Mechanical Design Report

ENGR3390 : Fundamentals of Robotics

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Team Alpha

Phase I - RC Robot Race

1 Summary

In the first phase of the development of the ground rover, our team developed a high-speed teleoperated vehicle in order to navigate the perimeter of the Oval between the Academic Center and the Campus Center of Olin College.

1.1 Design Philosophy

The primary motivation behind designing the robot was to create a readily maneuverable, high-speed robot. To this end, we introduced transmission components, which was a non-trivial increase in complexity given time and resource constraints: the transmission elements have been – from the beginning of the development phase – the greatest risk factor in the robot. In spite of this, the team was daring enough to take risks for the potential gains; we were ready to face the challenges and accept the failures for a better learning experience.

1.2 Performance

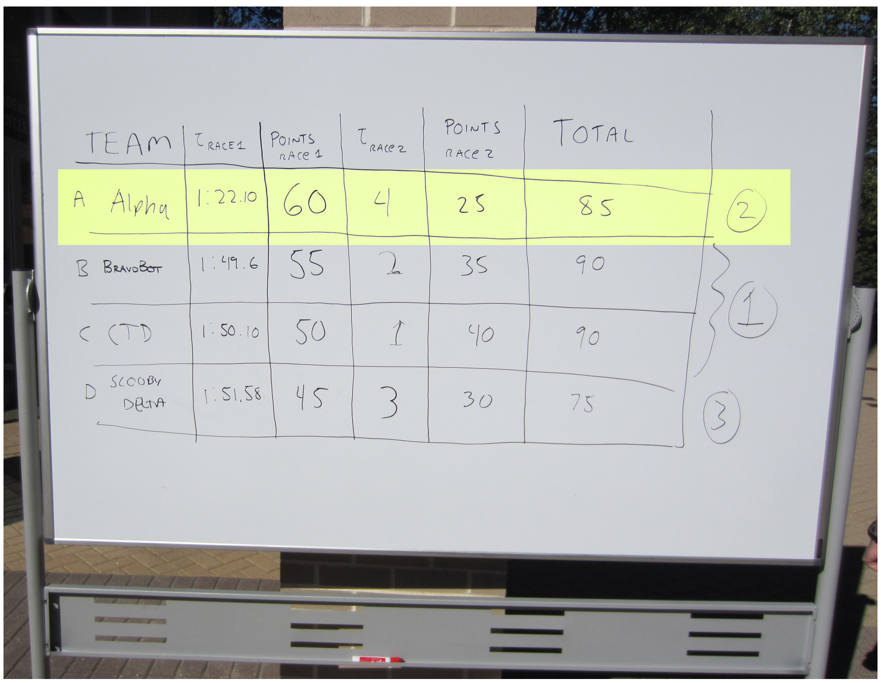

Figure 1: Record of the scores and time per lap during the two races; highlighted are relevant entries for Team Alpha.

The effect of transmission was quickly apparent - our robot held an immutable first-place throughout the first round of the race, 33% faster than robots without transmission[1]. Unfortunately, during the second round, the robot retired as it cleared about three quarters of the track. From later analysis, it became apparent that we broke the internal gearing for two of the motors, which we attribute to over-torquing the motors. We speculate that the accumulated stress over transmission components ultimately caused the chain to get caught, which laid incredible burden on the motors and ultimately broke them.

2 Design

As a result of taking upon more complexity in our design, we have undergone a lot of different iterations on our robot to cope with different issues throughout the designing process before settling on the final design.

[1] 1:22:10 to 1:49:06 (second-runner)

2.1 Initial Design

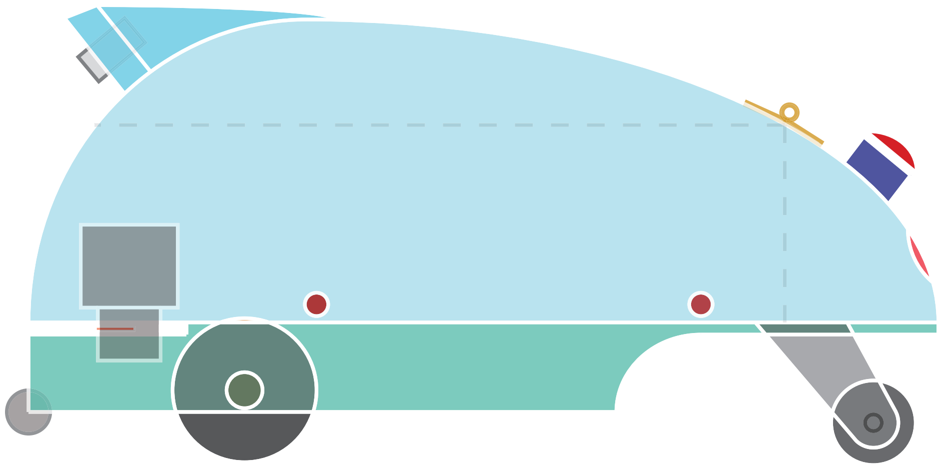

Figure 2: Side view of the conceptual figure for our initial design, denoted *"TearDrop"*

