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The All-Plastic Robot

A case study in organizing an FTC team around CAD/CAM

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About The Presenters

- Gaige Moore
  - Junior at Pope John XXIII High School in Sparta, NJ
  - Lead builder/programmer/driver on FTC Team 247 “Reboot”
  - 2015 Dean’s List Finalist
  - Proposed and spearheaded the all-plastic robot concept

- Steve Pendergrast
  - Coach/mentor of four Pope John XXIII High School teams including team 247
  - Ten years mentoring in FLL/FTC/FRC/Zero Robotics
  - Teaches AP Physics, Honors Robotics, and sometimes other topics at PJHS

CONTACT INFORMATION

- Copies of Slides and Questions or Comments may be sent to:

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One Word: PLASTIC!

- Early in the 2015/16 season I proposed a radical idea:
  - Ditch the kit of parts entirely for all structural elements
  - Design and fabricate every structural part of the robot using CAD/CAM
  - Use a CNC router and 3D printer to fabricate all structural parts
  - This includes custom gear boxes, rack and pinions, etc.
- At first, some team members were skeptical
  - Would it be strong enough to withstand competition?
  - Would it take too long to design parts that way during a season with short deadlines?
- My mentor made a small chassis prototype using ¼ inch HDPE plastic, and could literally jump up and down on it

Demo of the Robot

- We'll demonstrate some of the capabilities of the final robot now
- During this talk we'll show how some of the mechanisms evolved over time, and how our team was structured

Advantages of Plastic

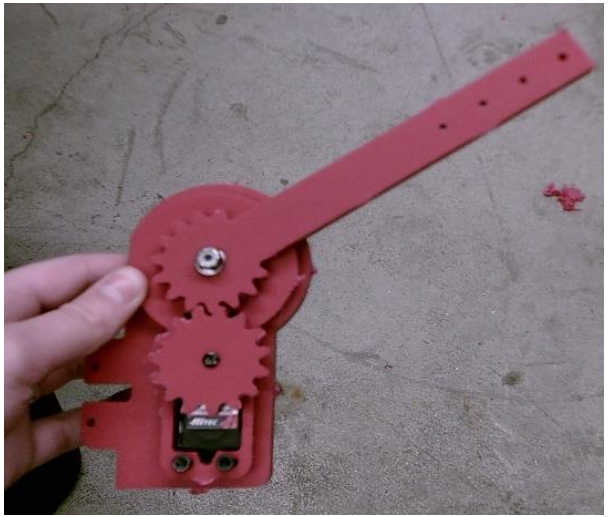
- Cost
- Ability to customize parts exactly
- Fabrication and assembly time
- Repairability
- Focus the team on DESIGNING rather than TINKERING
- ESD is no problem at all for the all plastic robot

Advantages of Plastic

- Cost
  - ¼” HDPE was good for just about everything
  - It costs only $4 per square foot
  - A square foot of HDPE replaced $30 to $50 worth of Tetrix structure
  - But for specialty parts the savings is even greater
    - An HDPE gear uses under 50 cents of plastic
    - Replaces a $27 Tetrix metal gear,
    - or an $8 tetrix plastic gear
    - (But our plastic gears were way more robust since we could create large sturdy teeth).

Advantages of Plastic

- Customizability
  - Tetrix metal has lots of holes, but let's face it: they're never quite in the right place!
  - Gears: we can make any ratio we want, exactly as needed for the given design.
    - We can also build extensions and actuator supports directly into gears as shown here



Advantages of Plastic

- Fabrication and Assembly time
  - The CNC router could cut tons of parts in a short period of time, and they were accurate to within a few thousandths
  - We built 8 versions of the robot. When a new version was ready to construct, the entire chassis and all mechanisms could be assembled by a few students in a single build meeting
  - The entire chassis is held together by only 12 screws

