VERSATILE MULTI-AXIS CHASSIS A SOLUTION FOR RESCUE OPERATIONS AND MOBILITY

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Abstract

The development of robots featuring holonomic drivetrains, more exactly swerves, is a comprehensive area of study with numerous potential applications across diverse industries and fields such as metallurgical or car production, where heavy weight mobile transporters are required. Unfortunately, the narrow use of this new technology produced in limited batches and its poor documentation led to its avoidance in some fields, such as hospitality or mining.

These drivetrains can precisely navigate through difficult terrains and environments, making them an optimal fit for search and rescue operations, where the need for quick and efficient mobility in remote, hard-to-reach areas is paramount. Moreover, sensors, LIDARs and cameras can be mounted on these robots to collect parameters providing information about hazardous environments without putting human lives at unnecessary risk.

Due to their high modularity, such chassis can be mounted on patients' beds in hospitals, where there is not enough space for complex maneuvers. Thus, mobility is enhanced in crowded situations where patients must be moved from one room to another, or during an emergency when an efficient evacuation is crucial.

To effectively assess the capabilities of the drivetrain, we designed a scaled-down prototype. We collected data on mobility, off-road capability, modularity, and maintenance requirements for our prototype and three conventional chassis. Upon analyzing the test results, we found that the prototype consistently demonstrated high performance, being 15% more efficient when averaged over all the experiments considered. The findings of this study confirm the effectiveness of this new generation equipment and can support its incorporation in various fields, especially healthcare.

Keywords: holonomic drivetrain, mobility, search and rescue, hazardous environment

JEL Classification: O14

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1. Introduction

Swerve-driven robots represent a fundamental discovery in the field of engineering due to the compact and reliable mechanisms that allow independent control of every individual wheel in any direction, having an extra degree of freedom compared to conventional wheels. Their high maneuverability and precision make them optimal for tasks that require precise positioning, such as machine vision systems and robotic arms. The capability to instantly change their direction of movement in response to different types of terrain or obstacles is unmatched by traditional fixed-wheel robots, making them invaluable in unpredictable environments.

Modularity is a particularly important point; swerve type chassis can be easily customized for any type of use ranging from mini scale robots to applications the size of huge industrial machinery. Also, the ease with which components can be replaced or upgraded ensures longevity, adaptability, and simple maintenance [4].

The ability to navigate through difficult terrains and environments where traditional chassis may struggle, makes these chassis a perfect solution for applications such as search and rescue. In military and police operations, the need for quick and efficient mobility in remote or hard-to-reach areas is primary. Conventional vehicles can be difficult to operate in challenging terrain, but a swerve-driven robotic chassis would offer increased accuracy and mobility. These robots can easily cross a range of surfaces including rocks, sand, or snow, which are typically challenging. Moreover, sensors and cameras can be mounted on these robots to collect parameters, making them able to provide information about the situation in hazardous environments while minimizing risking of human lives.

The use of these robots is also helpful in medical emergencies such as natural disasters, where access to locations is critical. In such scenarios a swerve-driven robotic chassis can provide an efficient and safe solution for carrying medical supplies or equipment, transporting patients, and providing first aid, all while being remotely operated from a safe distance, protecting rescuers. In addition, these chassis, being highly modular, can be mounted on patient beds in hospitals, where there is not enough space for complex maneuvers, thus allowing more mobility in crowded situations.

This type of chassis offers a high degree of precision and control, enabling precise operations in various fields such as manufacturing and industrial settings. They can be used for handling and transporting delicate equipment, reducing the risk of damage to the equipment itself but also of injury among workers. Production processes can be optimized by minimizing human error and increasing efficiency.

2. Problem Statement

Although swerve chassis offer numerous benefits that can enhance and optimize various industrial sectors, they are still not widely used, being relatively unexplored and tested. The direct competitor of these chassis, the mecanum ones, have gained popularity in the last decade, even finding applications in the aeronautical field (Fig. 1). Mecanum chassis can face challenges when moving on non-flat surfaces, a situation that does not affect swerve chassis, providing them with an added versatility. Swerve chassis represent an improvement for any field and can reduce maintenance costs due to their high modularity.[3]

Figure 1. Mecanum transporter for Airbus components[3].

Through this paper, we aim to prove that swerve-driven robots are the future of robotics and have the potential to revolutionize the field of robotics. By demonstrating the superior capabilities of swerve-driven robots, we hope to inspire more research and development in this area and help pave the way for new and innovative applications of this technology.

To prove our hypothesis, we compared swerves' performance to that of traditional omnidirectional chassis to demonstrate how these robots are better equipped to handle tasks with greater speed, accuracy, and efficiency. We designed, built, and accurately documented a small-scale swerve-driven robot, thus being able to test the most precise version of this chassis type.

