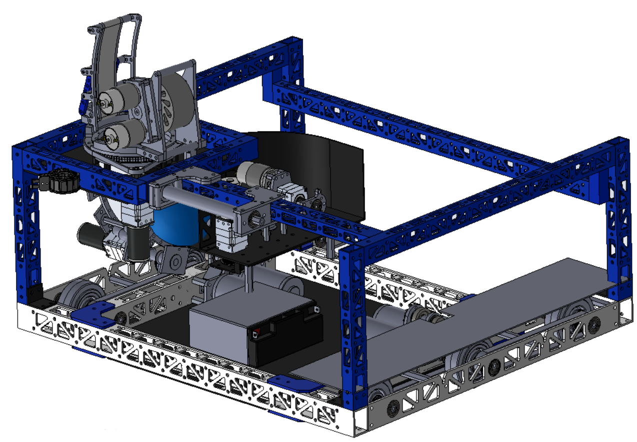
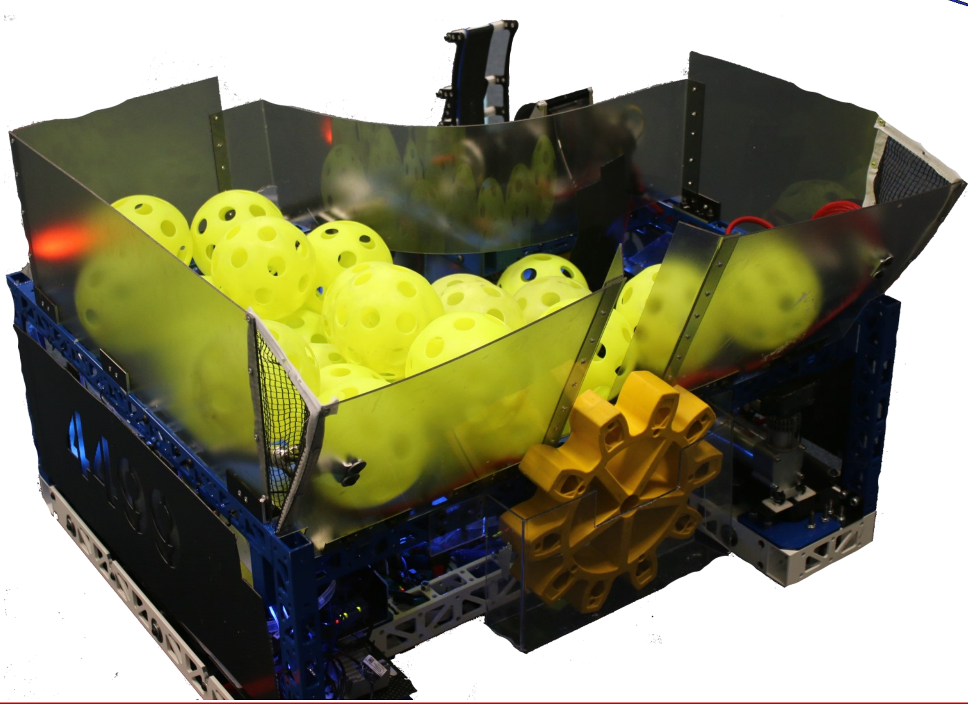
The Highlanders
FIRST Team 4499

2017 STEAMWORKS Engineering Design

BLITZAR





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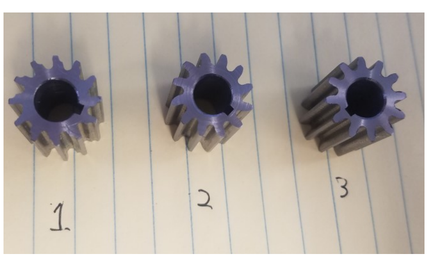
Gear Box Design/Manufacturing

Engineering Design

Our team has always been fascinated with gearboxes and gears in general. This preseason we decided to take our curiosity to a new level, the manufacturing of gears. This idea was sparked

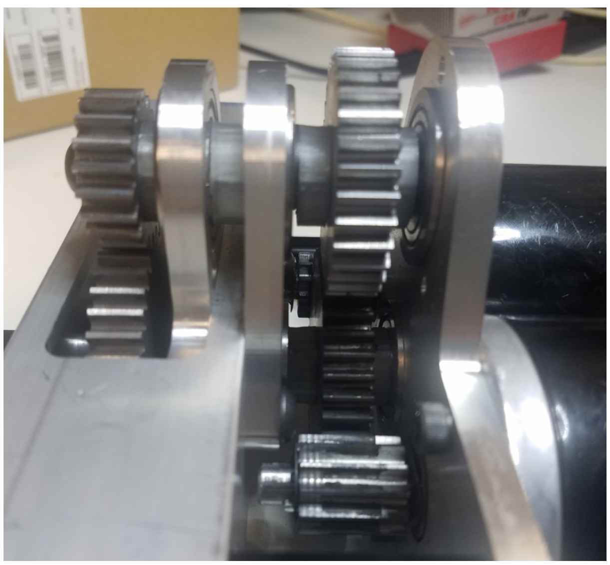
when we bought our most recent CNC mill which came with a 4^{th} axis. When we were trying to get the 4^{th} axis up and running, we discovered that the air brake was stalling out the motor which in turn fried the encoder. This needed to be replaced which allowed us to learn more about the motor and how it works. After the encoder was replaced, we decided that it was time to pick out what gear profile we would be using. We narrowed it down to an involute cutter with a diametrical pitch of 20 with a pressure angle of 14.5 degrees.



