Performance Comparison of Solarbotics and Mecanum Wheels in Diverse Terrains

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***Abstract*—This paper attempts to determine the optimal wheel selection for specific applications by testing terrains such as the Botball table, grass, rocks, and LEGO bricks. While Solarbotics wheels are best for flat surfaces, Mecanum wheels offer superior manoeuvrability on complex terrain due to their omnidirectional motion. This paper provides robotics teams with useful information to help them choose the right wheels, especially for Botball competition.**

The authors emphasise the importance of wheel selection and evaluate their performance on different terrains. Both wheel types have an impact not only on energy consumption but also on the overall design of the robot. Mecanum wheels are more manoeuvrable, but require additional motors and a more complex control system. While Solarbotics' wheels are simple and easy to use, they are limited by their simple shape. Although less adaptable, they remain an affordable and practical choice for simpler environments.

The key finding of this paper is that the Solarbotics wheels failed completely on rough terrains such as LEGO bricks and stones, whereas the Mecanum wheels managed all the terrains tested. While both wheel types performed similarly on flat and grassy surfaces, the superior adaptability of Mecanum wheels becomes essential in complex environments.

I. Introduction

The two wheel types covered in this article are Mecanum and Solarbotics wheels. Mecanum wheels offer omnidirectional movement while Solarbotics wheels are known for their reliability and simplicity. This paper attempts to provide a thorough comparison of their performance by conducting controlled tests on different terrains. The results will help robotics teams choose the best wheels for their particular applications.

In order to provide a thorough evaluation, this paper looks at how both wheel types perform on a variety of surfaces, including low-traction surfaces such as LEGO bricks, uneven terrains such as grass and stones, and flat surfaces such as the Botball table. These terrains were chosen to replicate real-life situations and to test the traction, stability and accuracy of the wheels. The aim of this research is to provide reliable data for robotic applications by testing under different conditions.

In addition to evaluating the mechanical performance of the wheels, this work also considers factors such as controllability and energy efficiency. Understanding these factors is necessary to optimise robot design, especially in competitive environments where precise motion and energy management are critical. The results of this research will help robotics teams to make informed decisions based on the specific requirements of their tasks and the environment in which they operate.

As well as contributing to the academic understanding of wheel performance, this work has practical implications for robotics teams. The findings will allow teams to make data-driven decisions to optimise their robots for specific tasks and environments. This approach ensures that our research is not only scientifically rigorous, but also directly relevant to the challenges faced by robotics enthusiasts and professionals.

During our Botball preparation, we encountered some notable practical challenges with the Solarbotics and Mecanum wheels. The Mecanum wheels occasionally lost grip or one wheel didn't fully contact the ground due to uneven weight distribution. Manoeuvring them also required more precise programming. The Solarbotics wheels, on the other hand, were easier to control but failed completely on structured terrain such as LEGO bricks and rocks. In addition, the Solarbotics wheels accumulated debris, sometimes causing the rubber to come loose.

II. Types of Wheels

A. Solarbotics Wheels

Solarbotics wheels are characterized by their round shape and rubber treads, which provide excellent traction on level surfaces. Because these wheels are lightweight and require only two motors to operate, they are easy to control and energy-efficient. However, their lack of omnidirectional capabilities limits their adaptability on complicated or uneven terrains. These wheels typically have a diameter of 2.5 inches (63.5 mm) and a width of 0.5 inches (12.7 mm) [3], making them compact and lightweight.

Solarbotics wheels consist of rubber treads made to reduce wear and increase grip, guaranteeing steady performance throughout time. A common 2 mm D-shaped shaft is used to mount the wheels, making installation easier and allowing for compatibility with a variety of motors.

Because of their price and ease of use, solarbotic wheels are especially well-liked in educational robotics. They are frequently utilized in beginner-friendly kits and projects where dependability and simplicity of use are valued more highly than sophisticated functionality. These wheels are still a good option for applications requiring simple, energy-efficient motion on flat surfaces, even with some drawbacks.