In our experiments, we evaluated the performance of the swerve-drive by comparing it to three other chassis types of similar size: a six-wheel drive, a mecanum chassis, and a tread drive. We examined mobility by testing robots on uneven and challenging surfaces, such as obstacle terrain and steep inclines. Precision and maneuverability were tested by subjecting the robots to tasks requiring accurate movement and positioning, including navigating through tight spaces, picking up and moving objects, and executing complex maneuvers. Our analysis was conducted using a standardized method, ensuring a comprehensive evaluation of each chassis.

3. Developing a Swerve Chassis

Swerve drivetrains use four or more independently controlled wheels usually mounted on the corners of chassis, each with its own motor and steering mechanism. This allows for

[3] Source: https://roboticsandautomationnews.com/2016/06/30/kukas-monstrous-robotic-vehicle-manoeuvres-gigantic-airbus-components-with-millimetre-precision/6005/

greater flexibility and precision in movement, as each wheel can move and rotate independently of the others.

To have a fair comparison between all four different types of chassis we built a similar sized swerve-driven one as the other three that we already had access to (all of them were First Tech Challenge chassis, dimensions varying from 28cm x28cm to 45cm x45cm).

For this first prototype it was expected that many things would change, thus we opted for a highly modular design, enabling an easy shift from one idea to another without manufacturing new sets of numerous complex components. We tried to use as many parts as possible from the local vendors, thus the iteration time being minimized, without the need to wait for the delivery of new parts.

Designing a robot chassis is a critical step in the development of any robotic system. It is crucial to design the chassis with precision to ensure that the robot operates smoothly and efficiently. Some of the main priorities while designing the first prototype were:

- Compactness: leaving the maximum free space for other systems that could be added to the chassis in the future (ex: a robotic arm).
- Modular design: easy changes between every iteration, being able to take apart every part of the system to study and find its failure points; parts that tend to wear faster can be replaced without disassembling the whole system.
- Easy to manufacture using standard 3D printers and a 3-axis CNC router; need to find solutions to restrict the manufacture process without reducing project's feasibility.
- Lightweight design for improved performance; used topology studies to determine the best weight/strength ratio for selected applications.
- An overall cost under 1500$

3.1 Design

To have a prototype with seamlessly integrated components, the use of 3D design software was mandatory. Having experience working with SolidWorks[4], a computer aided design software who can also provide support for computer simulations, which are useful during optimization process. Using this software, we were able to create and visualize in real-life a virtual model of the robot and test its performance before building the physical prototype.

One of the primary benefits of designing a robot chassis in 3D design software is that it helps identifying any flaws or design errors before building the real prototype. This approach saves time and reduces costs by mitigating the risks of building a faulty robot. In addition, 3D design software allows precise measurement for accurate dimensioning,

[4] https://www.solidworks.com/

having a small margin of error, which was essential for ensuring that all components fit together perfectly.

Moreover, CAD allowed us to test different scenarios and make modifications to the design quickly. This feature is particularly useful when designing complex robotic systems with multiple components and subsystems, like the swerve-driven chassis. We were able to test different configurations and evaluate how changes in one subsystem would have affected the overall performance of the chassis.

For the first iteration we decided to build the smallest possible reliable chassis, so we restricted its dimensions to a 300mm x300mm footprint (Fig. 2). Due to the high modularity, from this point dimensions always can increase just by changing one part, the main 6mm CNC machined aluminum plate that holds the hole assembly together.

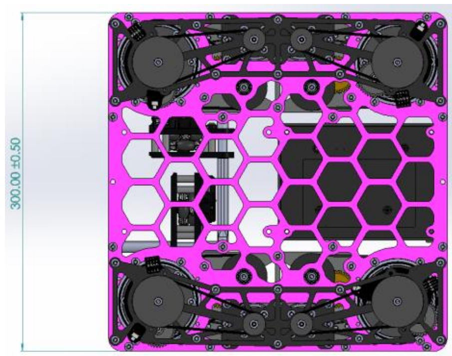

Figure 2. Top view of the swerve chassis showcasing its footprint.

We designed and manufactured our own wheels, thus enabling more freedom during the design process, without being restricted by wheel sizes offered of the vendors. Wheels are composed of two parts: a *3D printed rim*, and a *tire* (like car wheels). Due to the small dimensions, we couldn't fit a pneumatic tire, so we enhanced rims with Andymark's Gray Grippy Tread fixed with 4 bolts into the rim making it a very easy-to-change part. The first prototype wheels are 25mm wide and have a diameter of 72mm, making them able to cross obstacles of moderate size in relation to the size of the entire chassis.

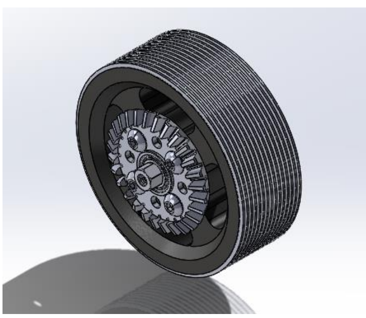

Figure 3. Wheel assembly.

