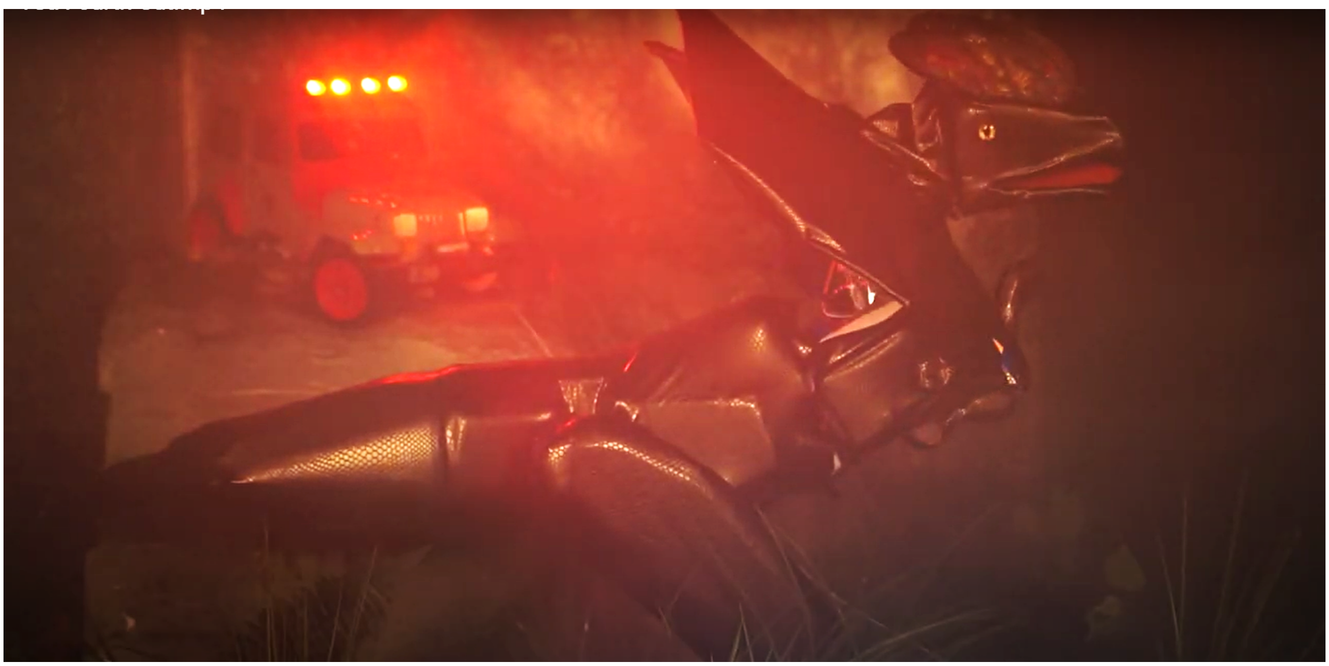
Colorado TSA National Conference 2021
Animatronic Design
Team ID: 2620-1



https://youtu.be/8VIsuYS6fxA

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Inspiration:

Our inspiration for this project was based off of a popular Hollywood movie that had some amazing dinosaur animatronics. A lot of the dinosaurs in this movie were puppets controlled by people, but they had some of their own mechanical features that made them closer to being completely animatronic. We were inspired by the complexity of the Dilophosaurus in the film because its movements were so unique, but they are still seen in modern day animals like lizards. We wanted to challenge ourselves with this project, and we thought that the Dilophosaurus from this movie would be the perfect challenge for our skills.

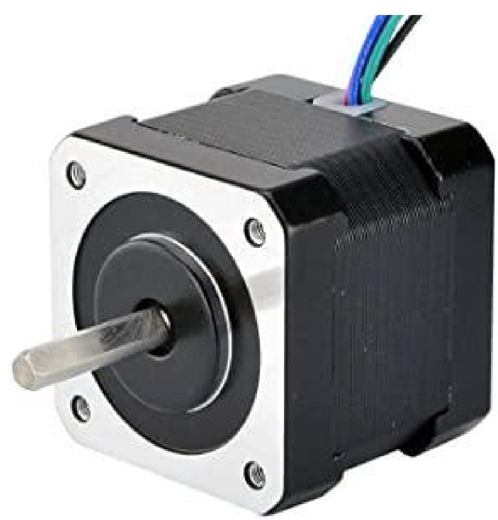
Audience:

When first faced with the challenge of creating a museum display for the animatronic competition, we were flooded with Ideas on what our display would look like. However, we realized that we needed to figure out who our audience was first.

