible in his availability

Special thanks to Johnathan Komperda, Assistant Professor at Department of Mechanical and Industrial Engineering at University of Illinois at Chicago, for giving great guidance and sharing ideas on how we could push our limits in bettering our design.

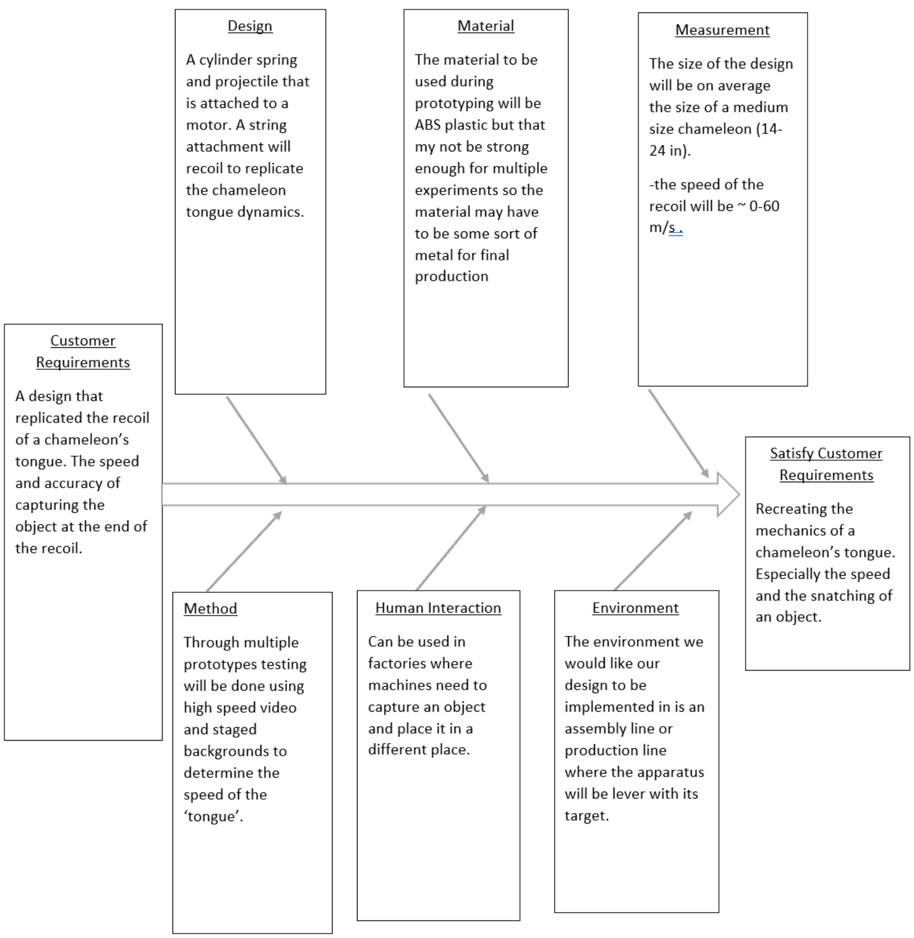
Special thanks to Debray, Wainwright, and Jurriaan in publishing their research studies, our group is thankful to be able to read through the published research and learn on the behavior of chameleons.

V. Appendix

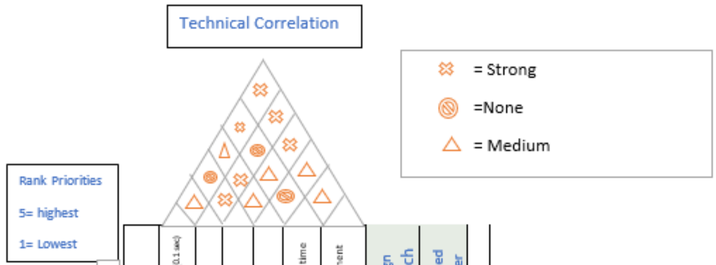
The below image shows the current stage of our Gantt chart, which changes weekly. It shows what has been completed, what is in progress, and what is yet to come. Our Gantt chart is the best way for each of us to know where each member is at and what has been completed so we do not overlap much. Knowing where each member is at allows us to focus on different topics so our team accumulates as much knowledge as we can before making design decisions.