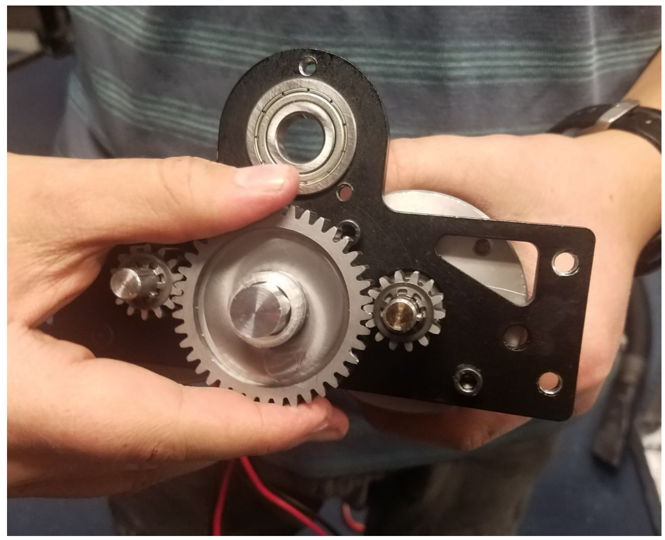
This allows for very strong teeth and matches commonly available gears in FIRST robotics. To hold the involute cutter in a BT 40 collet we decided to buy an r8 arbor and lathe it down to fit in the BT 40 collet. This is due to the inexpensiveness of r8 collets and the strength of steel that it comes with. To hold the work in the 4^{th} axis we devised a method of holding an available four jaw on the 4^{th} axis by making an alignment shaft to make the centers of each component concentric. To mount the four jaw on the 4^{th} axis, we needed to machine an adapter plate to convert the bolt pattern of the four jaw to the 4^{th} axis. After this, we also machined t-nuts to mount the adapter plate to the 4^{th} axis. Now that the four jaw is mounted to the 4^{th} axis, we needed to find a way to cut the gear. This problem was fixed by machining a perfectly concentric arbor in the lathe and then machining a hex profile into the end of the arbor to hold on hex gears.

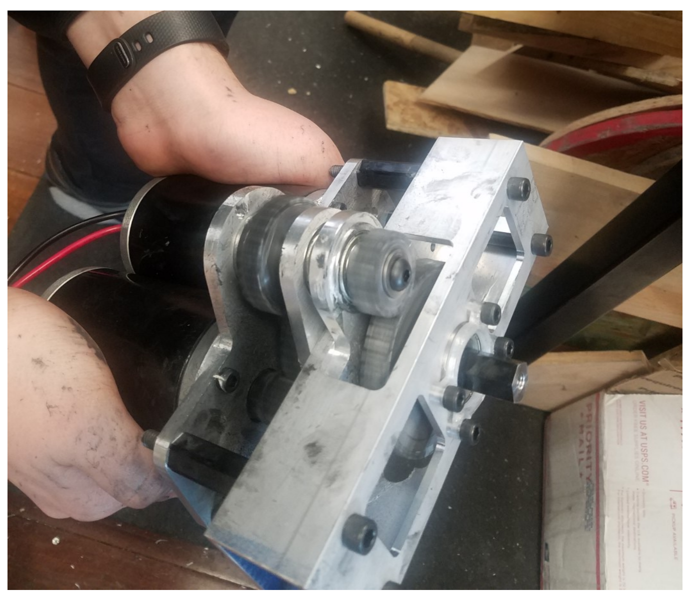
To generate the G-code to run the program we developed a python program that had several variables about the gear such as number of teeth, thickness, and program number which is all needed to generate the proper program. The final process to machine the gear is to lathe the gear to diameter, cut it off at the desired thickness, and then broach it to ½" hex.

The hex must be perpendicular to the face of the gear otherwise it would not spin properly. After the work is prepared the G-code is generated and the work is then manually zeroed. The involute cutter must also be prepared for the proper number of teeth that it is cutting. The larger a gear is, the less pronounced the profile becomes making the involute cutter slightly thinner. After this is replaced, the sequence is run and a gear is created. To reduce weight, we have also developed a



pocketing method for our steel gears. We do this by creating a block of aluminum with a hex profile cut out of the top of the block. This also has a bolt hole in the center to mount the gear down. Then when the gear is securely mounted and zeroed, a pocketing sequence is then run on both sides of larger gears. This process involves many variables that are hard to keep constant leading to many troubleshooting scenarios in which very strange “gears” are created. Overall this has been an amazing learning opportunity about the mechanics of making gears. In the future we hope to heat treat our gears but in initial testing, too many microfractures were created weakening the overall strength of the gear.