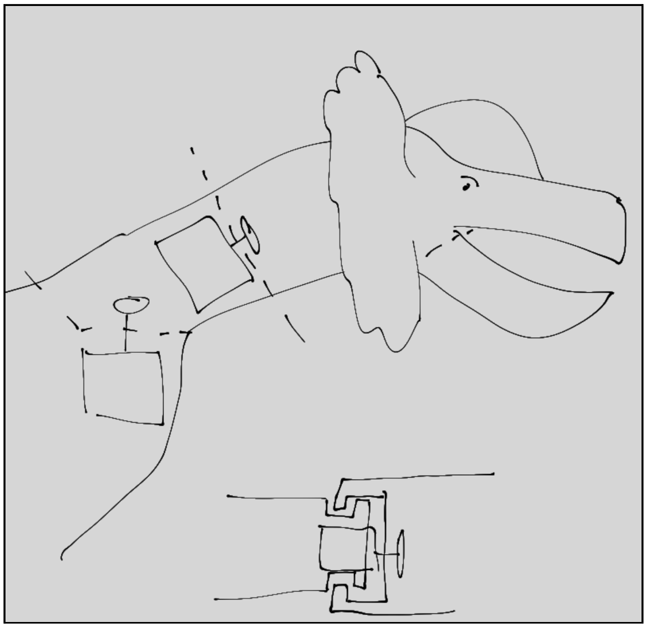
We decided that we wanted our audience to be younger kids because we wanted them to be inspired. Not just by dinosaurs, but also about the engineering behind it. We remembered going to the natural history museum and being inspired by the animatronics there, and we wanted to give the same inspiration to other kids.

Mechanical Components

We wanted our mechanical components to be strong, lightweight, and easy to manage. That way we could more accurately and consistently recreate the movements of a real dinosaur. We found that dinosaurs move fairly smoothly and do not need snappy and energetic movements as much as we had initially thought,



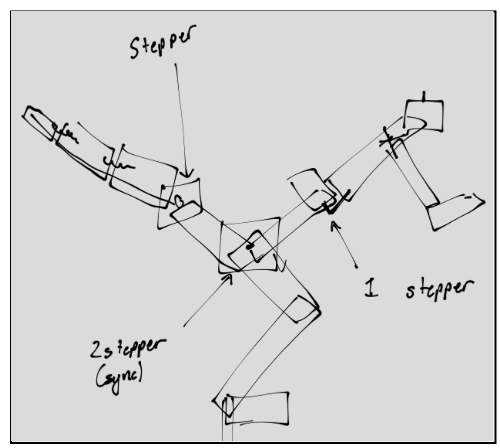
making it easier to decide to use **Nema 17 stepper motors.**



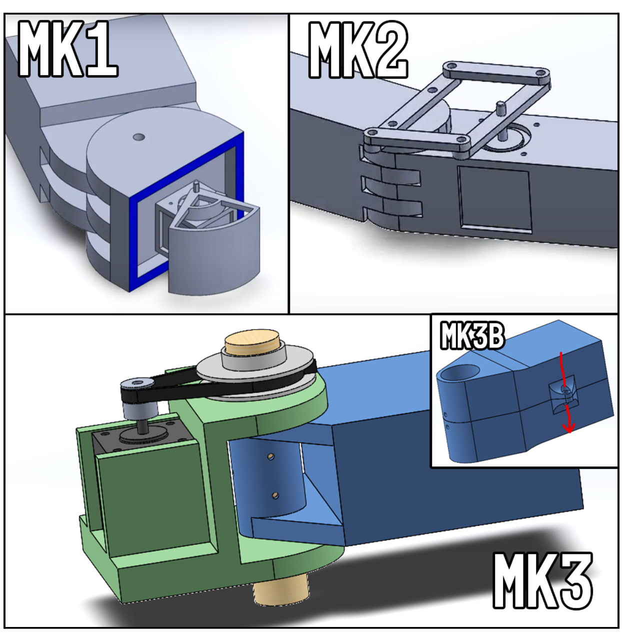
Ask: How are we going to recreate accurate and consistent movements in an animatronic mimicking those of a Dilophasaourus?

Problem: Animals have an incredibly smooth and natural movement pattern that is not easily recreated through technology. **How can we simplify the basic movements of a dinosaur to minimize the amount of joints we create but represent the movement of a dinosaur accurately?**

Imagine: This was one of the first problems we had to address in the brainstorming process so we could immediately start prototyping and building. After many meet ups at Starbucks, **we drew a final design consisting of 7 joints** detailed by dashed lines across the model. This plan helped us to design proportionally accurate joints to the entire model that would do its function while using as little space as possible. We referenced this drawing very often to make sure the model and prototypes accomplished everything they needed to.