					Week 13							Week 14							Week 15						
					11/14	11/15	11/16	11/17	11/18	11/19	11/20	11/21	11/22	11/23	11/24	11/25	11/26	11/27	11/28	11/29	11/30	12/1	12/2	12/3	12/4
Task	Member	Start	Finish	Days	Sun	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Mon	Tue	Wed	Thur	Fri	Sat							
Research																									
Tongue Mechanics	Zach	10/10	11/12	33																					
Tongue Forces	Baneza	10/10	10/23	14																					
Industry Applications	Gregory	10/10	11/1	21																					
General	Mohammad	10/10	11/12	33																					
Current Industry Designs	Gregory	10/30	11/12	14																					
Tongue Kinematics	Baneza	10/23	11/12	21																					
Preliminary Designs																									
Spring shooting	Gregory	11/8	11/19	12																					
Spring shooting : motor recoil	Zach	11/8	11/19	12																					
Material memory	Baneza	11/8	11/12	5																					
Accordion arm	Mohammad	11/8	11/19	12																					
Lever arm : linear retreval	Baneza	11/12	11/19	8																					
Technical Documents																									
Soldiworks Design	Zach	11/19	11/29	10																					
Motion Studies	Zach	11/19	11/29	10																					
Codes and Standards	Baneza	11/19	11/29	10																					
Fish Bone Diagram	Gregory	11/19	11/29	10																					
Industry Materials	Mohammad	11/19	11/29	10																					
Mid-Term Report Writing																									
Abstract	Baneza	11/28	12/3	5																					
Problem Statement	Gregory	11/28	12/3	5																					
Sponsor Background	Zach	11/28	12/3	5																					
Literature Survey	All	11/28	12/3	5																					
Design Criteria	Zach	11/28	12/3	5																					
Assumptions	Mohammad	11/28	12/3	5																					
Metrics	Baneza	11/28	12/3	5																					
Proposed Solutions	Baneza	11/28	12/3	5																					
Selected Designs	Zach	11/28	12/3	5																					
Preliminary Calculations	-	11/28	12/3	5																					
Calculations	-	11/28	12/3	5																					
Experimental Method	Gregory	11/28	12/3	5																					
Numerical Method	-	11/28	12/3	5																					
Technical Drawings	Zach	11/28	12/3	5																					
Algorithms	-	11/28	12/3	5																					
House of Quality	Baneza	11/28	12/3	5																					
FEMA	Mohammad	11/28	12/3	5																					
Conclusion	Gregory	11/28	12/3	5																					
Future Work	Zach	11/28	12/3	5																					

The below image is the fish bone diagram for our proposed solution. The fish bone diagram represents the how our design will be made along with its purpose and how it accomplishes the customer requirements.



The below image is the QFD diagram for our proposed design for the sponsor's project. It compares the customer's needs to how well our design can accomplish them along with other designs that we have came across while researching the topic.



Customer Needs		Metrics	Acceleration Speed (0.1 sec)	Motor power	Material	Weight (kg)	Order processing time	Product development cost	Coil gun Design From research	Clutch activated tapeline feeder
Speed (0-60 m/s) ~0.1-1 Sec	5		H	L	--	--	--	--	3	2
Spring	4		H	H	H	H	H	H	0	0
Length of arm extension (1-3ft)	4		H	--	--	--	--	--	4	2
Sturdy arm material	5		H	H	H	M	H	H	1	4
Motor	5		M	H	M	H	H	H	5	0
Light weight	4		L	M	H	H	--	--	5	3
Cost efficient	4		--	--	M	M	--	--	3	3
Strength of grip for snatching	5		H	H	H	M	--	--	2	0
Size (medium chameleon)	3		L	--	H	H	--	H	4	3
			156	123	133	131	95	107		

Target and Final Specification Rating

Relationship between customer needs and engineering metrics

H= high (5)

M=Medium (3)

L=Low (1)

VI. References

Reports, Theses, and Individual Papers

[1]Debray, A., "Manipulators Inspired by the Tongue of the Chameleon," Canon Incorporation, Biophysical Society, March 2011.
[2]Wainwright, P. C., Bennett, A. F., "The Mechanism of Tongue Projection in Chameleons" Department of Ecology and Evolutionary Biology, University of California, Irvine, March 1992.
[3]Lee, Dong-Jun, Jung, Gwang-Pil, "Snatcher: A Highly Mobile Chameleon-Inspired Shooting and Rapidly Retracting Manipulator" Department of Mechanical and Automotive Engineering, SeoulTech, Seoul, South Korea, July 202.
[4]Jurriaan H. de Groot, Johan L. Van Leeuwan, "Evidence for an Elastic Projection Mechanism in the chameleon tongue", The Royal Society, March 2004

Periodicals

[5]Muller, U. K., Kranenbarg, S., "Power at the Tip of the Tongue," Science, Vol. 304, No. 5668, 2004, pp. 217-219.

Codes and Standards

6ASME, 2008, "Data Acquistion Systems," ASME Std. PTC 19.22-2008.

7ASME, 1981, "Mechanical Spring Representation," ASME Std. Y14.13M-1981.

8IEC, 1997, "Electrical Motors," IEC 60034-21-1997.