We had two options to mount the main four X-contact bearings that connect swerve modules to the main aluminum plate, one was press-fit into the chassis frame and the other was to put four bolts that intersect the bearing cavity on both parts of the frame, acting like a shim for holding the bearing. The first option required a very thin tolerance on the parts and didn't seem as reliable and modular as the second one where any bearing can be taken apart if it is damaged only by removing four M4 bolts, so we stuck to the second option.

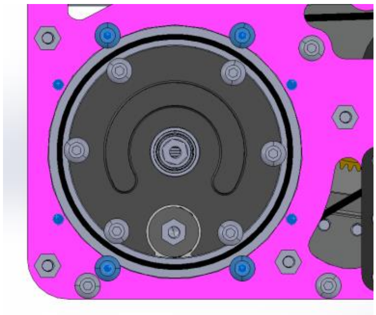

Figure 4. Top view of X-contact bearing fixed with 4 bolts highlighted in blue.

We had a variety of options for the motors that run every individual wheel; the main vendor sold bare motors with different gearboxes mounted to them. The stock gearbox offered by the vendor could wear out over time due to the inconsistencies during production phase, being very difficult to replace. Moreover, to accomplish our priority of having a modular design we chose to buy just the 6000RPM bare motors, without gearboxes attached to them.

Figure 5. Left[5] – Motor with Gearbox; Right[6] – Motor without Gearbox.

[5] Source: https://www.gobilda.com/copy-of-5202-series-yellow-jacket-planetary-gear-motor-3-7-1-ratio-1620-rpm-3-3-5v-encoder/
[6] Source: https://www.gobilda.com/modern-robotics-matrix-12vdc-motor-with-8mm-rex-pinion-shaft/

We manufactured a custom reduction gearbox so we could change its ratio accordingly to the mission. For the first prototype we chose a 1:10 reduction composed of three stages (Fig 6):

- The first stage: 1:2.5 by using a 3M HTD belt (was the best option because spur gear reductions would put very much resistance at the speed of 6000RPM that the motor shaft has)
- The second stage: 1:2 using spur gears.
- The second stage: 1:2 using 90-degree bevel gears.

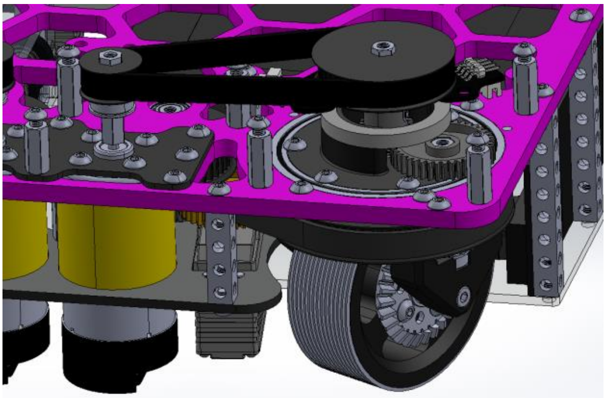

Figure 6. Motor and the 3 transmissions through which it powers to the wheel.

The module rotation must be fast and precise. The biggest problem was caused by the friction created between the wheels and running surface during the scrub generated while modules are rotating. Besides fast servomotors to rotate every module we needed some that can provide enough torque, thus having nearly infinite module rotation acceleration. To connect the servomotor with the module we chose belt drive (3M HTD) because a spur gear transmission would have passed all wheel shocks caused by the rough terrain directly to the servo shaft, causing its failure rapidly, thus we increased reliability. Servomotors spin modules to a 1:1 ratio composed by a first 2:1 spur gear stage and then a 1:2 belt stage, we chose these ratios to save up more space.

Figure 7. Servomotor connected to the module through two transmissions.

To ensure that the module rotation is as precise as possible we chose not to use servos with internal absolute encoders because, due to the two-stage transmission, inaccuracies could occur. Instead, we mounted an absolute magnetic encoder right above the module, thus monitoring its motion with outstanding precision.

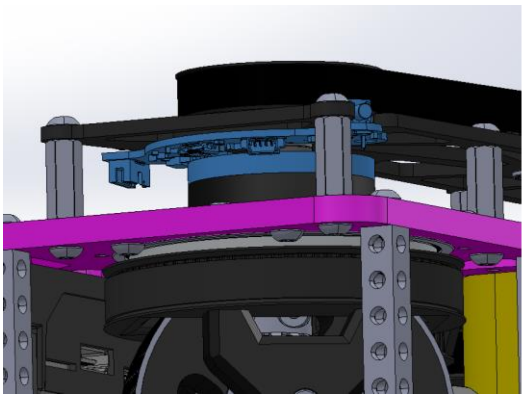

Figure 8. The external absolute encoder is mounted above wheel module.