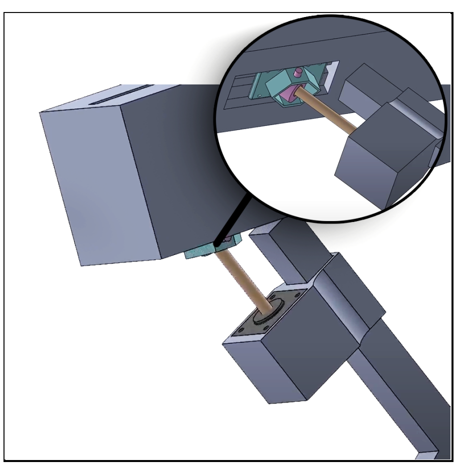
Plan: Because this was such an ambitious project, we wanted to start as early as possible. **We wanted to design each joint using SolidWorks**, a 3d CAD software that we could later use to 3D print the joints for the steppers to drive. After creating the design for the robot (shown to the right and above) we quickly got to work.



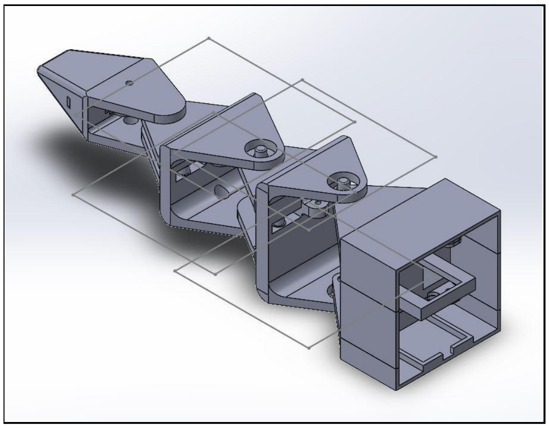
The first thing to be designed was the **body joint**, which went through 3 designs, all of which using a different pull mechanism. **Mk1 used a sled that rotated to pull the sides of the driven body, Mk2 used a bar linkage system to push and pull the driven body, and Mk3 used a 3D printer belt to turn the driven body like a chain and sprocket (all designs shown left)**. We ended up using the third because it was the most realistic and strong of the three and showed the most stress resistance. We found that in 3D printing these pieces for body joint Mk3, the supports were too difficult to remove (the blue piece is hollow), so we instead 3D printed 2 parts that when screwed together formed the shape it needed to and minimized support material in the print process, shown as Mk3B below. After using this full assembly, we resorted to using a larger disc for the driven body because we were not getting enough torque out of the smaller one.

The second joint to be designed was the **neck joint**. This one proved to be very difficult; we thought we would be able to directly link the driven neck to the stepper axle, but after 3 different designs we concluded that the **resistance in between the 3D prints created a huge problem in consistency and power**, so we needed a brand new design. This took a while to figure out, but eventually we landed on a **planetary gear**: a gear assembly that could gear down rotary motion in a vertical line. After a test print of the setup we wanted to use, we decided to use this in the final design. This went through 2 different iterations as well, all trying to make a more material efficient piece that was strong enough to support and drive the neck from a stepper motor but light enough to not drag the neck downwards. **The final design (mk5, right) included a base piece for the stepper to live in with a deck on top, one sun gear attaching to the stepper motor, two planetary gears that rested on the deck, and one large ring gear piece that the driven neck rested on.** Mk5 is currently on the robot and is one of the most consistent parts of the animatronic.

After the neck, we focused our attention to the **hip joint**. This was one of the most tricky joints, and ended up not working as well as the others. This joint needed to move the entire robot on an axis on the legs, so it had to have incredible load bearing qualities. Because of the difficulty of this part, we debated whether or not to include this joint at all, but we opted to try something new. **This joint went through one design (shown left)**; two stepper motors each fastened to 3D print Z-axis lead screws into a sled base on the robot. This design worked very nicely in SolidWorks simulations, so we decided that this would be an optimal design for the animatronic. When it was completely implemented, we realized that the angle of the steppers combined with the small space for the sled was creating unnecessary resistance and was actually reducing the power we got out of the system. Because the system still worked, we decided to not change it as we had many other more important fixes and designs to be made. This is one of the joints that will be remade for



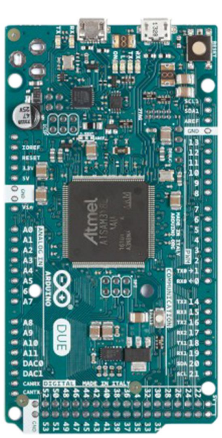
nationals if we are invited to attend! **All in all, however, this joint worked very well for a first design.** It solved the problems it faced and was consistent enough to not need any outside stabilization.