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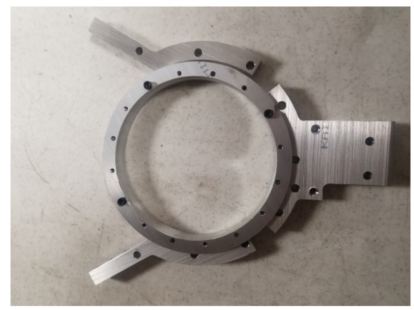
Shooter

Engineering Design

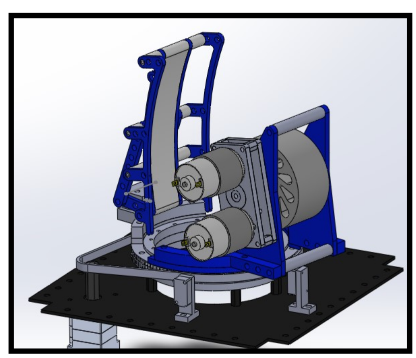
Based on expertise from previous years and the large number of balls we would need to move through the shooter in short period of time we decided to start prototyping a flywheel shooter as well as develop a solution to give the shooter the ability to aim without using the drive base of the robot.

The shooter prototype began showing great promise with the very first proofs of concept. We worked the first day trying different types of wheels lying around the shop finding 4” diameter soft rubber wheel gave the ball the most power. Developing the solid prototype rig was the next step of the process. We built a base out of wood and mounted the soft wheel and a back rail for the ball to run along. To improve the accuracy of the shooter we added side guide pieces and we reformed the back guide was multiple times to find the ideal shape to give a high arc shot.

Because we wanted to dictate all of the dimensions and functionality, we opted to build our own slew from scratch. We began with a small scale test of the different operations that would be needed to go into machining the slew ring. We printed a small ring with the Igus 3d printer filament and machined the rings to test the functionality and the pulley profile to make sure it matched the belt. From the first slew ring we learned a lot—the method of machining would need more care put into it, and the plastic bushings would need to be very carefully sized. Changes for the production included drilling high precision holes into the fixture plate and using indexing pins to position the blank. We also resurfaced the face of the fixture plate every time an operation was run. All of these changes lead to far more accurate part.



The first production version of the shooter had a powered hood that could be used to control the angle of the shot. This turned out to not be stable enough, and was changed in the next revision to be a fixed solution with longer guide rails to improve the accuracy of the shooter.



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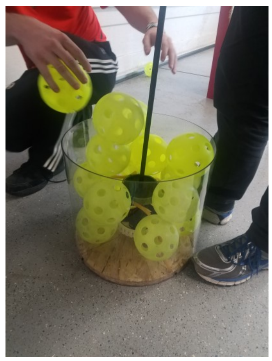
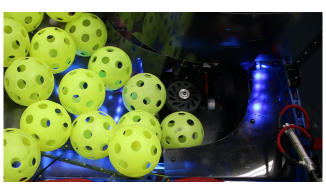
Ball Feeding System

Engineering Design

The vortex is the mechanism to send balls from our ball storage into the feeder than into the turret.

Our initial strategy of the 2017 season was to have a very strong high goal autonomous which we then decided we would need a large ball storage, an efficient turret, and a fast way to transfer the balls to the turret. To find a fast way to easily move balls from the storage to the turret, we tried a 6" wheel in a polycarbonate cylinder to spin the balls into a small opening in the side. This design in addition to the vent duct tubing did not work as efficiently as we wanted it to and was not as compact as it could be. In Solidworks, one of our teammates designed a new vortex which only included about a quarter of the original wall to give more space for ball storage.

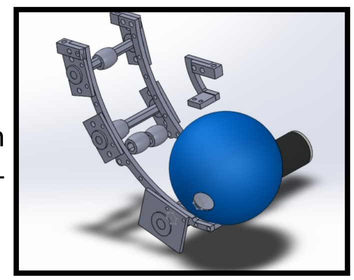




The wheel also changed from a 6" wheel to a 4" rubber wheel to give more compression to the balls passing through the vortex to ensure a greater feeding rate into the turret. The wheel in the center of our vortex is powered by a chain connected to a 775 Pro motor.

Even with the improved vortex, we decided that the balls were not feeding at a fast enough rate for what we wanted. Using previous knowledge of poly-cord and using it as a belt or pulley, we then decided to design a new feeder in Solidworks that was powered by a 775 motor and flat poly-cord run on 3D printed pulleys, also designed in Solidworks.

The next revision made on the feeder was powered with poly-cord belts and gave us an increase in the rate to get balls from the storage to the turret. This was a major improvement, however, we found a new problem in the design of the pulleys with the flat belt. A flat belt will travel to the highest part of a pulley and that led to the belts falling off the pulleys and stalling the motor. Our final revision of the feeder mechanism included pulleys of a convex shape to cause the flat poly-cord belt to travel to the center of the pulley while also being powered by a 775 Pro motor with a 5-1 gearbox reduction and a free spinning 2" wheel to give compression to the balls, while also aligning them on a track leading into the turret from beneath.