Localization is a means for being able to locate the position of the chassis at any point in time, for the precision tests we opted to add two OpenOdometry[7] modules, that use REV relative encoders, which, together with the IMU sensor inside the Control Hub, can precisely track robot's position. Odometry is a form of localization that uses data from encoders to derive an estimated position relative to a starting point.

[7] https://openodometry.weebly.com/

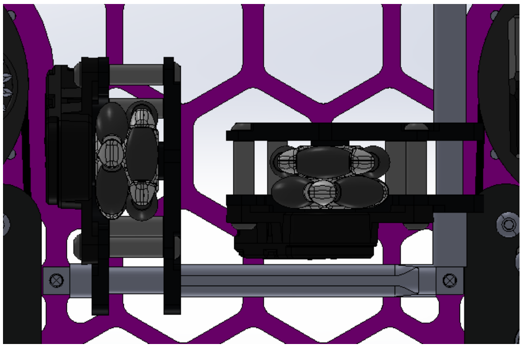

Figure 9. Position of the two odometry pods.

3.2 Mechanical Simulations

To facilitate the understanding of the functioning of the mechanical simulations and how they are performed, we have chosen to detail the process through which a standard part goes through its evaluation**.**

As shown in Fig. 10, the first step in performing a mechanical simulation in SolidWorks is to select which parts will remain fixed during the action of some forces. Basically, these parts will remain rigid.

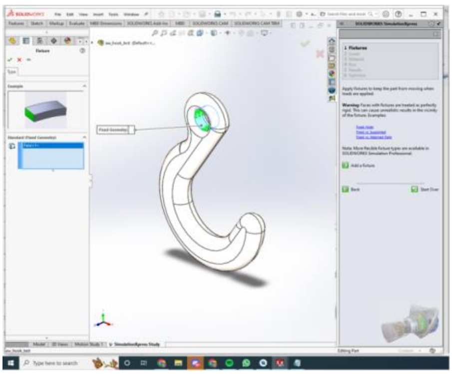

Figure 10. Selecting fixed points.

The next step is to apply the forces we want. In Fig. 11 we have to select the faces where the force will be applied, the plane on which the force acts and also its magnitude.

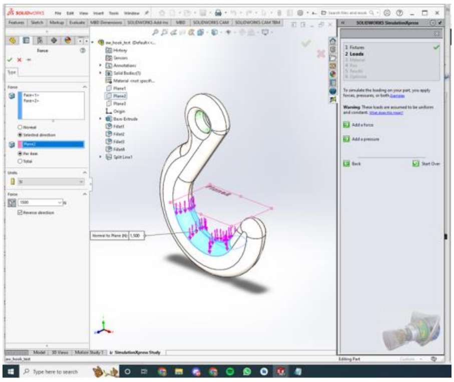

Figure 11. Applying forces.

The third step is selecting the material. SolidWorks gives us a multitude of materials and we can create our own materials, for example if we use a special plastic filament for 3D printers. The material selection interface is shown in Fig. 12.

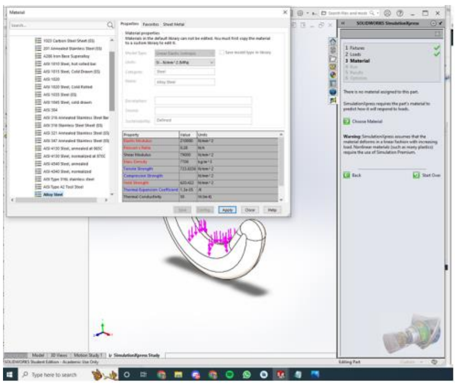

Figure 12. Selecting Material.

Once we have prepared all the necessary data for the simulation, we run it and get 4 things as a result:

- An animation showing the deformation of the part.
- A Von Mises stress graph.
- A graph showing how much each point of the part has moved.
- A graph that shows us where the safety factor is below the value we select.

The Von Mises Stress Graph For this part is the Fig. 13. Stress is represented as the multitude of internal forces generated by a flexible body when it interacts with an external force. The von Mises method of stress measurement is one of the most widely used in industry, measuring equivalent stress.

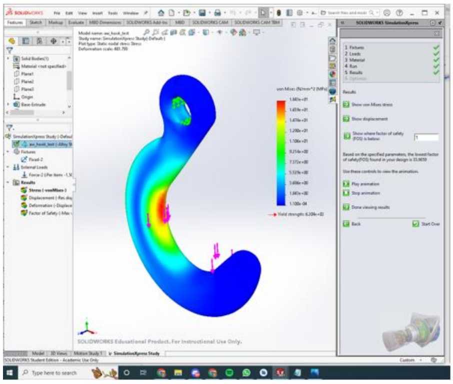

Figure 13. Von Mises Stress Graph.