The **tail movement** was another fun one to produce. We needed to create a system that could bend in 2 directions while curling each section attached inward. This joint took a lot of research to design. We came down to two solutions: a cable and disc setup like the ones used in professional tail animatronics or another 3D print belt to curl individual sections inwards. We ended up using the second solution because it was much easier to operate consistently with the electronic components we had currently; we also did not want to use more than one motor for these movements to reduce the need for extra components in the electronics. **This tail joint went through one incredibly consistent design (pictured above).** This one was very difficult to print as well, so it needed to print twice the amount of pieces cut in half to reduce support material used as well as print strength. After fastening it all together and using small bearings for each section we were very satisfied, so we left it as it was first designed to be.

Lastly, the **frills joint** was probably the most unique joint we needed to create. This was a defining part in the Dilophosaurus, so we needed it to be functional, reliable, and natural looking. The first design was incredibly bulky and used torsion springs instead of straight springs used in the final design. These torsion springs were too powerful for our purpose and the servo used for frills was not strong enough to pull them back, so w**e bent straight springs so they fit the print and were able to be pulled/released by the steppers**. The second print of the frills was a much more condensed version with less frill “bones” (the sticks connected to the base that would rotate about the base imitating the frills) for easier dressing. As of now, the frills must be reset manually, but we have a design ready to use for future versions of the frills that will wind and unwind naturally using two servos. This design worked nicely, but **could use a lot more stability upgrades and consistency changes in the future.** We will be implementing these immediately if we are invited to the national competition.

Electrical Components



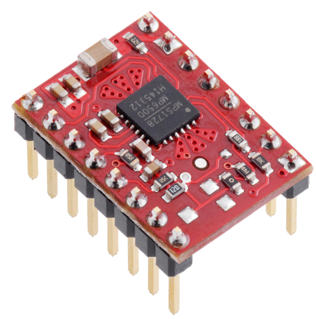
With such a wide variety of animatronic motion, we knew that we would have to stick to things that we are familiar with because we wouldn't have time to learn completely new hardware and code. We decided to stick with Arduino for the majority of the movement because we have had a lot of experience with them, and they have their own SPI to program them effectively.

Problem: With arduino as our main circuit board, we run into a bit of a problem: Arduinos only have **one processor, so they can only move one component at a time**. This is an issue because animals don't just move one body part at a time.

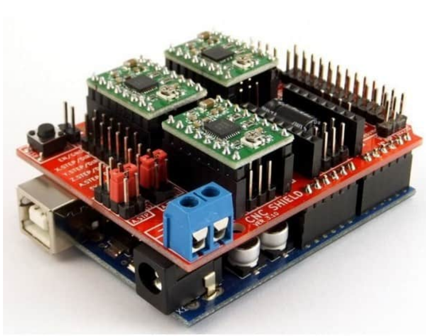
Ask: The big question was how do we allow for the animatronic to move multiple body parts at a time to look more natural in its movements?

Imagine: After thinking about this issue for a while, we came to the conclusion that it would be nearly impossible to allow for one processor to move all the components at a time unless we move away from function based code and just made one long loop for the dilophosaurus. **We took inspiration from supercomputers** (Image on right) that can split up tasks among multiple processors to do multiple tasks at a time.

Plan: Our plan comes from both the physical components and the possessors themselves as well as the code. All hardware needs to be designed with the code in mind so you don't run into issues later on. We already knew that **we wanted to use an Arduino Due as the main processor** (image above) controlling all of the signals going to multiple processors. The Due can handle more information because it is a stronger processor relative to other Arduino processors. We had the main processor, so we just needed to figure out what other processors need to be added to the branches.



- Our first issue we wanted to figure out was moving the stepper motors because they are the components that drive the main functionality of the dilophosaurus. **Controlling so many stepper motors at one time takes a lot of data on the Arduino** and could limit the other functions that we can add to the program. Instead, **we opted to use stepper motor drivers** (Image on right)**,** which will do most of the processing work for us, and letting us control the stepper motor with a fraction of the memory.