Advantages of Plastic

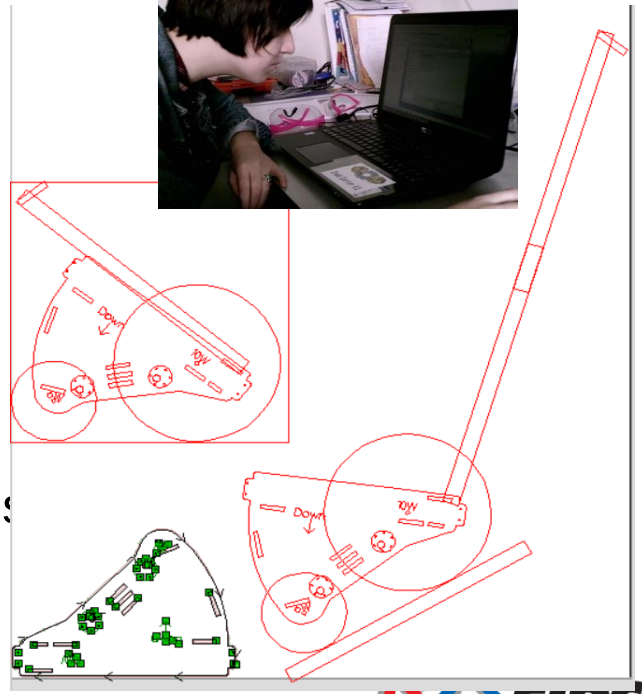
- Reliability
  - Screws self-tap into properly sized holes and very few need nuts
  - Screws don’t come loose from vibration, it’s like every one is using a nylock nut
  - Gears never come unmeshed because the axle holes are exactly spaced to be perfect
  - HDPE is naturally highly impact resistant and springs back to its normal shape after any impact likely to happen in FTC

Advantages of Plastic

- Repair
  - The HDPE plastic is quite tough and repairs were not often needed
  - But for parts under a great deal of stress like pinion gears, we could simply cut spare parts and have them ready to go
  - Most repairs took only minutes

Advantages of Plastic

- Focus on DESIGN, not TINKERING
  - Although some quick prototypes were made from time to time, most mechanisms were designed using a 2D design program from scratch
  - This forced team members to carefully think through issues like spacing, size, gear ratios that would be required, etc.
  - By the end of the season, almost every team member had learned to use at least one and often two or three 2D and 3D design programs
  - They learned to think like real Engineers!



Advantages of Plastic

- ESD was never an issue
  - Many teams this year had trouble with electrostatic discharge
    - Lost connection, phone rebooting or freezing
  - The all-plastic robot used HDPE plastic which has very good ESD prevention properties
  - We never had one single problem with ESD. The entire robot was effectively an insulator (other than electronics, which was all buried safely inside)

Disadvantages of Plastic

- CNC Router cut parts are inherently 2D (or 2.5D)
  - By using a Mortise and Tenon system we could design around that in most cases, but it took a little extra thought sometimes
- CNC Router is noisy an requires extensive dust collection
- 3D printed parts can be easy to break along layer lines
- Some students did not want to spend time learning 2D and 3D design programs, they were relegated to assembly jobs, scouting, etc.

What do you need?

- Hardware
- Software

What do you need?

- Hardware
  - Although we have used 3D printed parts in the past, and we prototyped some this season, by far most of the parts were CNC router cut
  - A CNC router such as the CNC Shark from Rockler costs several thousand dollars
  - However, many cities have “Maker Spaces” where you could use large industrial routers for a low monthly fee
  - Sponsors may also have machine shop, and some high schools also have a machine like this in their shops

What do you need?

- Software
  - We used a variety of software products for design
  - Vcarve: a 2.5D CNC router CAD/CAM system
    - Very easy to learn, most students could be making useful parts after a 2 hour training session
  - Geargenerator: a shareware program that can make spur gears and rack and pinion systems
    - Also very easy to learn, and the pay version is low cost ($25)
  - PTC ProE: full featured 3D design and analysis
    - Requires the largest commitment of time but is a professional package used by real engineers all over the world.

What do you need?