On the right of the part, it can be seen the von Mises stress scale, red indicates the maximum calculated stress and blue the minimum stress. This way we can see which segments of the part are most stressed and use this information to stiffen them.

Factor of Safety for the part analyzed above in Fig 14, it shows which are the points where the safety factor has a value below 1.

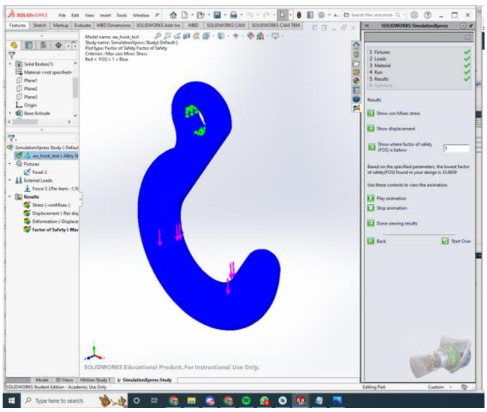

Figure 14. Factor of Safety.

The Factor of Safety is calculated by dividing the yield strength of the material by the equivalent stress at that point. The Von Mises criterion says that a point in a part fails when the equivalent stress at a point is greater than the material strength factor. If a point has a yield strength factor value below 1 it means that the material has started to break.

With this measurement we can tell if we have vulnerable points much more easily. We can also tell the maximum pressure a material can withstand.

For example, if we apply a force of N newtons at a point and the factor of safety at that point, estimated by SolidWorks, is K, the maximum force that can be applied is N*K. So, we can figure out what forces we can put on that system or part to get the maximum performance out of it.

For most of the manufacturing process we were able to use 6082 series aluminum plates and PLA filament for the 3D printed parts. To determine what material to use for every part we ran computer simulations to make sure that the desired material provides enough strength for its application.

Bearing in mind that for CNC milling we have access only to a 3-axis machine, we could only manufacture plates made of aluminum, no more complex geometry parts because they would require a 5-axis machine. So, deciding which parts to be made of aluminum was straightforward to us.

For the main plate we needed a 300mm x300mm x6mm aluminum plate which would be very heavy, nearly 1kg, so we were required to effectuate material removal to make it lightweight, the disadvantage of this solution is that it can affect its strength. To find the perfect relation between weight and strength we used a Factor of Safety bigger than 1.3, this way we were sure that it won't fail besides its low weight. The final item reduced its weight by more than 50%.

For this simulation we applied a force of 10000N on the plate, equivalent to a weight of 1000kg. The fixed points of this simulation were the holes where the modules will be mounted.

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude6 	Solid Body	Mass:1.03874 kg Volume:0.000387589 m^3 Density:2,680 kg/m^3 Weight:10.1796 N	D:\Robotica\SWERVE GAME\Placa swerve.SLDPRT Jul 12 01:19:27 2023

Figure 15. Main plate without weight reduction properties.

Solid Bodies			
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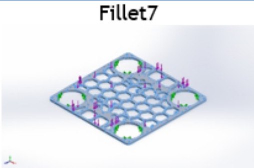
Fillet7 	Solid Body	Mass:0.565642 kg Volume:0.00021106 m^3 Density:2,680 kg/m^3 Weight:5.54329 N	D:\Robotica\SWERVE GAME\Placa swerve.SLDPRT Jul 12 01:19:27 2023

Figure 16. Main plate with weight reduction properties.

Although after the main plate's weight has been reduced to almost half due to the pocketing process, its structural integrity can still withstand our application (Fig. 17).

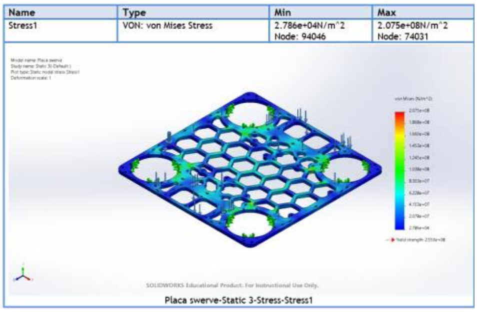


Figure 17. Von Misses stress graph for the main plate.

To determine the best shape for rims we implemented topology studies in the design process to find the part with maximum efficiency. Weight played a crucial role in this design because a light wheel has reduced momentum while spinning and improves performance. While running this study we applied a torque of 10Nm to the holes where the power shaft is attached and fixed the outer part of the rim, thus we ensured that the wheel won't break under big loads caused by the fast changing of spinning direction. The resulting item was a 3-spoke rim with 60% reduced weight.

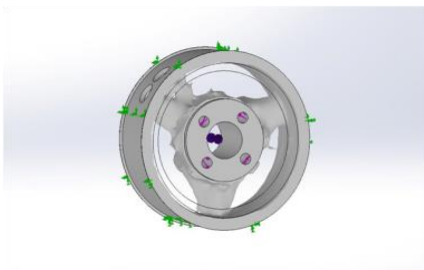


Figure 18. Wheel rim after running the topology study.

