The Effect of Weight Distribution on a Rover's Ability to Avoid Obstacles

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Introduction

Due to technological limitations, rovers remain to be the primary medium used to research areas that are either uninhabitable or unapproachable. A very important issue many engineers consider when developing a rover is how to avoid obstacles. This is done to ensure that a rover has a long enough lifespan to collect plenty of data, allowing researchers to yield a higher return on investment so that funds can continue to be given. Currently, most rovers use Light Detection and Ranging (LIDAR) sensors, ultrasonic sensors, or some other device used to measure the distance between the rover and the objects in its path. However, automotive makers prioritize the weight distribution of their vehicles to optimize their ability to perform sharp turns. This guarantees that the car has the mechanical ability to quickly avoid any unexpected obstacle found in its path. The goal of this research is to examine whether this concept used in the automotive industry can be applied to a rover. Accordingly, the question to be researched is: how does the weight distribution of a student-built rover affect the rover's ability to efficiently navigate through a given course, in the shortest amount of time?

Literature Review

Developing rovers that can easily navigate a setting while avoiding obstacles is important as it prevents the rover from crashing, shortening their lifespan. Rovers are extremely beneficial for serving various purposes such as providing information on the seafloor or extraterrestrial terrain. However, due to their high costs, ensuring that a rover can safely navigate around its surroundings increases its lifespan, yielding a higher return on investment. Currently, rovers are equipped with various autonomous systems and sensors to make sure that they can sense dangerous obstacles and take the safest path. Most of these obstacle avoidance features are based on Light Detection and Ranging (LiDAR) sensors, ultrasonic sensors, and/or cameras. Even so, there is not much research testing weight distributions and its effect on obstacle avoidance. A student-built rover that can be configured with different weight distributions will navigate a course to test its obstacle avoidance. The course will have turns and corners to help simulate a rover avoiding an obstacle at each turn. Each trial will be timed to determine which weight distribution provides the fastest completion of the course.

Rovers are robotic vehicles that are used to explore, transport, or collect data in locations that are generally difficult for a human to do (*IAU Office of Astronomy for Education*, n.d.). Rovers can come in various forms, with some having six wheels and used for recording visual data, or eight wheels used to traverse rougher terrain and collect physical samples (Zakrajsek et al., 2005). All these rovers are built for one purpose, to help with planetary exploration (Mateo Sanguino, 2017). Although rovers benefit planetary exploration, the technology developed for rovers is also implemented in other fields. For example, during a project known as MANSIO-VIATOR many marine and space related institutes came together to develop a deep-sea rover that faced similar problems that space rovers had (Flogel et al., 2018).

A major feature all engineers and scientists implement when designing a rover is how it will be able to avoid obstacles during operation (Shubhi Katiyar & Dutta, 2019). Currently, rovers are equipped with cameras for local obstacle detection, and LIDAR sensors are used with other software to accurately localize a rover's location similar to global positioning systems (GPS) (Carle & Barfoot, 2010). This allows the rover to detect dangerous objects that may be in its path and avoid them. There are also highly developed models such as the Model Predictive Controller (MPC) which uses information from various sensors to measure the position, angle, and velocity of a rover vehicle so that it may avoid an obstacle while in motion (Gadkar et al., 2022). All these obstacle avoidance features on a rover are important as they prolong its lifespan.

The high cost of developing a rover is a significant issue found in many projects. NASA's Perseverance rover costs $2.4 billion to create and that number is expected to rise to $2.7 billion by the end of the mission to support the entire project including launch services and operation (McCarthy, 2021). Ensuring a rover can avoid obstacles safely contributes to an increase in lifespan, ultimately resulting in a greater return on investment and continuous funding for future projects (Washington et al., 1999).

With new goals set for planetary missions including the Mars sample return and planetary base construction, rovers will need to be designed to travel at much higher speeds than before (Lu et al., 2023). It is in rovers like these where weight distribution will play a role, due to the significance of vehicle stability. As the rover is avoiding obstacles, it may take turns where stability is crucial, especially at higher speeds. In automobiles with a 50/50 weight distribution tires tend to reach maximum grip at the same time due to equal weight on each corner. However, as soon as the weight distribution changes, the vehicle will tend to understeer or oversteer (Racing car technology, 2020). To quantify the weight distribution of a vehicle or rover, the center of gravity must be calculated. This can be done by placing each wheel on a scale and using the set of equations of motion for a standstill vehicle indicated in Equation 1 below.