An important consideration for Solarbotics wheels is their tendency to accumulate dirt and debris in their treads during extended use. This not only reduces traction, but can eventually cause the rubber treads to separate from the wheel hub entirely. Teams using these wheels should do check-ups on a regular basis, especially when using them on demanding terrains like grass or dirt.

Fig. 1. Solarbotics Wheel: A light, thin, rubber wheel designed for flat surfaces.

B. *Mecanum Wheels*

Robots can move sideways, diagonally, and rotate in place due to the omnidirectional movement made possible by the angled rollers on Mecanum wheels. However, two significant disadvantages are their increased energy consumption because of the requirement for four motors and their mechanical complexity. These wheels typically have a diameter of 4 inches (101.6 mm) and a width of 1.5 inches (38.1 mm) [4], making them larger and heavier than Solarbotics wheels.

Mecanum wheels are ideal for medium to large robots due to their larger size, especially those that must traverse difficult terrain or confined spaces. However, their design necessitates frequent maintenance and precise alignment to ensure smooth operation, and each wheel must be powered independently, which increases energy consumption and calls for the use of four motors and sophisticated control systems.

Mecanum wheels' outstanding agility makes them popular in warehouse robots, industrial automation, and competitive robotics. They are frequently used, for instance, in autonomous mobile robots (AMRs) which have to maneuver precisely during docking or negotiate complicated situations. Although some teams may find their higher cost and mechanical complexity prohibitive, omnidirectional movement's advantages frequently outweigh the costs.

Fig. 2. Mecanum Wheel: An omnidirectional wheel with angled rollers for enhanced mobility.

III. Tested Terrains

To evaluate the performance of the two wheel types, a range of terrains was selected, including:

- **Botball Table**: A flat, relatively smooth surface - competition conditions.
- **Grass**: An uneven, natural surface, varying traction.
- **Stones**: A rough, irregular surface, outdoor environment.
- **LEGO tiles**: A structured, modular surface with low traction.

Each terrain was selected to test the wheels' traction, dependability, and accuracy while simulating real-world circumstances [5].

Fig. 3. Tested Terrains: Botball table (top-left), grass (top-right), stones (bottom-left), and LEGO tiles (bottom-right).

IV. Data Collection and Analysis

Data was collected using simple measurement tools, such as a tape measure, and observational data, such as on-display battery consumption. The results were analyzed using statistical methods and visualized using bar charts and tables.

A. *Experimental Setup*

Two robots were used for testing: the Main-Bot, equipped with four Mecanum wheels in an X-configuration, and the Second-Bot, equipped with two Solarbotics wheels and one rear caster for stability. Each robot was tested on all terrains, with 20 runs per wheel type to ensure statistical reliability.

To measure how accurately the robot followed a target path, we used the following formula:

$$\text{Accuracy (\%)} = \left(1 - \frac{\text{Average Deviation}}{\text{Target Distance}}\right) \times 100$$

Where the *Average Deviation* is in inches, and the *Target Distance* is 36 inches (3 feet).

Key performance metrics included:

- **Target Accuracy**: Successful target hits as a percentage.
- **Average Deviation**: Distance in inches from the intended path.

These tests were controlled, with the robot manually reset after each run. The data was processed and compared using statistical methods, including the calculation of mean values and standard deviations to assess consistency and significance. The experiments demonstrated high repeatability, with a low standard deviation (±0.05 inches for Mecanum wheels on the Botball table), confirming the reliability of the results. A total of 20 tests per wheel type were conducted, ensuring robust statistical validation of our hypothesis.

The robot's manual resetting after each run may have introduced inconsistency in positioning precision and initial orientation. While environmental parameters like temperature and humidity were kept under control, human intervention during resetting could have a subtle effect on results on uneven terrain. Future research might use automated positioning systems to ensure repeatability and incorporate inertial measurement units to provide real-time feedback on alignment errors.