- Plastic
  - We mainly used colored HDPE, ¼” thickness. This can be obtained from several sources these days as it is used for cutting boards and playground equipment. Plain white and black HDPE can be found at McMaster Carr.
- Other odds and ends
  - Flame polishing: plastic parts can be nicely cleaned up using a small butane torch or just a propane tank with torch attachment (fireproof gloves and fire extinguisher are a must)
  - Bearings can be made using several techniques, everything from simple nylon spacers to skate bearings worked for us

Team Organization

- Early in the season, training sessions were held to learn 2D and 3D design software
- More than half the team learned at least one package
- Later in the season, more students realized they could contribute a lot more if they learned 2D and 3D design software
- Organizing the team around CNC/CAD/CAM greatly encouraged more learning

Team Organization

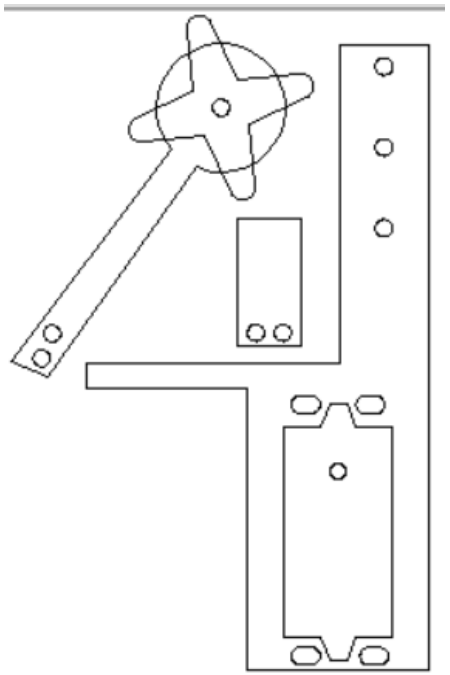
- Typically, a given mechanism had a primary “owner”
- A initial design would be created and reviewed for errors
- The design was then cut, assembled, and tested
- Team members would discuss what changes were needed, and those changes were fed back into a new version
- This process was repeated, sometimes many times

Life Cycle of a Scoring System

- Our “Camper Clamper” was a scoring system for scoring the two preloaded climbers in the basket (under driver control)
- It went through many iterations as we gained tournament experience and shows the power of iterating a design on a CNC file

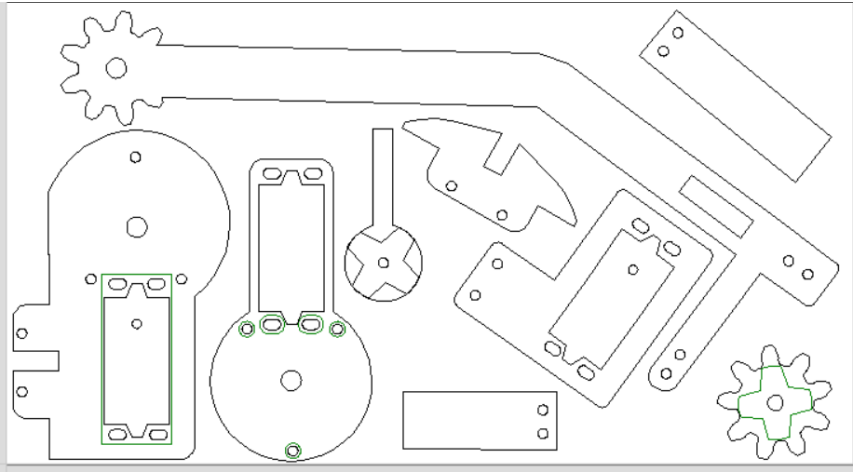
Life Cycle of a Scoring System

- The first version was a single servo that had a short arm that simply flung the two climbers into the basket
- The problem was, it was hard to judge when the robot was perfectly lined up for this fling
- Secondly, the “fling” had to throw the climbers over the light box, which was error prone