We also ran into some issues with the balls getting jammed up in the basin, blocking the pathway into the vortex and feeder. To prevent this, we added an agitator into the basin. The axle was turned by a belt driven off of the vortex motor. The agitator itself started out as a wheel with surgical tubing sticking out from it. That was the first of many iterations on the design. We tried multiple wheels stacked (the “Christmas Tree”), a u-shaped piece of polycarbonate (the “Blender”) and finally settled on dual-stacked, curved metal blades, affectionately known as the “Double Boomerang.”

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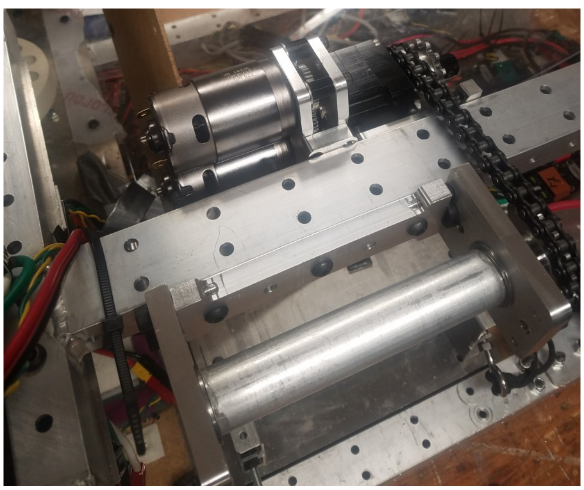
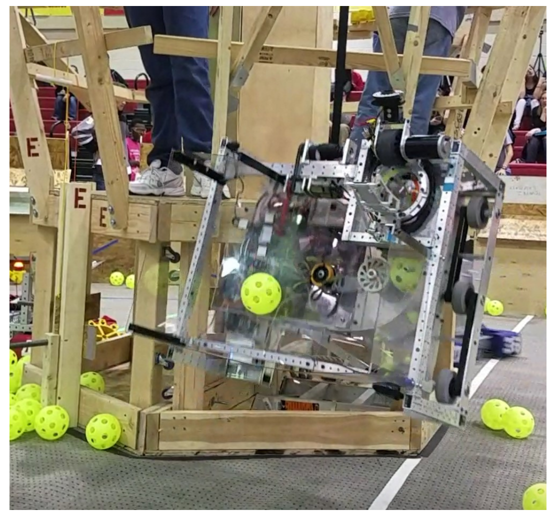
Climber

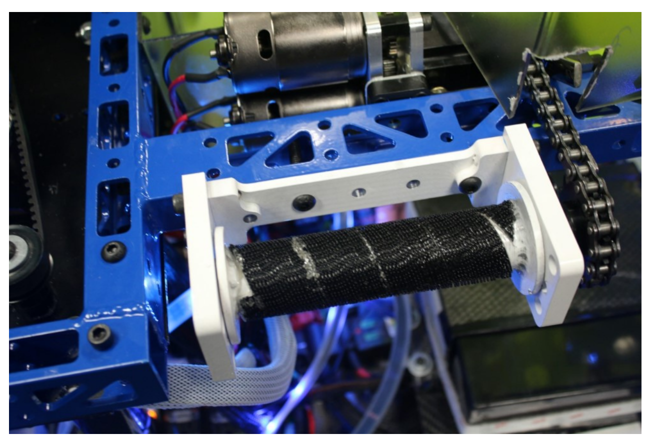
Engineering Design

The beginning prototypes of the climber consisted of a winch with a notch cut into the center of it to grab onto a knot in the rope. This prototype proved that the winching system works but lining up with the knot was very difficult to do. With the next revision, we tested how well Velcro gripped to the rope. The Velcro grabbed



the rope well and could climb it very easily, this is one aspect of the design that made it to the final revision. In the final revision, we used the Velcro on a spinning drum attached to a dual 775 pro custom gearbox. This gearbox allowed the climb to be very fast but still have enough torque to lift the robot. With the change to the Velcro we also switched to a thin tie-down strap for the rope. At that point we ran into a separate issue; the strap was winding around the drum in such a way as to bind up in the bearing on the side of the drum. This was solved by recessing the bearings and altering the design of the brackets holding the drum.





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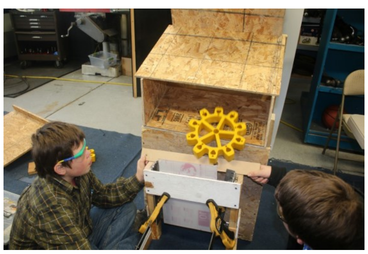
Gear Mechanism

Engineering Design

Trapdoor

We started prototyping the trapdoor mechanism at the beginning of the build season. This was a box whose front folded down and the gear fell onto the spring. This was not able to reliably collect the gear from the hopper or place it on the spring.

Pneumatic Clamper



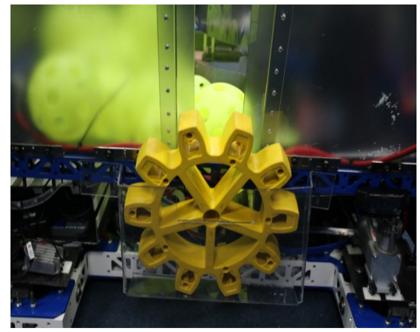
The initial design was to have two side plates clamp down on a gear and be capable of dropping the gear off on the spring by unclamping itself.
This design was promising in the preliminary stages but like the trapdoor mechanism it failed to reliably catch the gear.

