Washington State University

Manufacturing Processes

Hands-On Project Report

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ME 310

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Introduction

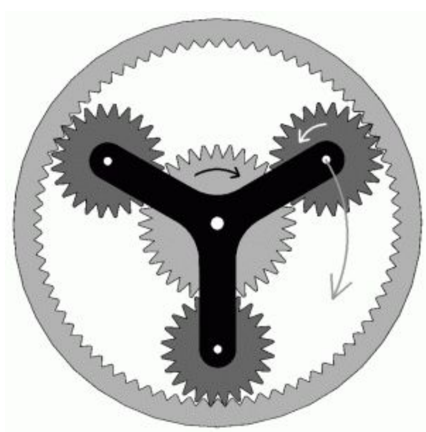
The goal of this project was to design a simple, functional and manufacturable 'gearbox' or gear system for the parallax robots used in ENGR 120. The gear system design needed to increase the speed of the robot by 2-6 times its original speed, preferably with the capability of adjusting the speed. It also needed to be easily manufacturable so that anyone could be given the part files with the assembly instructions and be able to build and assemble it without issues. We wanted the design to be effective at increasing the speed of the robot while maintaining as much stock geometry as possible including the cart height and track width. These were the main considerations taken into account when designing the gear system for the robot.

Progression of Design Ideas

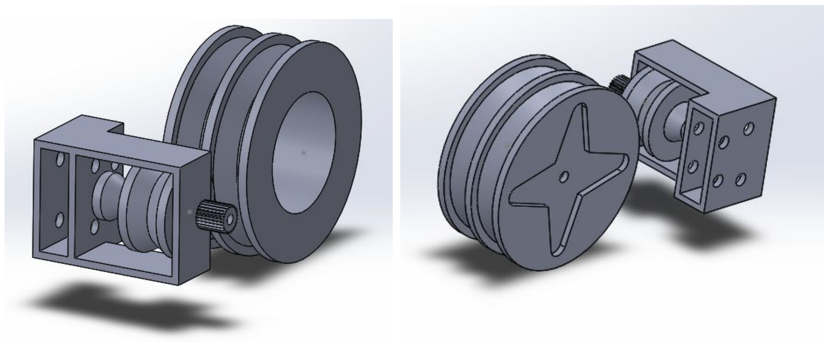
Design ideas rarely work out perfectly on the first try. Even with careful planning and consideration of potential issues, modifications are almost always needed to solve unexpected problems and make design improvements. Just as Thomas Edison did not develop the winning light bulb design on the first try, our group made several modifications to our initial design before reaching a functional design that met all requirements with optimal design features.

Initially, our group came up with three different design ideas:

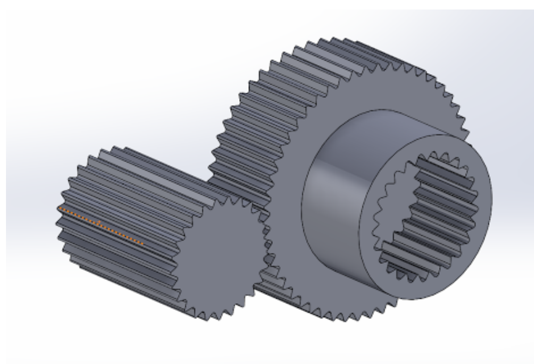
1. A planetary gear system



2. A bicycle type gear system with rubber bands for adjustable gearing



3. A simple, two gear system with various sized gears that can be swapped out to adjust speed

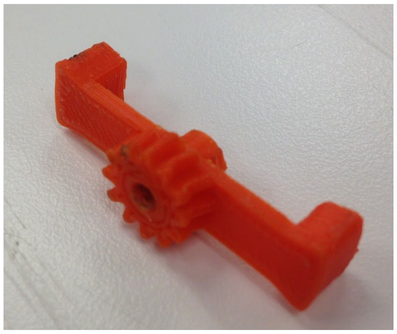


We decided to give each idea a try, so members in our group began modeling each of the designs in SolidWorks to assess the feasibility of each.

The planetary gear system idea was quickly ruled out because it involved many different parts that would require a complicated mounting system. The bicycle gear system idea offered a convenient method for adjusting the gear ratio, but the potential for slipping and gradual degradation of the rubber band presented several complicated issues. Ultimately, after considering each idea, we decided to pursue the simple two-gear system idea.