To yield accurate and consistent findings, the test environment was carefully monitored. Temperature and humidity were monitored and controlled during the tests. Each site was designed to match real-world situations as precisely as feasible. For example, the Botball table was cleaned and leveled prior to each test, and the grass and stone terrains were maintained to ensure consistent traction and surface irregularities. This attention to precision reduced external variables that could influence the results and assured that any observed performance differences were purely related to the wheel types evaluated.

In addition to quantitative measurements, qualitative observations were made during the experiments. These included observations about the robots' stability, ease of control, and any unexpected activity, such as wheel slippage or alignment issues. These insights offered useful context for evaluating the quantitative results and identified potential areas for development in future designs. For example, the Mecanum wheels occasionally had minor alignment issues on rough terrain, which may be fixed with better mounting mechanisms or more robust control algorithms.

While this paper gives useful information, it does have drawbacks. The studies were carried out in a controlled laboratory environment, which may not fully match real-world circumstances involving dynamic impediments or fluctuating weather. In addition, the robots used were prototypes with set motor configurations, limiting their applicability to alternative designs. Future research should involve field experiments and different robot architectures to test these findings in larger environments.

Another weakness of this paper is that it only considers a small number of terrains. While these surfaces were chosen to depict a variety of real-world scenarios, they do not cover all possible situations in which robots could work. For example, wet or icy surfaces, which have a substantial impact on traction and wheel performance, were not evaluated. Furthermore, the paper did not address the impact of different payloads on wheel performance, which is an important element in many robotic applications. Future paper should broaden the spectrum of terrains evaluated and incorporate dynamic load situations to have a better knowledge of wheel performance in various settings.

B. Results

The following results were obtained from the tests, with each wheel type tested 20 times to ensure statistical reliability.

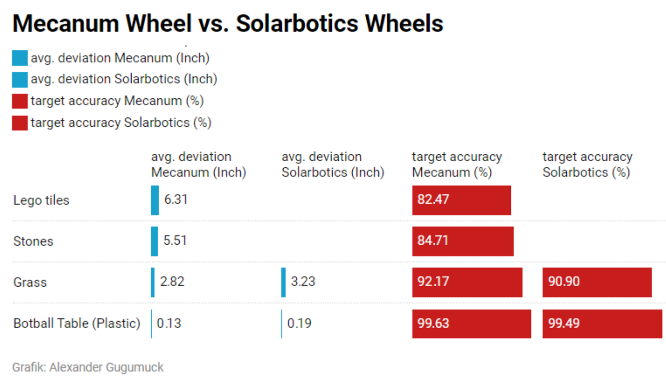

Fig. 4. Graphed comparison of wheel performance across terrains.

- **Mecanum Wheels**

Material	Average Deviation (Inch)	Target Accuracy (%)
Botball table	0.13	99.63
Stone	5.51	84.71
Grass	2.82	92.17
LEGO tiles	6.31	82.47

TABLE I
PERFORMANCE OF MECANUM WHEELS ACROSS TERRAINS.

- **Solarbotics Wheels**

Material	Average Deviation (Inch)	Target Accuracy (%)
Botball table	0.19	99.49
Stone	N/A	N/A
Grass	3.23	90.90
LEGO tiles	N/A	N/A

TABLE II
PERFORMANCE OF SOLARBOTICS WHEELS ACROSS TERRAINS.

On all kinds of terrain, but especially on uneven and difficult terrain, the Mecanum wheels worked wonderfully. The limitations of Solarbotics wheels on challenging terrain are highlighted by their inability to drive over stones and LEGO tiles. Due to their shape, the wheels were unable to even move up and over these materials.