3.3 Manufacturing

A key aspect setting this drivetrain apart is that 90% of its structure is composed of custom parts, unfortunately, having a limited manufacturing capacity, this implied a relatively long fabrication time of one week.

For the custom parts manufacturing process, we had access to standard 3D printers (Prusa MK3S+) and a 3-axis CNC (Shapeoko Pro XL). 3D printers were very important during this project, due to their speed and ability to generate parts with complex geometries.

Figure 19. The CNC machine and one 3D printer used in the manufacturing process.

To ensure that all components are seamlessly integrated, we have 3D printed all custom components first. This not only ensured a high level of convenience during the prototyping process, but also guaranteed that all components would fit correctly before manufacturing them out of aluminum.

However, 3D printing is not without its limitations. For instance, the strength of PLA plastic that we used is insignificant in comparison to metals such as aluminum, thus making 3D printed parts less suitable for the high-stress applications during this project.

The CNC machine, while requiring more setup time, has the edge in precision and versatility in material choices. For instance, aluminum, due to its high strength, corrosion resistance, and which can be easily found at local suppliers, was the ideal material for CNC machining the prototype plates.

Some 3D printed parts, for example the wheels, required heat-insert nuts mounted to have a safe mode of fixing bolts on them. Fig. 20 shows how the heat-inserts were mount on the wheels to help fix the grey grippy tread that is secured with screws.

Figure 20. Threaded heat inserts mounted in the 3D printed wheel rim.

After all CNC parts were produced some final adjustments were needed due to the machine's incapacity of making threads for the M4 bolts that hold the X-contact bearings. Unfortunately, one tap had an internal crack and during tapping it failed, making one hole unusable, luckily it didn't affect prototype's performance.

Figure 21. All CNC parts produced and a failed tap.

To prevent aluminum from oxidizing we chose to paint it. Having in mind that any paint chip that would enter in the bearing cavity will affect the tolerances, we decided to cover the important areas with tape.

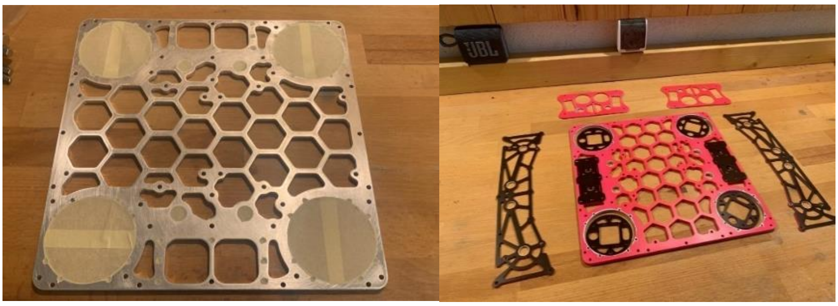


Figure 22. All parts before and after spray painting

3.4 Electrical Components

One of the key components in the first prototype are the four GoBilda 6000RPM 12V bare motors, which power the wheels. These motors are known for their impressive performance in any scenario, furthermore, the output shaft is an 8mm HEX to what transmission can be easily attached without being aware that it will have inaccuracies. These motors also provide an internal encoder that can be used for tracking the wheel's motion, making them the perfect choice for this drivetrain.

We have incorporated Axon Robotics MAX servos for individual module heading control, allowing for fast, powerful, and accurate movement. These standard sized servos provide 34kgcm torque and 0.115 sec/60° speed at 6.0V with titanium gears inside, making them a long-lasting solution.

Additionally, to track module movement we used Lamprey2 Absolute Encoders. Before selecting these encoders for our project, we tested them in comparison to other two magnetic and respectively optic encoders to different speeds of the rotating shaft varying from 5RPM to 6000RPM; the Lamprey2 proved to have the best accuracy.

To power these components, we have used the REV Robotics Control Hub control system thanks to its high-power capabilities in powering robot components and its big number of analog and digital inputs that can be used for sensors and encoders. A REV Robotics Servo Power Module that can provide constant 6.0V output for every servo was added. Teamed up with a 3000 mAh 12V NiMh battery, to ensure a fair amount of power supply for all 4 motors and 4 servos, for any situation.

3.5 Building

The building process required a high level of attention due to the slight tolerances that are featured in this demo version. The modular design enabled a straightforward way to build it by assembling all modules separately and then mounting them on the main assembly.

No additional interventions to the custom parts were necessary during the building process, showcasing the rigor with which the chassis was designed.

The first step was to mount the X-contact bearings that support the modules. Securing the bearings with four bolts on each side proved to be highly efficient, facilitating their process of mounting and removing without any additional speial tools.