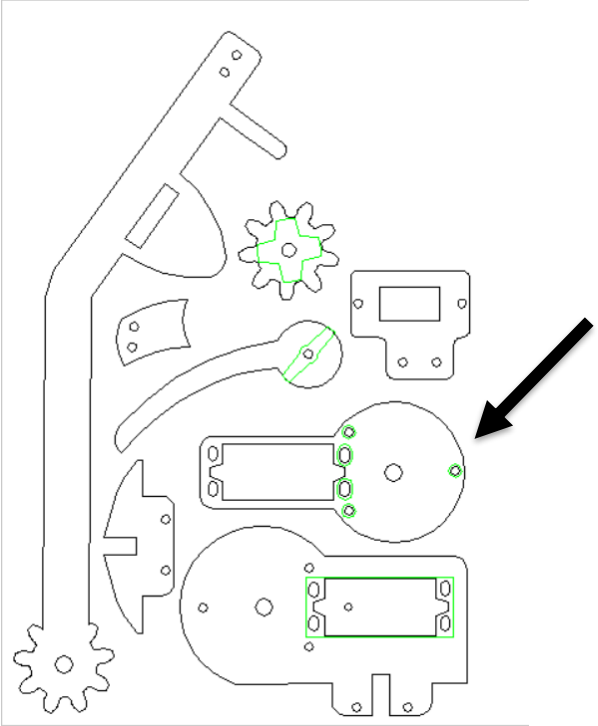
Life Cycle of a Scoring System

- Fast forward a few iterations, now there is a second servo mounted at the end of a long arm that can reach right over the light box
- The second servo means the climbers can be held until perfect alignment of the robot and basket
- The servo is no longer directly supporting the arm, that would endanger the servo axle



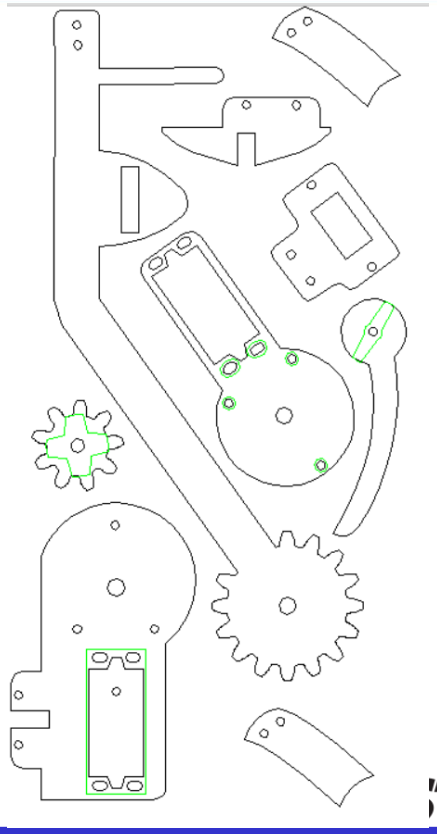
Life Cycle of a Scoring System

- Version 7: the servo at the end of the arm is now swapped for a tiny mini-servo to take load off.
- The design has become more stylish, with gentle curves and rounded corners
- Note the servo spacer (arrow) which makes the gears mesh more perfectly



Life Cycle of a Scoring System

- Version 8: This final version elongates certain parts to make climbers more secure and makes other tiny adjustments to improve performance
- The servo is now geared down 2:1 to allow more lift capability
- At the NJ State Championship this final mechanism worked 100% of the time



Life Cycle of a Scoring System

Here is the Final version:

Custom Gearbox Development

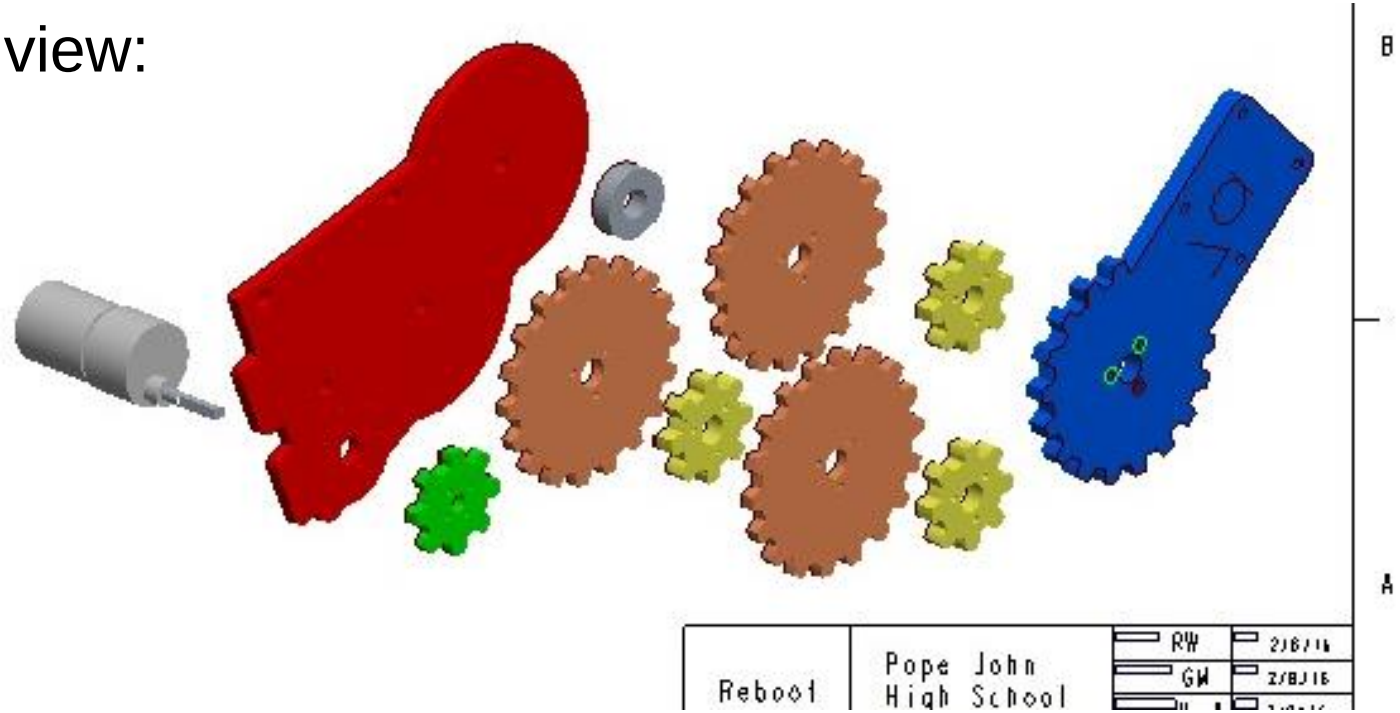
- One of the most complex mechanisms was our custom gearbox that can lift the entire robot's weight
- In the first version, the gear teeth were made too narrow, and the final small gear that had to lift the entire robot's weight would shear off after just a few lifts

Custom Gearbox Development

- Once the problem was identified, all the gears were redesigned to be “fat and square” and screw holes were moved away from the teeth
- The gear ratio was also adjusted higher because the initial prototype was straining to lift the robot’s weight
- Only three versions were required to get it right
- The final version reliably lifted the robot dozens of times between practices and tournaments with zero failures, no gears coming out of alignment, no gears stripping or failing