Initially, we planned on creating a three-wheeled robot with coupled motors on the frontal wheels to achieve greater speed, and the back caster-wheel for balancing. Inspired by aerodynamic and elegant design, we called this robot *"TearDrop"*; by creating a minimalist, compact design, the robot would have higher maneuverability.

In spite of its advantages, there were lasting concerns about the visual limitations on the LIDAR and difficulty of fabrication. Most prominent of them all was the issue of maintaining the center of gravity within the robot such that it would resist against flipping to damage expensive equipments – especially under harsh conditions such as sloped planes, or turning. While these concerns could be overcome with precise engineering, it was impractical to consider this option for a robot purposed to last through semester-long development. Thenceforth, we reinitialized the design for a four-wheeled rover instead.

2.2 Master Modelling

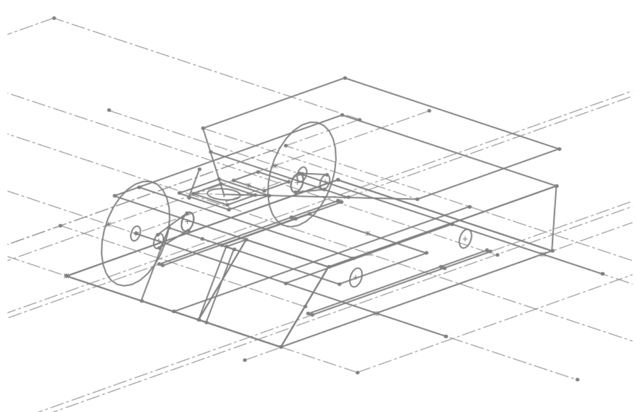

Figure 3: The *master model* of our robot assembly.

Even after transitioning to a four-wheeled rover, some challenges still remained: in order to fit the hull components into the provided amount of plywood sheet area, it was critical to parametrize the model such that the dimensions can be adjusted as needed. In pursuit of this goal, we have been introduced to the concept of *master modelling* – in essence, the technique is to base the dimensions on a single reference document, and create parts based on this ”master part”. This allowed for some degree of parallelization in terms of designing the parts, as the details of the part wasn't too concerning to the overall assembly as long as the dimensions matched. Most importantly, however, it also served as a clear guideline of how the parts were to be designed.

2.3 Final Design

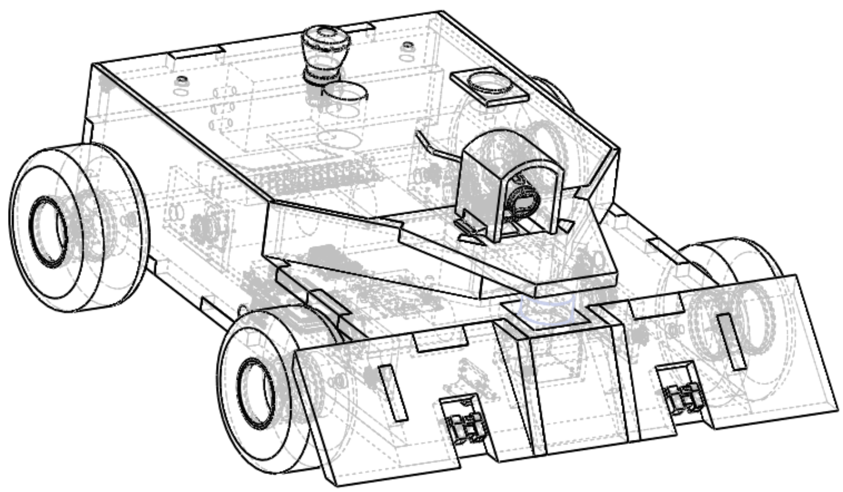

Figure 4: Final Assembly

Our final design was largely a minimalistic robot that focused on function, after which the shape was adapted to fit the function; in order to maximize resistance to environmental hazards, only a bare-minimum number of holes were drilled into the hull to accomodate electrical interfaces such as the E-stop and voltage monitors.

As for sensing, we provided a 270° clearance for the LIDAR[2] in order to take full advantage of the powerful distance-sensing. In addition, we two infrared sensors at an angle at the front plate of the vehicle to prohibit the robot from falling down the stairs, as well as a basic obstacle-avoidance agent to protect against collision; sonar sensors were placed on the sides for similar purposes.