Equation 1

$$I_{yy}\omega_y = F_{z1}a - F_{z2}b$$

$$l = a + b$$

$$mg = F_{z1} + F_{z2}$$

where F is the normal force, I_{yy} is pitch mass moment of inertia, ω_y is the pitch acceleration, l is wheelbase and m is mass. This will give two values, a and b , where a and b represent the distance between the center of gravity and the front and rear tires (Gori et al., 2024).

Optimizing a rover's lifespan is primarily achieved by ensuring it avoids obstacles. This research project's goal is to test different weight distributions and see how they affect obstacle avoidance. A student-built rover will be designed to achieve different weight distributions. These weight distributions will then be tested to see how they affect the handling of the rover. This will be done by comparing the amount of time it takes for the student-built rover to complete the same obstacle course, which in turn would provide an insight into a neglected but possibly important factor related to the rover's lifespan optimization.

Methodology

An Elegoo line tracking rover kit was built and controlled autonomously via an Arduino Uno microcontroller. The rover equipped with weighted plates housed at the front and rear ends using custom-made 3D printed mounts, navigated a pre-designed course with three different weight distributions, 60/40, 50/50 and 40/60. To determine the rovers' center of gravity, the wheelbase and normal forces of the front and rear axle were determined. The wheelbase represents the length from the front axle of the rover to the rear. The normal forces were determined using a scale placed under each wheel to measure the mass of the front and rear axle. By dividing the mass of an axle by the mass of the entire rover, the mass percent of that axle was found. The weight of each axle was calculated by multiplying the mass of the axle by the acceleration due to gravity. The weight of the axles is proportional to the normal force so long as the rover is horizontal. The calculated normal force of each axle was divided by the total weight of the rover, and the result was multiplied by the wheelbase, as indicated in Equation 2 and Equation 3 below.

Equation 2

$$a = \frac{N_F}{mg} l$$

Equation 3

$$b = \frac{N_R}{mg}$$

In Equation 2 and Equation 3 above, l represents the wheelbase N represents the normal forces, $a$represents the distance between the front axle and center of gravity, and b is the distance from the rear axle to the center of gravity.

A single turn course was constructed using a white posterboard and black electrical tape. To allow the moving rover to track a line, an infrared sensor was mounted on the bottom of its chassis. The infrared light was reflected back to the sensor. Due to the contrast in color from the poster board and the electrical tape, the light that hit the tape reflected with lower intensity. The sensor recorded this information and used it to create a path for the rover to follow. Using this system, the line tracking rover followed the same path, created by the black tape, during each trial. The curve on the course, formed by the black tape, symbolizes a rover turning to avoid an obstacle in its path. To quantify the rover's ability to avoid obstacles, a stopwatch was used to measure the time it took the rover to complete the course. This was done several times for each weight distribution, followed by a calculation to determine the average completion time for those weight distributions.

To visualize the moving rover’s path, a hole was drilled in the center of the chassis where a marker was glued in place, as shown in Figure 1 below. As the rover moved through the obstacle course, the marker mapped its path on the posterboard.

Figure 1

To measure the deviation, the distance between the furthest point from the mapped trajectory to the black tape, a digital caliper was used. This was then repeated for the 50/50, 60/40 and 40/60 weight distributions over several trials, followed by calculating an average deviation value for each weight distribution

Results

A comparison of the completion time of the rover with three different weight distribution set-ups shows that the rover with a 50/50 weight distribution completed the course with an average time of 3.45 seconds. This was then followed by 3.46 seconds completion time for the 60/40 weight distribution, and lastly 3.48 seconds for the 40/60 weight distribution.

Data collected to provide a different perspective of how various weight distributions affected the rover's ability to avoid obstacles indicates that a 60/40 weight distribution had the smallest deviation at 2.20 mm, followed by the 50/50 distribution with a deviation of 3.98 mm and the 40/60 distribution with a deviation of 16.94 mm.