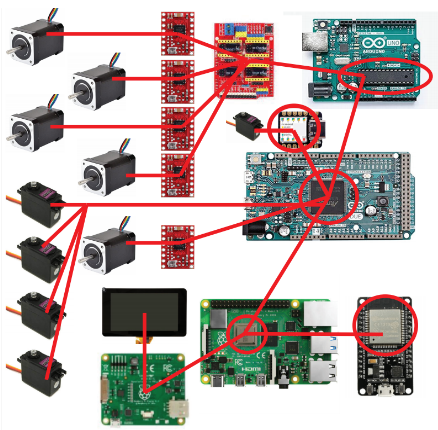


    - In order to control five different stepper motors at a time, **we decided to reprogram a control board for a 3D printer.** This would allow us to use multiple drivers controlled off of one processor. **It would also allow us to make smoother motion, and program in acceleration to the movement of the**

dilophosaurus. We found a 3D printer shield for an Arduino Uno that can run the 3D printer motherboard off of one processor with Arduino code (image on left). This would allow us to run four of the five motors with the shield, and would only leave one more motor to be controlled by the mother controller. **This would use a lot less data than it would to control all five.**

- For the other motion that uses servos, we decided to use the processor on the Due because it is advertised to **be able to control up to 60 servos without servo jitter or sporadic motion.**
- For the frills we planned to use a Seeeduino XIAO (Image on right). Although it is not an official Arduino board, we can still program in through the Arduino SPI. **The benefit of the Seeeduino is space**. It is just larger than a quarter, so it saves us a lot of space for the frills where we don't have a lot of space.

- To make the whole exhibit user friendly, **we wanted to create a simple user interface to make the exhibit more interactive for our audience.** We wanted to have a **touch screen display** that has options to control the dilophosaurus. We decided to use a Raspberry Pi circuit board for this because running a touch screen is a very large task that an Arduino board would struggle to handle. We wanted to use NodeRed to program the user interface. **We also wanted to make the exhibit COVID friendly as well, so we want to use an ESP32 board to connect it to the global network to be able to be controlled from an app on our phones** as well to try to prevent everyone from touching the same screen spreading the virus.



The final step of our planning process was to create a general diagram of the whole entire tree of circuitry (shown at left). This **helps us with overseeing the whole system as a whole to avoid silly mistakes while putting it together.**

Create: Overall, the creation of the circuitry went almost exactly as planned. There were a few issues creating a common ground between all of the processors, but other than that, the creation went smoothly. The only other thing we needed to add during the creation process was the code. **We ended up using the Arduino SPI and wrote over**

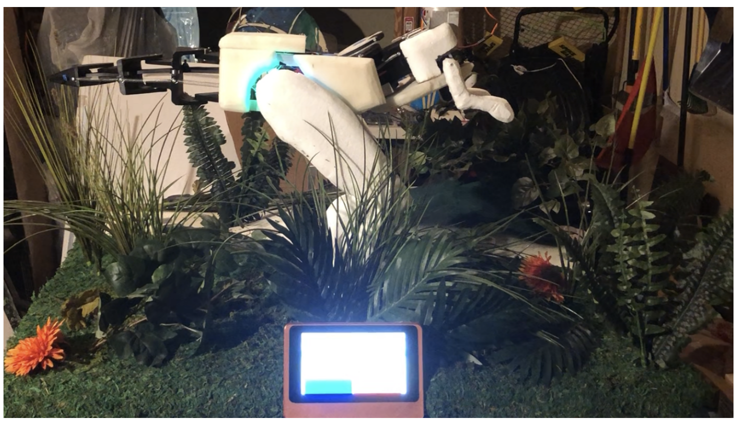
```
byte pin, analogPin;

/* DIGITALREAD - as fast as possible, check for changes and output them to the
 * FTDI buffer using Serial.print()  */
//checkDigitalInputs();

/* STREAMREAD - processing incoming messagse as soon as possible, while still
 * checking digital inputs.  */
while (Firmata.available())
  Firmata.processInput();

// TODO - ensure that Stream buffer doesn't go over 60 bytes

currentMillis = millis();
if (currentMillis - previousMillis > samplingInterval) {
  previousMillis += samplingInterval;
  /* ANALOGREAD - do all analogReads() at the configured sampling interval */
  for (pin = 0; pin < TOTAL_PINS; pin++) {
    if (IS_PIN_ANALOG(pin) && Firmata.getPinMode(pin) == PIN_MODE_ANALOG) {
      analogPin = PIN_TO_ANALOG(pin);
      if (analogInputsToReport & (1 << analogPin)) {
        Firmata.sendAnalog(analogPin, analogRead(analogPin));
      }
    }
  }
  // report i2c data for all device with read continuous mode enabled
  if (queryIndex > -1) {
    for (byte i = 0; i < queryIndex + 1; i++) {
      readAndReportData(query[i].addr, query[i].reg, query[i].bytes, query[i].stopTX);
    }
  }
}

#ifdef FIRMATA_SERIAL_FEATURE
  serialFeature.update();
#endif
}
```

1500 lines of function based code (small part example on right). We also used NodeRed to make the touch screen user interface, and Blynk to make the app for the phone.