[2] According to specifications, the LIDAR spans 240° for up to 5 meters in range.

2.4 Hull

Figure 5: Hull

In designing the hull, we concentrated on having maximum strength with least excess materials; another important aspect, naturally, was aesthetics. The front bumper were extended sideways to serve as basic wheel-guards, although we plan on augmenting this feature for further iterations. Moreover, the hinge on the split back-plate facilitated easy access to the entire internal circuitry

In terms of fabrication, our hull was mostly joined via Finger Joints and Mortise & Tenon Joints, and the gaps were filled with Wood Filler to ensure protection against environmental conditions. In addition, We have designated specifically designed mount plates for sensitive electronics such as the LIDAR and cameras so that they would not only be waterproof, but also be resistant to external impacts.

2.5 Transmission

Figure 6: Internal view of the transmission, placed within the assembly.

The distinguishing factor of our robot is the transmission. As shown in the above diagram, we sought to achieve greater speed by implementing a 12 : 8 Gear Ratio from the motor to the wheel. In order to minimize the effect of friction, we supported the shafts with ball bearings, which were then affixed to sprockets with piercing spring pins. The motor was firmly mounted to the hull so that its rotation would be invariant to the motion of the robot.

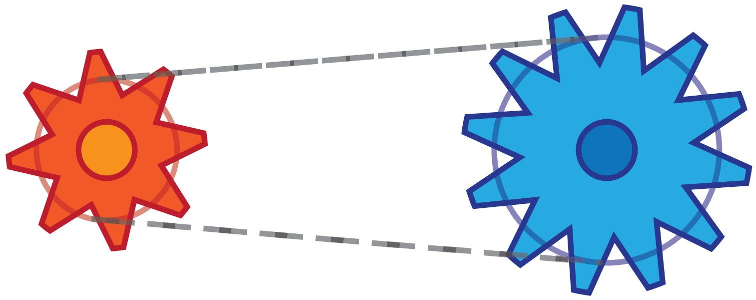

Figure 7: Supplementary diagram for the 12 : 8 Gear Ratio connected via chain drive; effectively achieving 1.5x speed multiplier.

The basic idea behind the transmission was the chain drive, connecting the two sprockets with precisely-dimensioned chains. In retrospect, the absence of chain tensioner in the transmission assembly was likely detrimental to the system, as we speculate the chain's jamming to be the most probable cause of the system failure.

2.6 Wheel

Supplied foam within the wheel was unable to support a robot weighing 22 pounds: as it collapses, the contact area of the wheel to the ground would increase.

Figure 8: Under the anticipated load of 25 pounds, the wheel was blatantly collapsing, which raised concerns about frictional force and overloading.

This causes greater frictional force counteracting the motion of the robot, which would not only reduce the efficiency of the robot's maneuvers but also cause a heavier load on the motors.

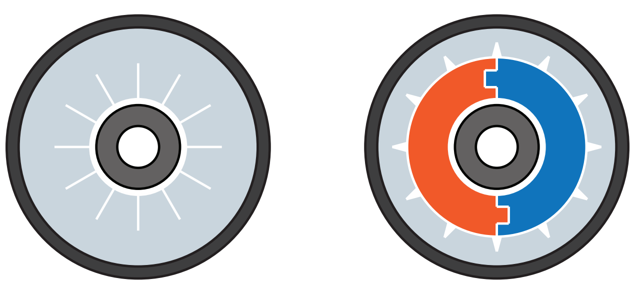

Figure 9: The wheel was reinforced by a 3d printed core, mated via housing joint and held together through tension by the compressed external foam; similar architecture was later adopted by a number of other teams.

In order to combat this, we inserted a 3d printed core for the wheel and wrapped it on the outside with the foam. This would maintain the intrinsic shock-absorption by the foam while also reinforcing the structural integrity of the wheel.

3 Narrative

3.1 Race I : Individual Race

Figure 10: Snapshot of our robot during the first race, about to enter the obstacle portion of the course.

We had finished assembling the robot the day before the race, when we got the Sabertooth Motor Driver as replacement for the malfunctioning RoboClaw. We had undergone testing sessions during the day as well as night; consequently, on the race day, the robot had covered a fair bit of distance, which assured the team of its stability; given the amount of time we had spent practicing driving the robot, the team was quite confident about its maneuverability as well.

On the race day, our robot was the only one with the comparative advantage of having a 12:8 multiplier for the transmission, which would greatly enhance the speed. We had concerns because of the relative weight of our car, but we were mostly confident as the race track was primarily flat, and large enough to be linear in small scales.