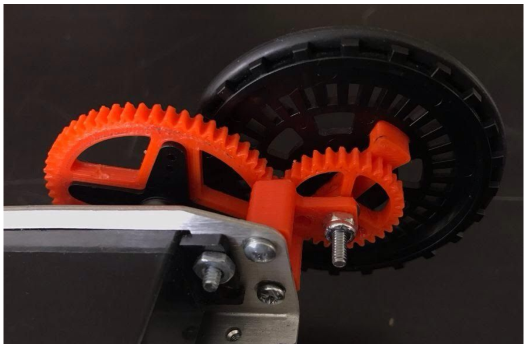
We initially planned to print a large gear that would fit over the servo horn with tiny printed teeth to prevent slipping. Unfortunately, we found that the tolerance on the 3D printers would not allow for such precise printing. Our next idea was to simply print the gear with a tight hole that would press fit onto the servo output shaft. This idea worked well, but after assembling the gear system a few times, we noticed that the press fit was beginning to wear off the splines on the shaft. Since we wanted a more durable system, we came up with the idea of fitting the large gear over the existing servo arm as shown to avoid damage to the servo.

We faced a similar issue for the attachment of the wheel onto the small and medium gears. Hoping to again avoid press fitting, we decided to add extra material to the small and medium gears so that they would grip the wheels.



Finally, to minimize the amount of material needed to print the gear assembly, we cut out sections of material from the body of our gears, switching from a solid design to a spoked design. This modification did not alter the performance of our gears, but simply eliminated material, thus reducing the overall cost of the assembly.

Our final design includes a large gear that screws through the existing crosspiece, into the servo horn; a small and medium gear which can be interchanged to adjust the speed, and a mounting piece containing two holes for mounting either the small or medium gear.



Design Features

For our robot we kept to the guidelines and produced a simple but effective gear system. In fact, its simplicity is one of its most valuable features that sets it apart from other designs. To start off, all of the new parts in the improved system are 3D printed thermoplastic. The thermoplastic used for these parts was Polylactic Acid (PLA). This material is low cost compared to many others and is used for many shapes and sizes. The applications of this material is extremely versatile.

This of course means that our group only used one machine to create this gear improvement and that is the 3D printer. This should make preparation of the robot kits for the ME 201 class very simple. Each kit would contain a total of only six gears, two printed mounting plates, and six additional screws. Another perk of this gear kit is that all of the screws are Philips head and are roughly the same size as the screws in the original kit. There were only six total additional screws needed for the gear kit. Also, only one tool is needed to install the gear system, a Philips head screwdriver, which will make the assembly process faster. Our group was able to install the new gears in only just five minutes, so for someone following our assembly instructions it shouldn't take any longer than ten minutes to install the gears and speed up the robot. The assembly is easy and again requires only a screwdriver. There are no glued parts on the new design which makes our design fast to assemble, allows for disassembly, and leaves little room for user error.

The design of the gears was well thought out and improved to utilize minimal material and increase the speed of the robot without affecting the functionality. The low amount of material used in the design makes printing of the gears much quicker of a process and keeps the cost of production lower. We estimated the cost of this whole project and its development to be less than five dollars. The design of the gears also increases the robot's speed. There were two sets of gears printed for the new gear system so there could be two different speed settings. The medium sized gear increased the robot speed by a factor of 1.89 and the small gear increased the speed by a factor of 4.13.

No matter which speed setting is installed though, the functionality of the robot will remain the same. The new gear system does not change the height of the robot so the light sensors will work just as well as they did originally. In fact, everything about the robot will still function as it originally did only now the robot is faster. Our group is very proud of its design and accomplishment of meeting all of the goals set for the new design.