Improve: One of the most useful improvements we made was to **add a small LCD screen connected to the main microcontroller.** This allowed us to easily print out messages from the motherboard to help us troubleshoot when things weren't quite working in the code. We ended up using this countless times to aid us in finding bugs making the process a lot easier and faster

- For nationals, **we plan on doing the most of the improvements in the code to make the movements look more natural.** Once we know that the circuitry is working, the only thing we need to change is the code. **We also are looking into better ways to drive the frills** to make them look more natural and more efficient.

Environment:



Problem: One of the most important parts of any museum display is the environment that it is in. A museum display can either make or break the realism of the exhibit. We want to make the environment as real and engaging as we possibly can.

Ask: How can we create a realistic environment that is both true to the movie as well as creating a functional, engaging exhibit for the audience?

Imagine: We knew that **we wanted to have the animatronic interact with the environment** itself. We wanted to have the movements of the animatronic move the plants to create an effect as if it were ruffling the grass. We also wanted to **make a running waterfall** to give the viewer an eerie vibe as if they were actually in the environment during a rainstorm. We wanted it to be as close to a tropical environment as we could make it.

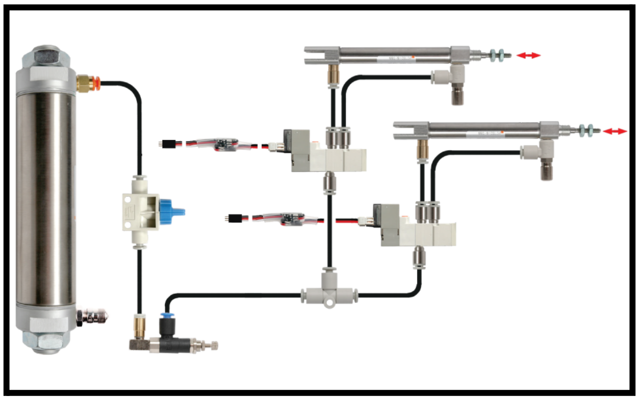
Plan: We broke the environment into three separate sections: The foreground with all of the tropical plants, the waterfall with running water and realistic rock textures, and a fully functional jeep to make the scene closer to the situation in the movie.

Create: To start off with the creation process, we began constructing the waterfall by creating a central base that will be able to withstand the weight of the artificial rock formations as well as the Jeep. After creating the main frame of the waterfall with plywood, we had to create a multi layer foam base in which the water would soon be flowing down. We did this by taking a thick foam pad, and cutting it into the desired shape of the waterfall. We glued all of the foam pieces together and snipped off some more foam to make some of the realistic details of an inconsistent rock formation. **We then took a joint compound and smothered it all over the foam to give it the appearance of the texture for a rock**. After the compound dried, we used a textured spray paint to give it the dark gray color of our desired rock formation. Now that the base of the waterfall was complete we could now add some running water. We found creating the water flow was one of the most difficult obstacles that we had to overcome. **With all of the electronics located so close to the waterfall, we had to be very careful and ensure none of them would get wet.** With the waterpump that we had located, we found that it had a water pressure that was far greater than desired. We had to slow down the amount of water feeding into the waterfall. What we had to do was divide the pressure among two separate hoses, one large central hose that fed directly back into the water reservoir, and one smaller hose that fed the water back into the waterfall. We found this solution to be very reliable and give the perfect waterfall appearance. We finished the waterfall off with some greenery to give a more life-like look to it, and as well as the Jeep Wrangler, which perfectly finished the last details we were seeking for the environment. We also found that the Jeep's lights gave the dinosaur a scarier appearance, especially when they had a red color to them.