We went first, and held the first place throughout the race with the lap time of 1:22:10, a staggering 27.5 seconds of difference with the second runner.

3.2 Race II : Competitive Race

Figure 11: Snapshot of our robot during the second race, with a strong start.

As anticipated from the first race, our robot again started strong, and seemed to be in a good shape – essentially, it was racing against itself: victory seemed to be decided. The robot maintained its position in the first-place, so far away in the lead that the other robots didn't seem of much concern. With the three robots tailing right beside each other back in the course, the robot was simply cruising through the course like a breeze.

As the robot neared the finish line, teammates grew excited in anticipation for a triumphant end to the long journey of making the robot work – the days of building the transmission and sanding the hulls have finally come to fruition. Cedrik was an expert driver by now, and the robot stood the test of time for at least three hours. In any respects, the chances of failure seemed scarce – but if only it were so.

With a hideous sound of a dying motor, the hissing sound as though piercing through the hearts of unsuspecting engineers, the robot was at its last breath; it started to lose its maneuverability, leading itself astray into strange directions. Soon, its other motor died, and that was the end of the race – the harsh load on one of the sides broke the spring pin on the other side as well, and there was no way a single motor could carry the entire robot. The race was over.

4 Teamwork

In our team, the division of labor wasn't necessarily equal. The following PI chart, alongside the accompanying commentary for each of the members, should illustrate my opinion of his/her contributions to the team:

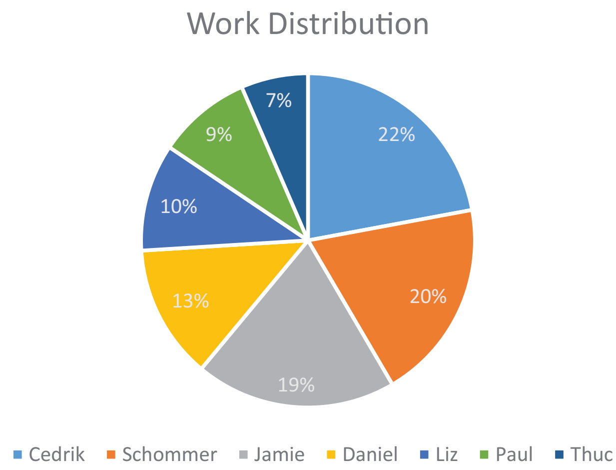

Figure 12: Work Distribution

- Max Schommer Max designed the parametric version of the robot based on *master modelling*, and finalized the hull for fabrication. During discussions, he passionately shared his ideas, and provided valuable insight into a great number of design choices we had made.
- Cedric Kim

  Cedric worked on the preliminary overall assembly and fabrication of the transmission. With his ample experience in mechanical engineering and ground vehicles in particular, he was the driving force behind getting the car to work.
- Jamie Cho

  I partook in overall fabrication of the hulls, most of the electrical wiring, as well as organizing the tasks and keeping the team updated on the progress. I was away for a week due to a conference, but I spent an extraordinary amount of time afterwards in order to compensate.
- Daniel Daugherty

  Daniel collaborated with Cedric in designing the transmission; he also designed the mounts for sensors, and helped readying the hulls before the painting process. He was readily available for tasks when we needed him, and was a dependable member of the team.
- Liz Sundsmo

  Liz partook in designing and fabricating the hulls, as well as actively engaging in most of the discussions and the design process. Unfortunately, she fell ill for the latter half of the project, so she couldn't quite contribute as much.
- Paul Krusell

  Paul was in charge of electrical testing, and partook in fabrication as well. Frankly, he is probably one of the victims of our team's overshooting the workload: the team was constantly chased by time and was often unable to gather around for a length of time to reorganize. As he was also often busy due to external classwork, he couldn't participate as much as the other members.
- Thuc Tran

  Thuc was mostly very involved in the discussions. He had numerous suggestions, although some were speculations that failed to take account of any of the available resources. In spite of the fact that he usually didn't have time to contribute, he was willing to help when he did.

5 Summary

In order to turn this tragic episode into an opportunity for learning, our team decided to fully analyze the cause of the failure of the motor; while we're modifying our designs to incorporate direct drive of the motors, we plan on concurrently continuing the efforts to examine the full cause of the failure of the transmission.

Figure 13: Disassembled Motor

As part of such efforts, we have disassembled the broken motor and inspected the state of the internal gearings. From the figure, the left are right portions of the motor individually operate fine; in the shown planetry-gear connection, however, the sun gears fails to mate with all three planet gears, thereby failing to fully transmit the rotational power.

As for our next steps, from this point onwards, we will concentrate on making a smarter robot that can optimize on high-level path planning and trajectory estimations rather than trying to make the fastest robot.