Design Testing

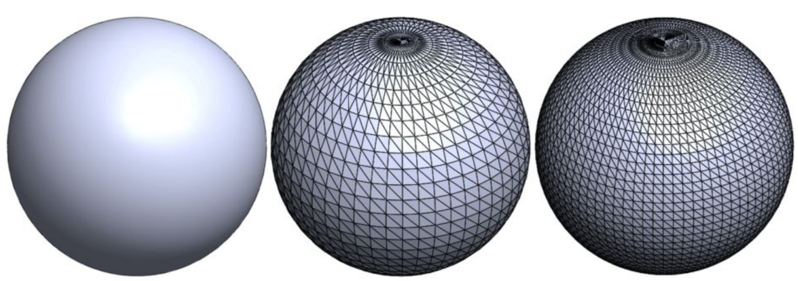
To check the validity of our design we first verified that the robot would move under its own power with the new gear system in place. After seeing it was capable of moving without damaging any part of the robot, we set up a 4 foot long straight path marked by tape on a table. We used a stopwatch to check how much time it took the robot to cross the 4 foot length starting from rest. This was done two times with each gear setup and with the gear system removed. The experimental results for the speed ratios were slightly under the theoretical values, likely due to friction and the required torque for the higher gearing.

The results of the speed tests are shown below.

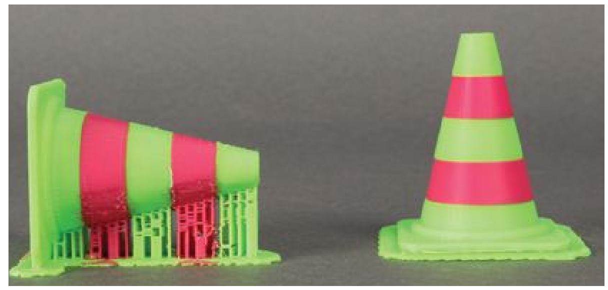
	no gear system	medium gear (mid speed)	small gear (high speed)
time trial 1 (sec)	8.16	4.43	2.02
time trial 2 (sec)	8.38	4.42	1.98
Avg. time (sec)	8.27	4.425	2.00
avg speed (ft/sec)	0.4837615	0.903955956	2.0002
Experiment speed ratio	1	1.868598291	4.1346819
Theoretical speed ratio	1	2	5

Fabrication Instructions

All parts for the final design, except for metal hardware, were fabricated using an Einstart-S desktop 3D printer. The einstart printer utilizes fused filament fabrication where a continuous thermoplastic filament is extruded through a 0.02 inch diameter nozzle. Using the Cartesian coordinate system, the printer lays down a shape in the X and Y axis. The print bed moves after each layer in the negative Z axis as the part is created.   For this project, SOLIDWORKS was the CAD system of choice and with each part an STL file was saved. STL stands for STeroeLithography or Standard Triangle Language and breaks down geometries into a series of triangles, whereas the more triangles there are, the higher the resolution (as shown on the left). When designing a part for 3D printing, there are factors that must be considered such as time/material, tolerancing, and support material. Due to certain geometries, such as arches for example, excess material must be laid down to



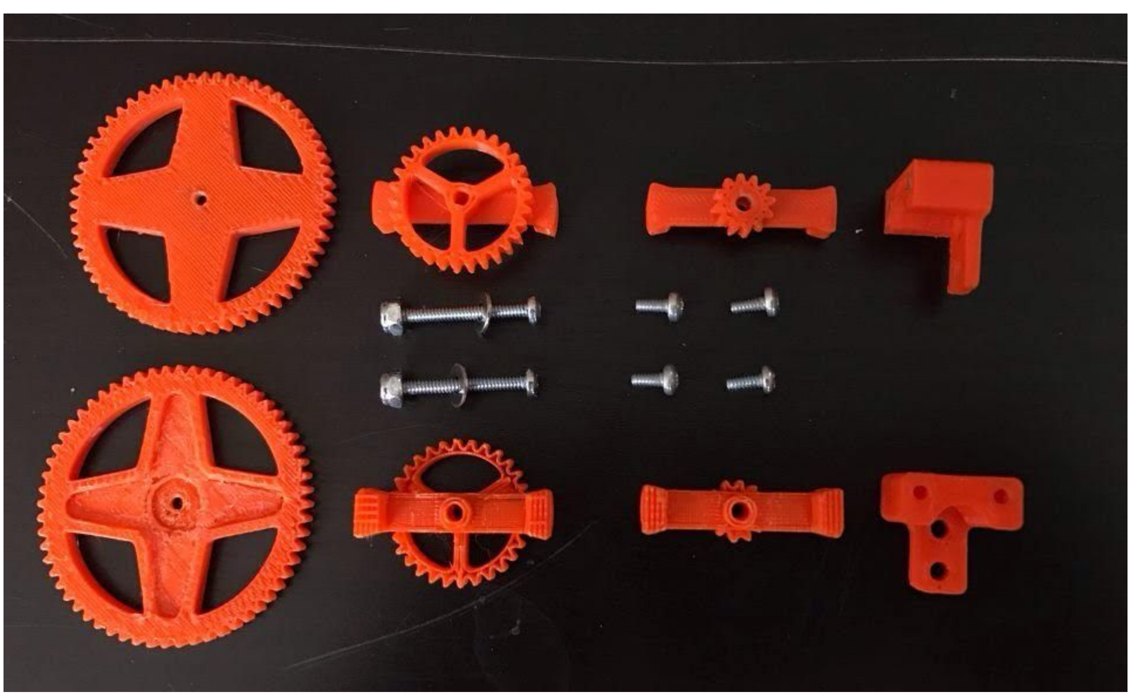
support the structure. Support material not only increases print time and material but also is difficult to remove. For this reason one must visualize the possible different orientations that will minimize support materials. It is shown in the figure to the right that rotating the cone 90 degrees eliminates all print material.