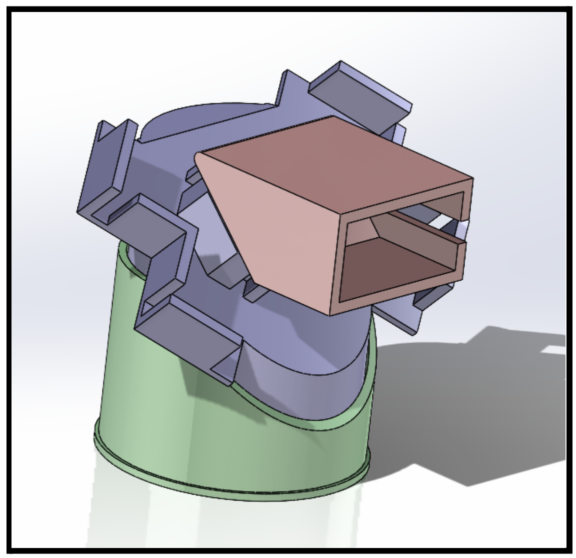
Improve: Although we didn't have any time to improve upon the environment for state, we have many plans on how to improve it for nationals. We want to add a lot smaller plants to fil in the empty space around the taller plants, as well as try to add a bit of life to the foreground as well. This could be things like fake bugs. We also want to figure out a new way to decorate the waterfall. At the moment we have some areas with moss, however, we want to figure out how to get some of the tall grass to also be in the rock without ruining the perspective of the exhibit.

- In addition to the environment, we brought in a fog machine during filming to create even more of an eerie tropical vibe to the video. This was the final touch that brought the whole project together.

Nationals Changes:



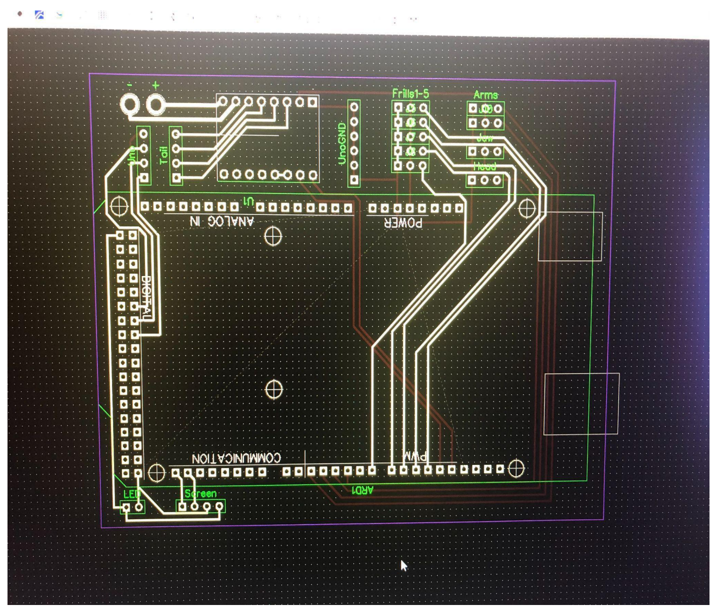
For our second design, we used VEX Pneumatics to propel the hips upward and downward in a much more powerful manner, resulting in more natural movement. We wanted to use hydraulics at first, but after finding out how expensive the full system was going to be, we opted for a cheaper option. After our first few rounds of tests using scales, different weights, and even replicas of the joint, we decided it was fit for use. We installed the pneumatic cylinders using custom 3D printed attachments and found out that it was actually too powerful. This was solved using **NinjaFlex 3D printed material** to add a cushion to the chest of the dinosaur and on the thighs. This made the movement much more natural and easy to use.

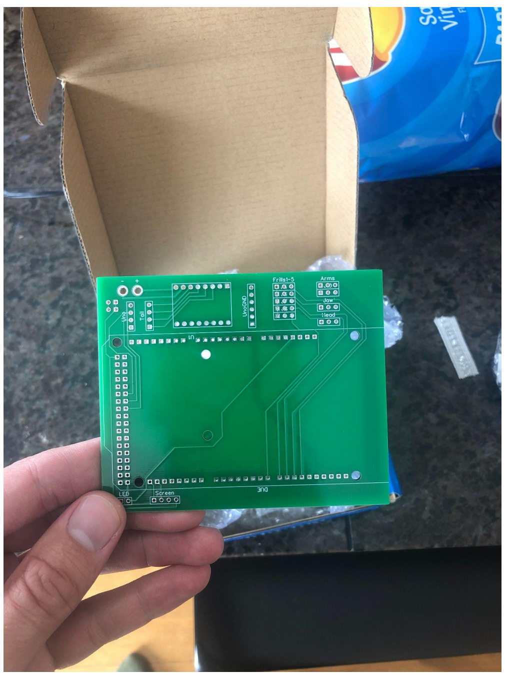


We also updated the frills on the dinosaur. Because our last solution was only a one time use fixture, we chose to use a simpler yet more robust approach: individual servos controlling each bone of the frills. The picture to the right shows the 3 3D printed parts we used on our robot (3 so the prints would be more linear/easier to take supports off of, resulting in higher quality). **This design went through 3 different changes as well**, the first 2 being combinations of the purple and green parts while the 3rd and final solution split it into different parts. **After some simple tests, this worked very nicely**, and we were able to add simple effects like shaking of the frills as well as more precise movement.