Pneumatic Gate

This mechanism was very similar to the trapdoor mechanism. It was a box that was opened by a piston extending and pressing on the handle of the gate which forced the mechanism to open and release the gear. The gate was considerably more reliable in obtaining the gear from the hopper. This design was the most successful in testing stages, but was limited by the already built frame of the robot.

Pneumatic Box

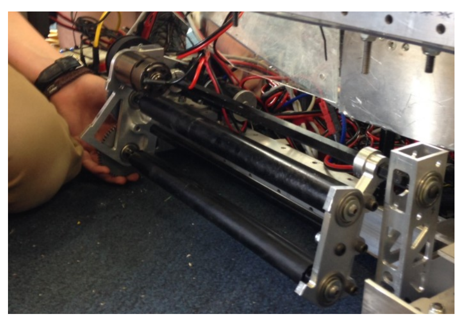
This design was made in the last week of build season. It was originally a polycarbonate box that was bent to fit within the frame perimeter. Because the polycarbonate box could not reliably receive gears from the hopper, we attached it to the side of the basin. This actuated out, allowing the basin to expand and also tilting the gear mechanism to make an easier catch from the feeder station.



This was the mechanism that we used at the Hub City Regional. While we were able to easily deposit the gear on the spring once we had it, we were only able to catch 50% of the gears from the feeder station. Worse yet, the failures to catch actually ended with the gear inside the basin, making it illegal for us to get any others. It also interfered with the balls in the basin, impacting our ability to shoot.

Roller Intake

On our return from Lubbock, we started working on a mechanism that would allow us to pick gears up off of the floor rather than requiring us to get it directly from the feeder station.



We developed a mechanism with roller bars to grab the gear after the robot drives over the top of it. The entire mechanism then rotates 90 degrees to hold the gear vertically. Once the gear is on the peg the rollers back drive slightly to release it.

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Programming

Engineering Design

This year, we used Java as our primary programming language. It offers various, robust libraries to accomplish our needs, and there is plenty of support for it from the FIRST community.

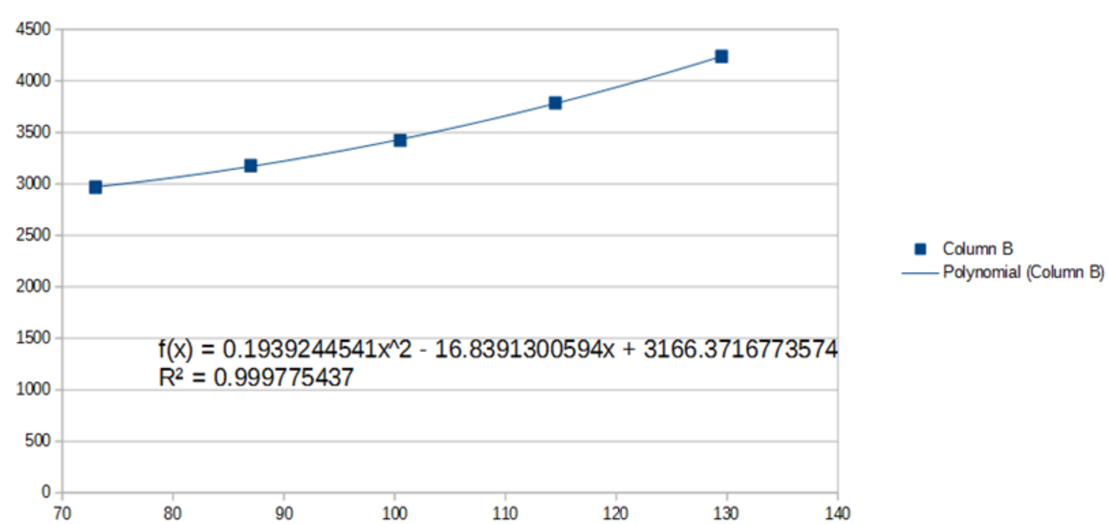
The Vision System

From kickoff day this year, our team decided that we needed a powerful autonomous. Because the boiler is three times more efficient in autonomous, we also decided to shoot for the high goal. Doing this without a vision processing system is very difficult, because the robot only has a limited knowledge of its surroundings. Therefore, we sought to create and implement a robust system to help with aiming. Additionally, we concluded that a vision system would be valuable in teleop because obstructions like the airship limit the sight of the drivers.