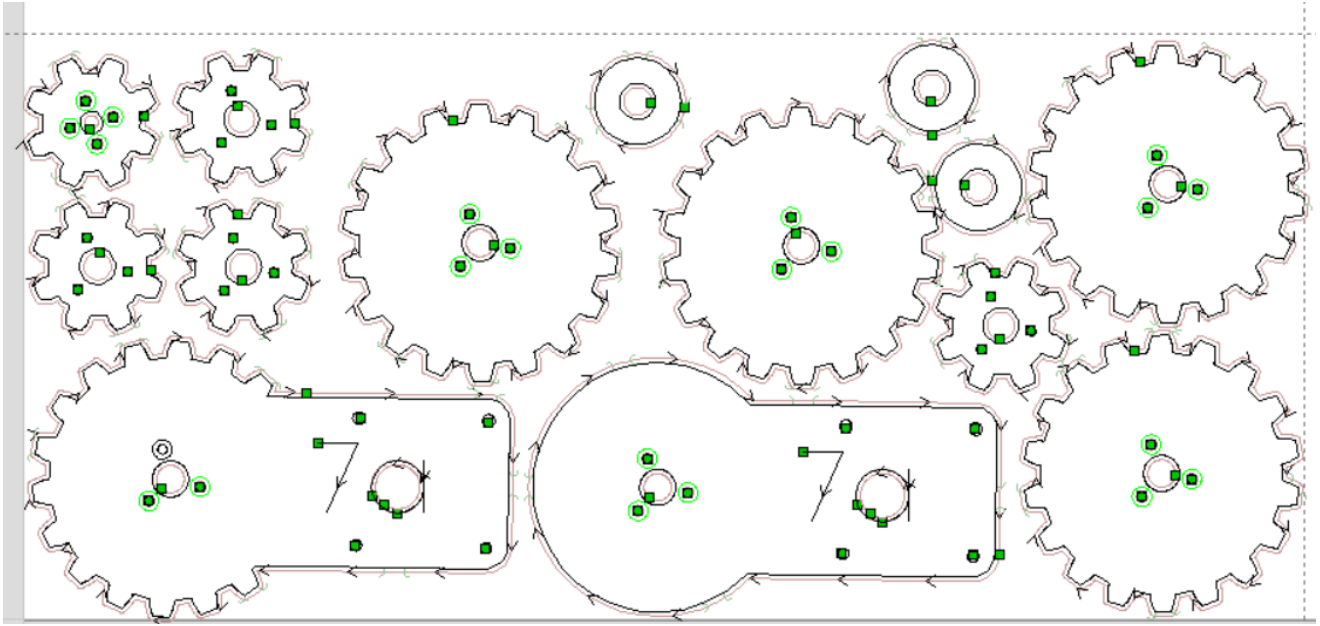
Custom Gearbox Development

PTC exploded view:



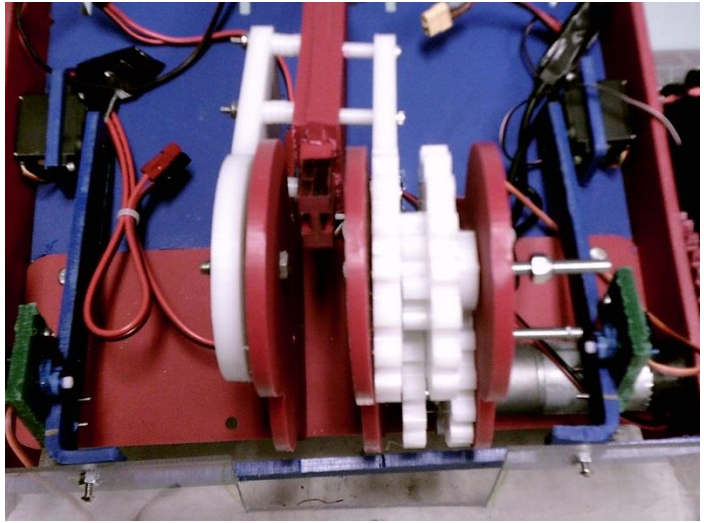
Custom Gearbox Development

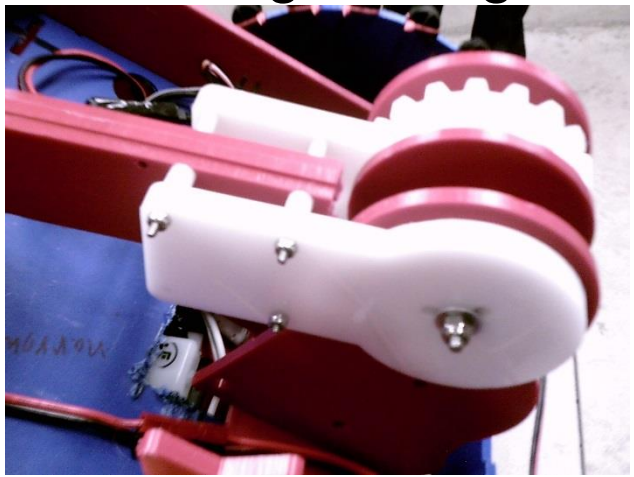
Vcarve file for gears and spacers:



Custom Gearbox Development

Final Gearbox: 25.6:1 ratio, 4 stages, using 60:1 gearmotor, supporting a custom rack and pinion arm for grabbing the bar





Conclusions

- The all-plastic robot was a transformative experience for our team
- Team members focused on software training and iterative design instead of tinkering and patching as we had often done in past seasons
- Plastic had many advantages, from cost to ESD resistance
- The robot also looks striking and got many compliments from judges, mentors, and other teams