Lastly, we made **slight changes to the body joint** in the middle of the robot. For our state submission, we directly attached a stepper motor to the belt which was attached to the driving wheel, but we recognized that this was very weak, and added a gearbox between the stepper and the belt/drive mechanism. This 16:1 gear ratio gave us the torque we needed, at the cost of speed. We weren't very concerned with speed however, as dinosaurs (unless in pursuit of something) do not have that aggressive of movements side to side, so it looked more natural if anything. **This joint became much more reliable and was able to carry the weight of the extra servos on the neck with ease.**

Circuitry:
At state, we ran into issues with the circuitry taking up too much space. For nationals, We designed and ordered custom PCBs that were able to cut the size of the circuitry almost in half. This created more reliability, more space, and cleaner, more organized looking circuitry. This was a good experience for us because we learned how to make our first gerber files as well as work with professional industry companies to bring our products to life.





Code:
For improving the code, we wanted to create a more interactive experience for the viewer. We added video extensions to the touch screen so when you press a button, we have a “tour guide” show up on screen and talk about the animatronic. We acted like paleontologists to keep our intended audience active. We also added audio into a headset for the watcher to hear the tour guide.

We also added a control panel to the touch screen where the user can control each individual component of the animatronic to demonstrate the motion.

All of the new code was done in NodeRed, which is a Python interpreter.

Skin improvement:
We ordered a new skin to create a more realistic exterior, however it was shipped from Europe and our package was flagged down due to COVID exposure in its country of origin. Unfortunately it still hasn't come in, so we had to resort to our original skin.

STUDENT COPYRIGHT CHECKLIST

(for students to complete *and advisors to verify)*

STUDENT: Answer question 1 below.

1) Does your solution to the competitive event integrate any type of music and/or sound? ☑ YES ☐ NO

If NO, go to question 2.

If YES, is the music and/or sound copyrighted? ☐ YES ☑ NO

If YES, move to question 1A. If NO, move to question 1B.

1A) Have you asked for author permission to use the music and/or sound in your solution and included that permission (letter/form) in your documentation? If YES, move to question 2. If NO, ask for permission and if permission is granted, include the permission in your documentation.

1B) Is the music/sound royalty free, or did you create the music/sound yourself? If YES, cite the royalty free music/sound OR your original music/sound properly in your documentation.

CHAPTER ADVISOR: Sign below regarding your student's answer(s) to the use of music/sound in his/her competitive event solution. Even if your student answers "NO" to question 1, please sign below noting that you have evaluated the competitive event solution and the student answered the question(s) accurately.

I, Kent Al______ (chapter advisor), have checked my student's solution and confirm that any use of music/sound is done so with proper permission and is cited correctly in the student's documentation and/or the solution has been found to have no music/sound included.

STUDENT: Answer question 2 below.

2) Does your solution to the competitive event integrate any graphics/videos? ☐ YES ☑ NO

If NO, go to question 3.

If YES, is(are) the graphics/videos copyrighted, registered and/or trademarked? ☐ YES ☐ NO

If YES, move to question 2A. If NO, move to question 2B.

2A) Have you asked for author permission to use the graphics and/or videos in your solution and included a permission (letter/form) in your documentation for graphic/video used? If YES, move to question 3. If NO, ask for permission and if permission is granted, include the permission in your documentation.

2B) Is(are) the graphics/videos royalty free, or did you create your own graphic? If YES, cite the royalty free graphics/videos OR your own original graphics/videos properly in your documentation.

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I, Kent Al______ (chapter advisor), have checked my student's solution and confirm that the use of graphics/videos with proper permission and is cited correctly in the student's documentation and/or the solution has been found to have no graphics/videos included.

STUDENT: Answer question 3 below.

3) Does your solution to the competitive event use another's thoughts or research? ☐ YES ☑ NO

If NO, this is the end of the checklist.

If YES, have you properly cited other's thoughts or research in your documentation? ☐ YES ☐ NO

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I, Kent Al______ (chapter advisor), have checked my student's solution and confirm that the use of the thoughts/research of others is done so with proper permission and is cited correctly in the student's documentation and/or the solution has been found to have all original thought with no use of other's thoughts/research.