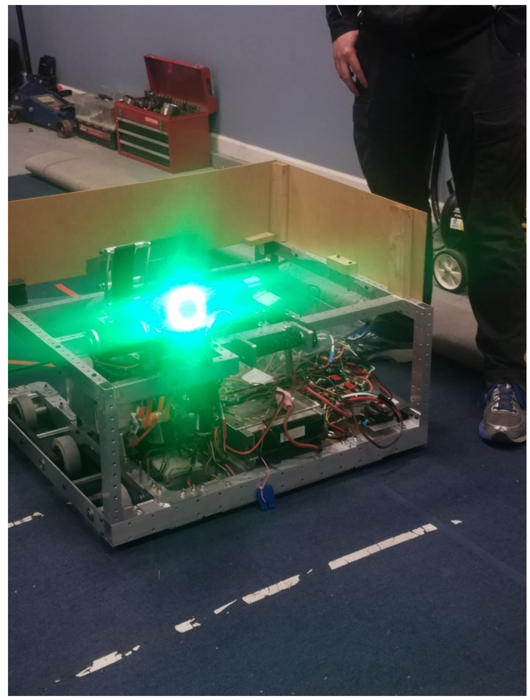
To accomplish this goal, we utilized a powerful tool from Nvidia, the Jetson TK1. The Jetson TK1 is a mobile development board with excellent graphical capability. The TK1 was the optimal solution for us because it offloaded processing from the roboRIO, and provided better frame rates, due it its enhanced graphical processing optimization.

Our robot features a turret to fire fuel balls, which can turn to aim and align with the goal. It also utilizes a rubber flywheel, which can speed up or slow down to adjust the robot's effective firing range. Naturally, there are two problems for the vision system to solve: the adjustment of the turret's angle and the changing of the flywheel's velocity.
Reflective tape on the boiler makes target alignment ideal; the vision system can identify “X” and “Y” coordinates of the goal, which is computed by

	A	B
1	129.5	4237
2	73	2968
3	100.5	3422
4	87	3178
5	114.5	3786



a convolutional neural network trained by the hundreds of field images published by FIRST. These coordinates are transmitted to the roboRIO for further processing through a socket on the router, yielding low-latency coordinates of the goal's position for further processing. They are transmitted as a JSON string, an efficient and universal communication protocol, designed for data transfer between systems.



By using the X coordinate from the Jetson TK1, the roboRIO is able to compute the angle that it needs to turn in order to be aligned with the goal by using trigonometry. This motion is then accomplished by a motion profile running on the Talon SRX. Then, to determine the speed that the flywheel needs to spin, we needed to determine the robot's distance from the goal. By fixing our camera's angle of inclination from the floor, we were able to gather data points relating the robot's actual distance from the goal, and the Y coordinate. After gathering several data points, we put those data points into Libre Office Calc and applied a quadratic curve fit to get an equation to convert the Y coordinate into distance. Then, we repeated that process to convert distance into flywheel speed, again by taking data points from observed performance of our robot and creating a function to convert distance ideal flywheel speed. After all this, we had automatic goal alignment from the X coordinate, and real time conversion from the Y coordinate into flywheel speed.

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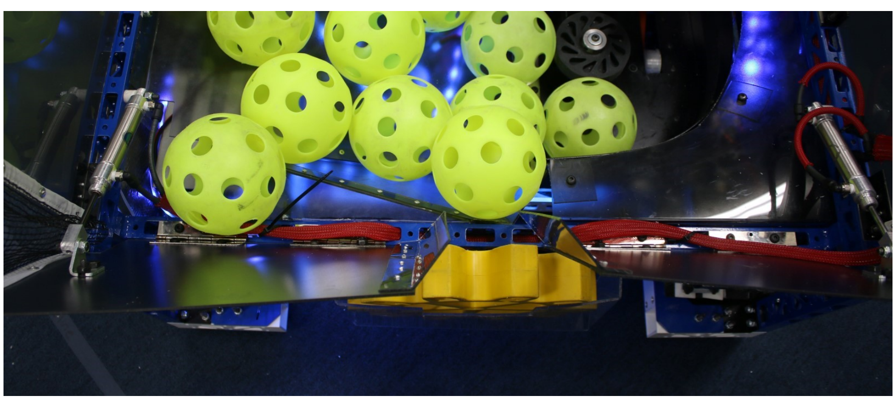
Pneumatics

Engineering Design

Our 2016 robot was very pneumatic intensive. Between a long stroke piston for the intake and an intricate ballast-based catapult launcher, Magnetar required vast amounts of air pressure and pneumatic control. It also proved a large source of failure in the robot's function. While this year's robot does not require as much air, there are many places where we could use our learning experience from last year on our 2016-2017 robot, Blitzar.

One large area of improvement was tubing routing. We realized that tubing routing required significant priority when planning out the pneumatic systems, and planned accordingly. An entire shelf was designated for the primary pneumatic



systems, the compressor and array of air tanks. Tube layout was prioritized, and we managed to avoid large curves, and have no U curves in the entire system. Channels through the chassis tubing to the piston subsystems were designated, and all the tubes were covered in nylon sheathing as to not catch. Our team learned, and put together a routing system that greatly improves to that of last year.

We also realized there is a limit to how much a person can do with better planning, and improved our equipment as well. We found a new supplier, McMaster Carr, for better performing pneumatic parts. We favored parts built for industrial toughness. We found and equipped our robot with fittings and tubing that are much less likely to pull out of components and break the pneumatic seal, a consistent issue during our 2015-2016 season. We found and utilized the proper tools to ensure our robot succeeded in the 2016-2017 season.