Using 3dStart, which is the program that corresponds with Einstart 3D printers, the parts can be placed and saved as .gsd files. When creating .gsd files parameters such as printer speed, extrusion thickness, and nozzle temperature can be altered and affect the quality of the print. For the Einstart 3D printers, the preset setting of "standard" quality was used. After uploading the .gsd file to the printer the part is quickly printed and can be added to the tangible assembly of parts. In some cases, support material cannot be avoided and can be removed through the x-acto knives, files , or the squeezing of pliers.

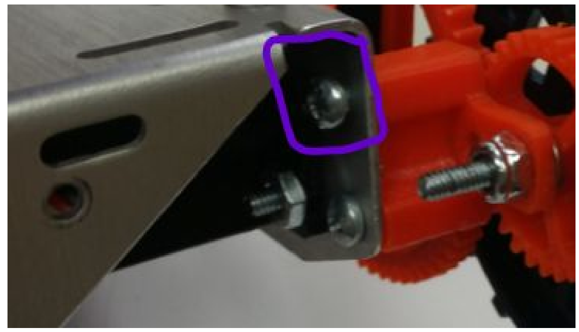
Assembly Instructions

The final design for this project utilizes several parts that are not included in the "stock" robot. These additional parts (pictured below) include: 4 (4-40 x ⅜ in) machine screws, 2 (4-40 x ⅝ in) machine screws, 2 lock nuts, 2 washers, 2 large gears, 2 medium gears, 2 small gears, and 2 mounting plates.



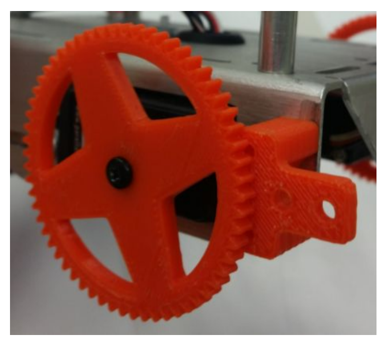
None of the additional parts were created with threading, all of them will need to be threaded using the screws provided. There are a total of 2 mounting plates, each with 2 holes for mounting onto the robot and 2 holes used for mounting the small or medium gears.

This image of the mounting plate shows both where and at which orientation the mounting plates will be threaded and screwed onto the robot frame. Both mounting plates will need to be threaded and screwed onto the frame from the inside of the robot as shown (with the 4, 4-40 x ⅜ inch screws). The wheel mounting slots of the mounting plates should be pointed away from the robot frame.



After the mounting plates have been attached, the 2 large gears need to be connected to the servos. The large gears have been designed with cross slots in them. These slots allow the servo arms to fit snugly into the gears securing them. These slots also give the large gear the correct spacing to be able to interlock with the small/medium gears.