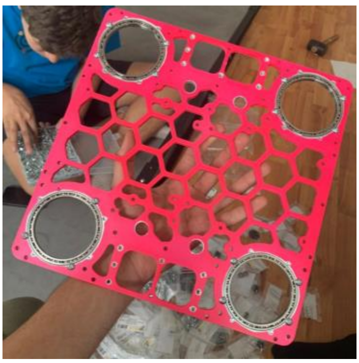


Figure 23. X-contact Bearings are mounted to the main plate.

The next step was to mount the motors and servomotors. At this point we observed that some servos, while mounted on their gear transmission, spined slightly restrained than others. After a fast debug we found that the servomotors that we used had a bigger mounting hole diameter (>4M) which let a slight play for adjusting servos position, thus we were able to adjust the pressure between gears in the transmission without having excessive friction, solving the problem.

Figure 24. Left – Motors are mounted; Right – Servomotors are mounted.

Mounting wheel modules on the chassis. Here additional +0.25mm shims were necessary to maintain a constant spacing between the 90-degree bevel gears for all four modules, thus minimizing the performance differences between them.

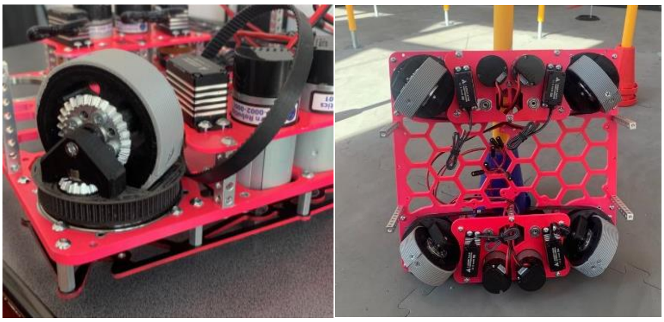


Figure 25. Wheel modules are mounted to the chassis' main structure plate.

After having the wheels mounted and secured it was time to mount the last mechanical components: the upper main transmission and the lamprey encoders for module's rotation tracking.

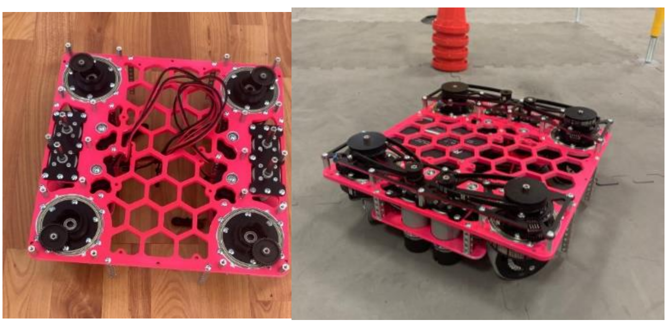


Figure 25. The upper motor transmission and absolute encoders are mounted.

Cable management: having a large number of cables, eight for each module, the best way to retain them and to avoid any hazardous situations was to add a polycarbonate plate under the system to protect them from external interactions.

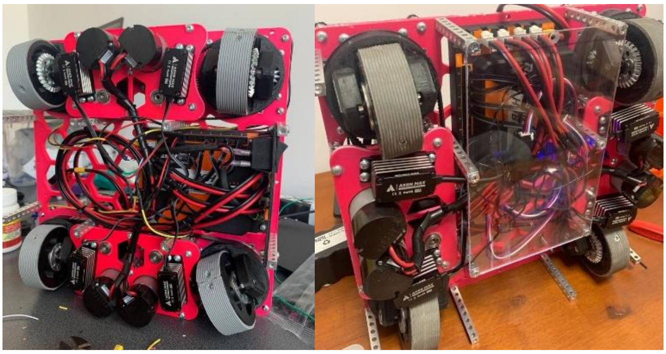


Figure 26. Covering all cables with a guarding polycarbonate plate.

The final step was adding the odometry modules, that, for customization reasons, can be detached using only three bolts and without making changes to the whole assembly.

Figure 27. The odometry subassembly

3.6 Costs

A large part of the cost of this project was allocated to the electronic components as follows:

- REV Robotics Control HUB – 350$ x1
- REV Robotics Servo Power Module – 57.5$ x1
- REV Robotics Through Bore Encoder – 48$ x2
- Modern Robotics/MATRIX 12VDC Motors – 25$ x4
- Axon Max Servomotors – 75$ x4
- Lamprey2 Absolute Encoder – 50$ x4

- Matrix 12V 3000mAh NiMH Battery – 50$ x1

Costs of belts, bearings and other mechanical components bought from vendors – 150$

Aluminum sheets and 3D printers' filament – 150$

Total: 1453.5$

Approximately 2/3 of this amount is allocated towards the acquisition of essential electrical components. The remaining budget is dedicated to the procurement of components that cannot be manufactured in-house and materials for manufacturing. These include items such as belts, bearings, aluminum plates, and Polylactic acid (PLA), utilized in the manufacturing of custom parts through CNC machines and 3D printers.