The Highlanders

3D Printed Parts

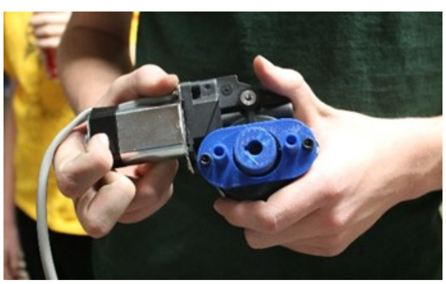
Engineering Design

3D Printed Parts Design

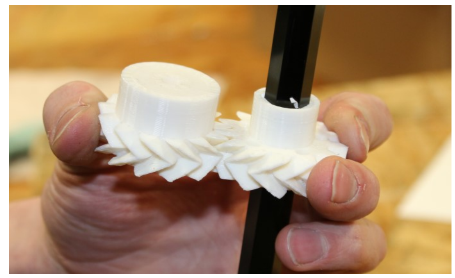
Many of the parts on our robot are 3D printed because the 3D printer can make parts faster than the manual machines when strength and dimensional tolerances are not of extreme importance.

We choose to design and 3D print parts when we can because it is simply faster to do them on the 3D printer, and they do not need the strength gained from aluminum or steel. 3D printing also allows us to use complex shapes that we could not make any other way. We received a printer from a sponsor during our 2013 season, and have recently added a second, dual-head printer. Our robot is cooler-looking and easier to make because of our use of this technology.

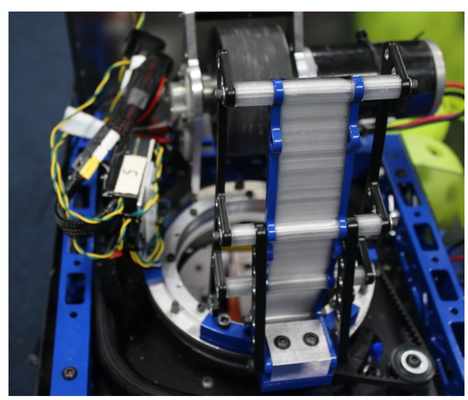
We did see the limits of the capability of a 3D printed part in 2013 when we used ABS to make a mount for a window motor. While the printing could easily deal with the complexity of the part, the torque applied to it exceeded its capacity, and it failed. We redesigned with a metal part, and learned a valuable lesson.



Each year we have printed many spacers for our robot as well as mounts for our cameras, router, and robot signal light. For the 2017 season we have introduced some new 3D printing materials – IGUS Iglide180 Tribo, Novo 1800 and Colorfabb HT filaments. We used the IGUS filament to print plastic bushings for the slew rings for our shooter. The properties of the filament made it perfect to allow the slew ring easy, low friction motion to rotate the turret. It is also abrasion-resistant and so should not wear out during competition.



Both the Novo 1800 and Colorfabb HT filaments are co-polyester plastics and so have a low coefficients of expansion. We used these filaments to build high strength, high accuracy parts. - Pulleys, encoder cases, spacers and back of the shooter mechanism. Another advantage of the Colorfabb HT is the impressive heat resistance, as it can stand temperatures up to 100 degrees Celsius.



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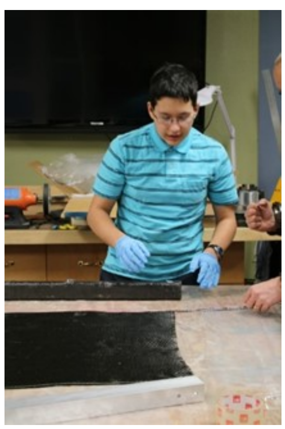
Carbon Fiber

Engineering Design

One of our favorite materials is carbon fiber. We like the great strength-to-weight ratio, which allows us to have more weight available for mechanisms, and the ability to form shapes we might not be able to otherwise. Our training of new students includes both how to create carbon fiber parts from raw carbon fabric and epoxy as well as how to safely handle, cut and machine finished carbon fiber parts. We are particularly aware of the safety aspects including: handling and cutting raw carbon fiber fabric, layup and epoxy construction (and cleanup) in a small shop, safe handling, cutting, drilling and sanding of finished parts.

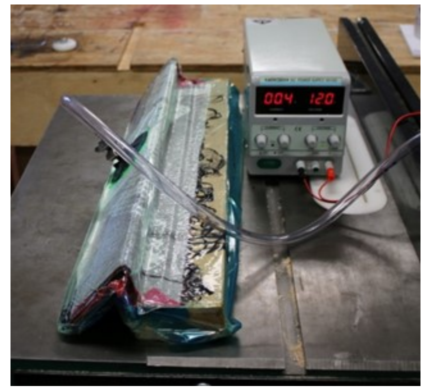
We have constructed carbon fiber tubing, solid carbon fiber sheets and carbon fiber sandwich sheets (plywood core and foam core) from raw carbon fiber fabric and epoxy in our own shop.



The more complex parts are molded with the help of a vacuum system. Rub off of the shop's compressor and a Raspberry Pi computer, the vacuum: Creates parts with greater strength to weight ratios, decreasing voids in the parts as well. as removing any unnecessary epoxy. Allows us to create formed parts with complex contours.