The Mecanum wheels on the Botball table have a high accuracy of 99.63%, demonstrating their precision in controlled situations. This precision is achieved through their omnidirectional capabilities, which allow for fine-tuning of the motion. However, the additional motors needed to drive each wheel independently result in higher energy usage. Understanding this trade-off is critical for design teams looking to balance precision with energy efficiency. However, their performance on more challenging terrains, such as rocks and LEGO bricks, shows a noticeable drop in accuracy, with target accuracy dropping to 84.71% and 82.47% respectively. This suggests that although the Mecanum wheels are versatile, their performance is still influenced by the complexity of the terrain. On the other hand, Solarbotics wheels achieved a comparable accuracy of 99.49% on the Botball table, but failed completely on rocks and LEGO bricks (marked N/A in Table 2) starkly demonstrates their limitations on anything but flat terrain.

The consistency of the results over 20 test runs further validates the reliability of the data. The low standard deviation observed for both wheel types on the Botball table (e.g. ±0.02 inches for Mecanum wheels) indicates that the experiments were highly repeatable. This consistency strengthens the conclusions drawn from the paper and provides a solid basis for future research into wheel performance under varying conditions.

V. Energy consumption

The Main-bot, equipped with Mecanum wheels, remained stationary on the Botball table and rotated for one hour and 26 minutes, while the Second-bot, equipped with Solarbotics wheels, ran for one hour and 50 minutes. The Mecanum wheels require two more motors, which increases energy consumption, accounting for the majority of the difference in running time. However, no significant variation in energy efficiency was found between the two wheel types, implying that energy consumption per motor is similar.

To go deeper into power consumption, future testing may use tools such as multimeters to measure the power consumption of each motor individually [6]. This would provide more precise information on how much energy each wheel type expends under various weights and terrains. For example, measuring each motor's current and voltage while in operation could reveal how energy usage varies with speed, payload, and surface conditions. Such precise assessments would allow robotics teams to optimize their designs for specific jobs and situations.

Furthermore, testing under varying conditions, such as changing speeds or payloads, may provide a better understanding of the energy efficiency trade-offs between Solarbotics and Mecanum wheels. Higher speeds or larger loads, for example, may have a disproportionate impact on Mecanum wheels' energy consumption due to their mechanical complexity and the increased friction caused by the angled rollers. Solarbotics wheels, on the other hand, may have more constant energy efficiency across a broader variety of situations due to their simpler design. These insights would be especially useful for teams developing robots for long-duration jobs or in energy-constrained locations.

Another topic for future investigation is the impact of wheel alignment and maintenance on energy efficiency. For example, misaligned Mecanum wheels can cause uneven load distribution and greater friction, resulting in increased energy consumption. Regular maintenance and correct calibration may alleviate these issues, but they can increase operating complexity. Understanding these aspects would enable teams to make more informed decisions about the trade-offs between performance, energy efficiency, and maintenance needs.

VI. Target Accuracy

Target accuracy is a critical metric [7] for evaluating the performance (of the wheel types). It directly impacts the robot's ability to complete tasks accurately. Target accuracy was measured as the percentage of successful hits on target, over a distance of 3 feet. As discussed earlier, the results show that the Mecanum Wheels achieved higher accuracy across all terrains, especially on the Botball table, with an accuracy of 99.63 %. The Solarbotics wheels performed better on flat surfaces, achieving 99.49 % on the table, while failing at Stone and LEGO tiles. In our case, we used the following formula to define the Target Accuracy:

$$\text{Accuracy (\%)} = \left(1 - \frac{\text{Average Deviation}}{\text{Target Value}}\right) \times 100$$

where the *Average Deviation* is measured in inches, and the *Target Value* is defined as 3 feet, representing the driving distance for the bots to determine their accuracy.

The Mecanum wheels accuracy can be attributed to their multi-directional capabilities, which allows for precise adjustments in movement. This comes at the cost of increased mechanical complexity. These results highlight the difference in possible uses of the two wheel types for robotics teams. For example, Mecanum wheels are clearly superior for activities that need high precision, such as dealing with small spaces or performing precise movements. However, their complexity and higher energy consumption make them unsuitable for simpler tasks where precision is not as important.