Discussion

A rover relies on various sensors to localize itself in 3D space and form a path that avoids obstacles. If the rover were to deviate from such path, it may not entirely avoid the obstacle in its way. Therefore, the rover with a weight distribution which deviates the least from the course would be the most accurate at avoiding obstacles. Through this study, one may see that a front-loaded weight distribution is favorable for rovers that want to achieve obstacle avoidance. On average, when the rover used in this study had a 60/40 weight distribution, its deviation from the course was 2.20 mm, making it the most accurate at avoiding obstacles. On the other hand, a rear loaded weight distribution, 40/60, deviated the most from the course at 16.94 mm. This makes it the least accurate weight distribution at avoiding obstacles in its path.

The time it takes for the rover to complete the course is also important. For a rover to be efficient at avoiding an obstacle, it not only must deviate the least from the path, but it must do so in a timely manner. Measuring deviation on its own simply tells a person how accurate a rover is at avoiding obstacles. However, measuring completion time alongside deviation quantifies the efficiency and performance of that rover's ability to avoid obstacles.

This study did not give a linear trend on whether having a front- or rear-heavy rover is more efficient at navigating the given course. On average, a rover with a 50/50 weight distribution was able to complete the course in the shortest amount of time, 3.45 seconds. The 40/60 weight distribution had the longest course time of 3.48 seconds, but it also deviated the least from the course. This shows that when course completion increases, deviation from the track decreases, making these variables inversely proportional. This is most likely due to the rover navigating the course at a slower pace; however, it may also be caused by the limitations of the infrared sensor. At higher speeds, some infrared sensors struggle to make precise measurements.

In addition to sensor limitations that might have affected the accuracy of the data collected, the method used to measure course completion time represents another limitation in this study. This experiment utilized a handheld stopwatch that was controlled by a person to record the amount of time it took the rover to complete the course. However, a comparative study between handheld stopwatches (HHS) and electronic timing has found that HHS have a human latency of “0.15 +/- 0.20” seconds (Hetzler et al., 2008). This latency of 0.15 seconds becomes significant when considering the total difference in time spent completing the course for all the weight distributions was 0.03 seconds.

The rover used in this experiment was given a specific set of commands on how to navigate a curve based on the line that it is tracking. This ultimately influences how the rover deviates from the given course, as deviation is dependent on the path formed by the rover. Therefore, the findings of this study can only be applied to this rover as a line tracking rover that has been given another set of commands, will follow the line on the given course in a different manner. Another study limitation is related to the testing environment. The experimental terrain used in this study was created using a posterboard which has a smooth and flat surface. This does not accurately represent the terrain conditions that most rovers encounter in a real-life environment. For example, lunar rovers wander on paths that contain dust, soil, and rocks.

Lastly, this study had a small number of trials for each weight distribution, which in turn limits the reliability of the data.

Conclusion

Despite various limitations, this study provides valuable information on the effect of weight distribution on a rover's ability to avoid obstacles. It was shown that rovers with a more front-heavy weight distribution avoided obstacles with the most accuracy while remaining efficient. However, rovers with a 50/50 weight distribution were found to be the most efficient at avoiding obstacles while remaining to be accurate. The rear-heavy weight distribution, 40/60, had the poorest performance by being the least accurate and efficient at avoiding obstacles.

When deciding what weight distribution to prioritize in the process of designing a rover, it comes down to the intended objective that the rover must achieve. If a rover's goal is to very accurately avoid obstacles with no time constraints, then this study shows that a 60/40 weight distribution is favorable. However, if a rover is constrained to a limited amount of time to traverse through a terrain, then a 50/50 weight distribution makes more sense. This is because the 50/50 weight distribution completed the course in the shortest amount of time, while still maintaining an acceptable level of deviation.

This study only focuses on rovers with a two-axle four-wheel design, which is a small percentage of rovers. Rovers are designed in various ways with some having two, three, or even eight wheels. These differences in design may affect a rover's ability to avoid obstacles even with the same weight distribution. Therefore, to expand this research, testing how weight distribution affects obstacles avoidance on rovers with different geometries is important. Additionally, recognizing that every line tracking rover has its own code which it uses to follow a path, one may also consider testing line tracking rovers that follow different commands.

This research can also be expanded by using more accurate equipment to collect data. This will enable future experiments to focus on finding a rover’s optimal weight distribution for obstacle avoidance by allowing testing with much smaller variations. Lastly, with the given limitations on the course and sample size, it is also important to create a variety of testing environments, such as granular, rocky, or sandy and have different elevations. By testing a rover in various environments and using a large sample size, future experimenters will gain a better understanding of the real-world applicability of this study.

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