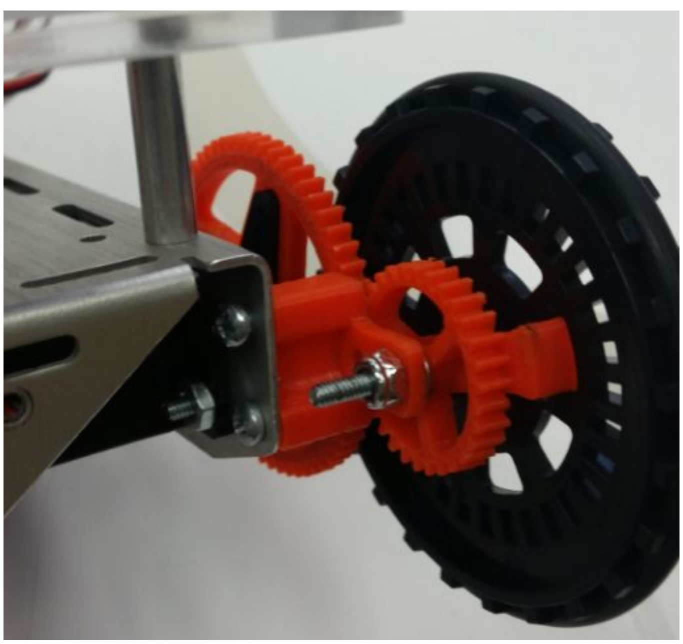
The servo arms should be fit inside of the large gears and then attached to the servos. From this position, the screws that were previously used to attach the wheels directly to the servos should now be used to secure the large gears to the cross pieces. The image on the right demonstrates what the large gear will look like after attaching it to the servo.

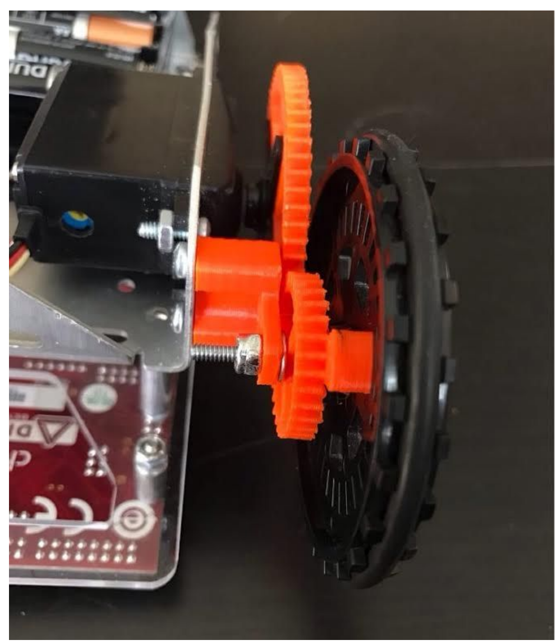


The next step in the assembly process is to attach the gears (either medium OR small) to the wheels and then to the slot on the mounting plate. The small and medium gears are designed with arms that fit into slots in the wheel providing additional points of attachment. This part of the assembly process will assume we chose to use the small gear.

The small gear will be attached to the wheel by first fitting the arms into the corresponding slots on the wheel as shown. The 4-40 x ⅝ inch machine screws will be threaded through the wheels and gears from the outside of the wheel (pictured above). Next, a washer should be placed on each screw, making contact with the small gears. These screws should then be threaded onto the holes in the mounting plates closest to the servos (if using the medium gear, use the holes farther away from the servos). Lastly, the lock nuts should be fitted onto the screws from the opposite side of the mounting plates which should then be tightened. Make sure to not tighten the wheels and lock nuts too tight, otherwise the wheels might create too much friction and move sub-optimally.

Once the gear system is assembled and the robot is ready to run, the code for the servo speeds must be made negative so that the wheels will run in the forward direction. If not, the robot will run in reverse. Alternatively, the servo motors could be swapped, left to right. In this case the plug-ins for the servos would also need to swap positions on the plug-in board.





The pictures above show the assembled gear system (shown with medium gear attached).

Conclusion

To sum up our project, the main goal was to create gearbox for the robot in an effort to increase the robot speed by 2-6 times the original speed of the robot. Functionality and simplicity were important goals we aimed for during the gearbox design creation. As we had hoped, our gear design allows the robot to speed up original robot. It has been recorded that the robot can now operate more than four times faster with our gear system. Formulating the design in SolidWorks and then printing out the parts required us to be precise and accurate in measuring and designing accordingly. Also, we have been aware of the imperfections of 3D printing and we had to keep in mind the limited tolerance of most 3D printers. Ultimately, after making several design modifications, we have developed a simple gear system design that is cheap, fast, and simple to assemble, yet effectively speeds up the robot with adjustable gearing.