The formula provides an easy way to determine how closely the robot is following its intended path. By comparing variances relative to the target distance, we avoid the bias that might occur with absolute error measures, making the results easier to comprehend for teams with varying robot sizes or motor configurations. By comparing deviations relative to the target distance, we reduce the biases that can occur with absolute error measures, making the results easier to comprehend for teams with varying robot sizes or motor configurations.

Future research can expand this statistic by integrating additional variables such as speed or dynamic impediments. For example, evaluating accuracy under time limits or while avoiding moving objects may offer new information about wheel performance in real-world circumstances. Such additions would help to close the gap between controlled experiments and real robotic applications.

VII. Discussion

The 20 tests demonstrated high consistency, with minimal standard deviations across all terrains. This suggests that the results are consistent and reproducible, providing a good foundation for deriving conclusions about the performance of the Mecanum and Solarbotics wheels. The low standard deviation (±0.05 inches) for Mecanum wheels on the Botball table indicates a well-controlled test setup and consistent wheel performance under the same conditions.

However, it is important to note that the tests were impacted by possible human interference because the robot was manually reset after each run. While every attempt was made to maintain consistency in the resetting process, tiny deviations in placement or alignment may have resulted in small inaccuracies. For example, slight deviations in the robot's beginning position or orientation could have influenced the accuracy and deviation readings, especially over uneven ground like grass or stones. These minor differences underscore the necessity for automated reset mechanisms in future studies to eliminate human error and increase the accuracy of the results.

Mecanum wheels demonstrated versatility [8], particularly on uneven terrain, but faced challenges on structured surfaces such as LEGO tiles.. This adaptability is due to the omnidirectional design, which allows for accurate lateral and rotational movement. However, this advantage is outweighed by their increased mechanical complexity and energy consumption. Teams must carefully consider these trade-offs based on their individual requirements, such as precision vs. energy limits.

This research has a big impact on robotics teams, especially on those competing in the Botball tournament. While Solarbotics wheels are a more affordable option for simple situations, Mecanum wheels are recommended for teams that require precise mobility across a variety of terrain.

Mecanum wheels are also more mechanically complex, requiring constant maintenance and an advanced control system - the upside is greater maneuverability. Teams, especially on beginner-levels, have to decide for themselves if the trade-offs are worth in their cases. In contrast, Solarbotics wheels, with their simpler design, offer ease of use and lower to no maintenance, making them the easiest use option in most environments, especially for teams with limited knowledge or resources. These are important considerations that need to be taken into account before a decision is made.

Conclusion

In this paper, the benefits and drawbacks of Mecanum and Solarbotics wheels are examined precisely. Mecanum wheels are ideal for a variety of terrains because of their exceptional adaptability and accuracy, whereas Solarbotics wheels are reliable and energy efficient on level ground. Future research, such as [9], should focus on hybrid wheel systems, long-term durability, and energy efficiency under a variety of loads to improve robotic performance.

The findings of this paper are very important for robotics teams, especially in competitive environments. Teams can use these results to base their wheel decisions depending on their needs. Mecanum wheels are recommended for tasks requiring high precision and accuracy, while Solarbotics wheels are cheaper and useful on flat surfaces, where precision is less critical.

Beyond competitive robotics, this knowledge can be applied in industrial and service robotics. As example, warehouse robots can fit tight spaces and move very precisely using Mecanum wheels, while delivery robots benefit from Solarbotics wheels and their ability to drive over flat surfaces, while being cost- and energy efficient. Future research could also explore the integration of advanced control systems to further optimize both wheel types. This research should include three key areas:

- **Hybrid Wheel Systems**: Combining Mecanum's agility with Solarbotics' energy efficiency for versatile applications.
- **Durability Testing**: Evaluating performance in extreme conditions such as gravel or mud.
- **Energy Optimization**: Developing algorithms to dynamically adjust motor power based on terrain feedback.

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