We have used carbon fiber sheets as electronic boards, skirting and side shields on our robots. We've used some tubing but have especially taken advantage of the forming capability to make right angles, including shelves for our electronics.

To share our carbon fiber knowledge, we have held workshops for other FRC teams, and done hands-on demos at expos in our area.



<u>Solid Carbon Fiber Plate:</u>

Some of the applications of solid carbon fiber plates for various applications on our robots:

The base board and vertical boards of our 2017 bot are carbon fiber plate made with a core of fiberglass. The light weight of the parts allows us to add in more complex mechanisms to overcome obstacles without exceeding weight limits.

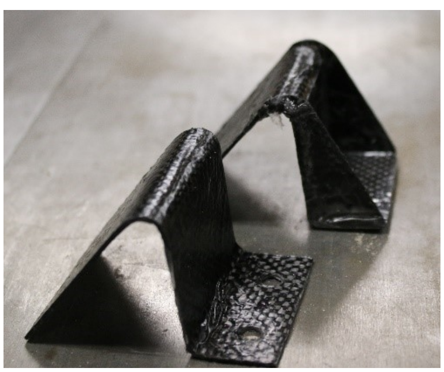
The intake wheel assemblies on 2015's robot were supported by carbon fiber 'springs' – rectangular pieces cut from carbon fiber plate that allow the intake to flex horizontally without any flex vertically or any noticeable twist.

Molded Carbon Fiber Plate:

With the vacuum system we have been able to create carbon fiber pieces formed to spec.

For the 2017 robot, we molded a battery holder – we created a wooden model of a battery and then used the vacuum system to form the carbon fiber to the mold.

In 2015 we prototyped hooks for picking up totes. This was a complex shape, but the parts came out in the proper dimensions. Unfortunately the material wasn't suited to the application, and the carbon fiber couldn't withstand the impact required.

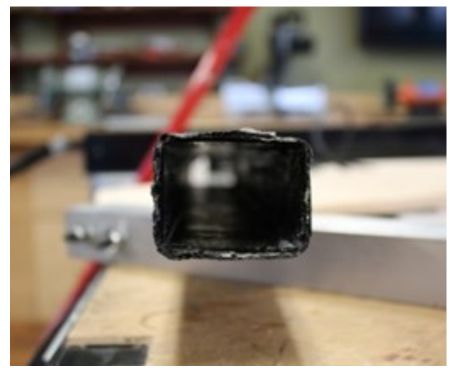


Rectangular carbon fiber tube:

We created three pieces of carbon fiber rectangular tubing for the intake mechanism of our 2014 robot.

The "intake arm" on our early prototype robot was made by welding three 28" pieces of aluminum tubing together. In our final robot we replaced approximately 20" of the aluminum tubing (from the middle of each of the three pieces) with custom built carbon fiber tubing.

Carbon fiber tubing was constructed with an inner cross-sectional dimension equal to the outer dimensions of the aluminum tubing. Each carbon fiber tube was about 26" long and each replaced approximately 20" of aluminum by overlapping aluminum lugs at each end.



Mixed Materials:

In 2017 we have also combined the use of sheet metal and carbon fiber – we created doors for our new robot cart by embedding our team logo into carbon fiber – a great look, and a great combination of two of our manufacturing strengths!

The Highlanders

CNC Plasma Cutter

Engineering Design

This year we have used our CNC plasma for many things. Some of the very few things we made were the vortex bottom, the shooter mount, the vortex belt protector, the camera mount.

One of the most interesting things about the plasma is how it interacts with other machines in the shop. One of the other machines we use the most with the plasma is the metal bender. When we were making the camera mount and the vortex belt cover we used the bender. most plasma parts are bent. The advantage to this is that we can create odd shapes then bend them to create parts that couldn't be made out of simple tube stock. Another machine is simple, but effective. The drill press! The thing about the plasma is that it doesn't manufacture holes all that well. So we use the drill press to clean these up. If it weren't for the drill press we wouldn't be able to put bolts through our plasma parts. The plasma is a extremely inventive machine that allows us to do amazing things. One of these things is the carbon fiber robot cart door of which you can read more of in the carbon fiber section.

The CNC Plasma jet was an off-season project in 2014. Completed just before the 2015 build season started, it was a journey of discovery through the fall.

CAD Design

Designed on our own, based off of other designs we saw on the internet. We customized it for the type of plasma cutter we already had and for the dimensions we wanted.

Basin

We were able to bend the metal to make the basin on our own metal brake. We welded the corners, then tack welded aluminum strips widthwise on the bed. Stainless steel strips that run across the aluminum ones support the metal to be cut and are sacrificial; cutting the part will also cut the steel, but these can be easily replaced.

Software

When we started using the plasma cutter instead of the expo marker, we realized that the software we had created lines, not tool paths. The difference is that, since a plasma stream is wider than a single point, the cutter needs to have offsets that are different for inner and outer cuts. The software we use now is SheetCam, who is also a sponsor for the team.

We have used our CNC Plasma Cutter successfully for cutting robot parts as well as some fun items.

Final Product

We have used our CNC Plasma Cutter successfully for cutting robot parts as well as some fun items.