Owning such machinery for production of the custom parts may not be a feasible option for all entities looking to implement a swerve drivetrain. An alternative route for such cases is to engage the services of local businesses that specialize in such manufacturing processes. The cost of these services will vary depending on the locality and market conditions, and it is advisable to research and negotiate with multiple providers to secure the most cost-effective solution.

4. Studying all chassis

In this section, we conduct a comprehensive analysis of the different chassis types presented in our survey, including the swerve-driven prototype and three conventional chassis: a six-wheel drive, a mecanum chassis, and a tread drive.

Our evaluation focuses on key criteria that are crucial for assessing the effectiveness of each chassis type. The criteria include:

- Mobility: Ability to traverse challenging terrains, including uneven surfaces, obstacles, and steep inclines.
- Precision and Maneuverability: Capability to perform tasks requiring accurate movement and positioning, such as navigating through tight spaces, picking up and moving objects, and executing complex maneuvers.
- Modularity: The extent to which the chassis can be customized for different applications, considering ease of modification, replacement, and upgrade of components.
- Maintenance Requirements: The ease with which maintenance can be performed, including the replacement of worn-out or damaged parts.

Each criterion has been measured using a standardized scale ranging from 0 to 5 (0 representing the lowest performance and 5 the highest).

	Swerve Drive	Mecanum	Six-Wheel Drive	Tread Drive
Mobility	5	3	1	2
Precision and Maneuverability	5	4	2	2
Modularity	4	5	5	4
Maintenance Requirements	4	4	5	4

Table 1. Results obtained by every chassis type for different tests.

Following a closer analysis of all the chassis, we were able to determine certain weak points and strong points for each one.

The mecanum suffered loss of grip due to the specific construction of the wheels with rollers placed at 45 degrees. There is a risk that residues get stuck between the rollers, drastically reducing performance. The maintenance of the rollers was difficult, but at the same time the possibility of quick change of the wheels allowed a high modularity. The precision and maneuverability were similar to those of the swerve type chassis, with small redundancies on challenging surfaces.

Six-wheel and tread drives have shown impressive capabilities to transport heavy objects due to the increased traction they offer. Maintenance for both was very easy, having a small number of moving parts that can wear out during use. Modularity was a strong point, allowing the chassis to be adapted to many conditions. However, maneuverability and mobility suffered, these chassis not having the ability to move holonomically, making them unusable in areas with reduced freedom.

Swerve drives managed to combine all qualities of the chassis presented above. With traction equivalent to six-wheel or tread drives and with the ability to move holonomically like mecanum chassis, swerves become the perfect choice for applications that require a high degree of versatility. Although the system requires a more complex construction to benefit of all these attributes, when implemented correctly, it acquires modularity and easy maintenance, similar to common chassis. The subsystems allow for isolated replacement of faulty parts without requiring the change of the entire assembly as in the case of mecanum wheels, becoming much more efficient in terms of costs over an extended period of time. These chassis offer a variety of options through which can adapt to any environment, for example incorporation of a suspension in module's design [5].

5. Conclusions

The exploration of versatile multi-axis chassis, particularly the swerve-driven robots, represents a groundbreaking solution with far-reaching implications for various industries. The study conducted here affirms the exceptional capabilities of swerve chassis in terms of mobility, precision, modularity, and maintenance efficiency.

The swerve-driven robots showcase unparalleled maneuverability, allowing independent control of each wheel in any direction. An attribute invaluable in tasks that demand precise positioning, making them optimal for applications such as search and rescue operations. The ability to navigate challenging terrains and hazardous environments, coupled with the incorporation of sensors and cameras, enhances their utility in scenarios where human safety is a top priority.

The research undertaken involved the development of a scaled-down prototype, which underwent rigorous testing alongside conventional chassis types. The results clearly demonstrate the superior performance of the swerve-driven prototype, outperforming other chassis in terms of efficiency. This affirms the potential of this new generation equipment, emphasizing its efficacy in diverse fields, particularly in healthcare settings where space constraints and the need for quick, efficient mobility are crucial.

Despite the evident advantages, it is noted that swerve chassis technology is still relatively unexplored and underutilized. The study highlights the need for increased research and development in this area, encouraging broader adoption of swerve-driven robots across various industries. The comparison with other chassis types, including mecanum, six-wheel drive, and tread drive, emphasizes the unique strengths of the swerve-driven design, positioning it as a versatile and efficient choice.

In conclusion, swerve-driven robots present a paradigm shift in the field of robotics, offering a solution that combines the traction of traditional drives with the holonomic capabilities of mecanum wheels. The study aims to inspire further exploration and application of swerve chassis technology, paving the way for innovative and impactful advancements in the realm of robotics and automation.

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