2024-2025 SEASON

ROBOAS

Inovation Design Creativity Impact Problem-solving STEM Build

INTO THE DEEP

NATIONAL COLLEGE "ANDREI ȘAGUNA"
BRAȘOV

RO_009

#19082

Autoliv Partnership

Autoliv is a globally recognized leader in designing and manufacturing car safety equipment and custom parts for production lines. Fortunately for us, they have a factory right here in Brașov, which provided us with a fantastic opportunity to collaborate.

From the beginning, we established a strong connection with members of their engineering team, who were excited about our work and impressed by our progress in the competition.

Their support went beyond simply providing necessary components—they shared their valuable expertise with us, teaching us systematic approaches to problem-solving that they use in real-world industrial design.

As part of their mentorship, they gave us multiple guided tours of their factory, explaining how they develop industrial robots and automation systems for the automotive industry.

Seeing their process firsthand was an eye-opening experience, revealing how closely our work in FTC robotics aligns with real-world product development in a competitive market.

One of the biggest contributions Autoliv made to our team was helping us build our first lift prototype in their workshop. Since the design required precisely shaped and pressed steel sheets, their manufacturing capabilities were essential to bringing our vision to life. In addition to this, they further supported us by ordering several critical robot components and manufacturing custom aluminum plates, which played a major role in our success this season.

3Ddot parthnership

3Dot is a Brașov-based company specializing in professional 3D printing services. We were fortunate to collaborate with them and gain valuable insights into 3D printing technologies that enhanced our robot's design.

One of the key highlights of our partnership was being invited to a major tech event in Brașov, where we shared a stand with 3Dot. This opportunity allowed us to showcase the potential of 3D printing in robotics while engaging with a diverse audience, including technology enthusiasts and individuals interested in the FIRST Tech Challenge. Our interactions at the event helped us promote FTC robotics and our team while also learning from experts in the field.

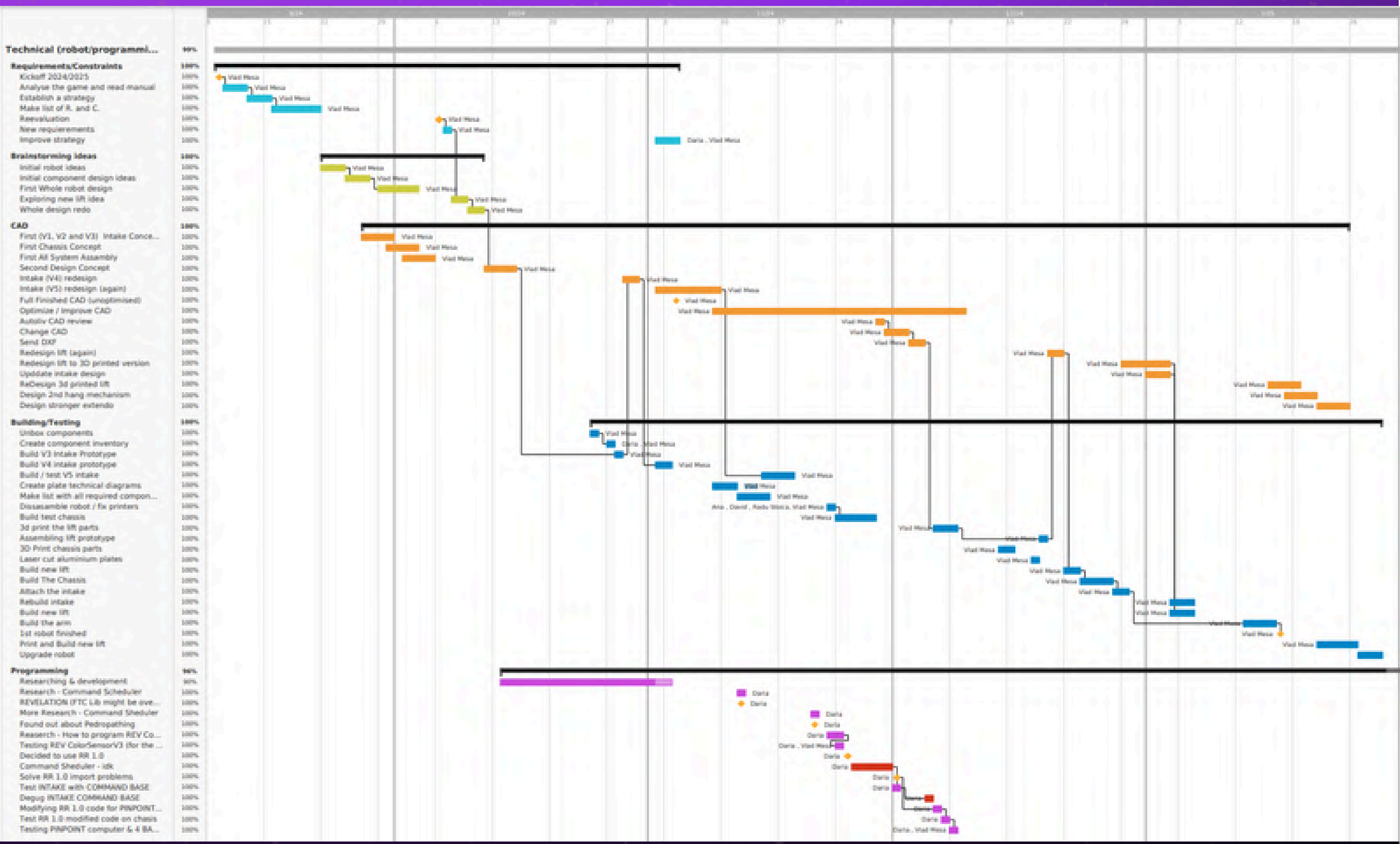
On the technical side, 3Dot provided crucial guidance on different types of 3D printing materials, their unique properties, and which ones would be most effective for reinforcing our lift. Thanks to their expertise, we were able to make informed design choices that improved the strength and durability of our robot. Additionally, they supplied us with essential materials and printing time, significantly accelerating our design process and helping us achieve optimal results.

Team Organization

Managing an FTC robotics team while simultaneously building a high-performance robot presents many challenges. To stay organized, improve efficiency, and ensure no tasks were overlooked, we used TeamGantt, a professional project management platform. Their generous sponsorship provided us with a free €500 subscription, allowing us to fully leverage their tools.

With TeamGantt, we were able to create and assign tasks for ourselves and other team members, ensuring that everyone had a clear overview of the project timeline. The platform automatically adjusted our schedule whenever a task was delayed or completed earlier than planned, helping us stay on track throughout the season.

We made it a priority to document every completed task within the platform, detailing our processes, challenges, and key learnings. This created a comprehensive and easily accessible record of our progress, benefiting the entire team.



The Gantt chart shown here illustrates the breakdown of engineering tasks and how they aligned with our overall design process. Our workflow closely followed structured steps, including:

- Identifying requirements and constraints
- Conducting brainstorming sessions
- Developing designs in CAD
- Proceeding with building and assembly
- Finalizing programming and testing

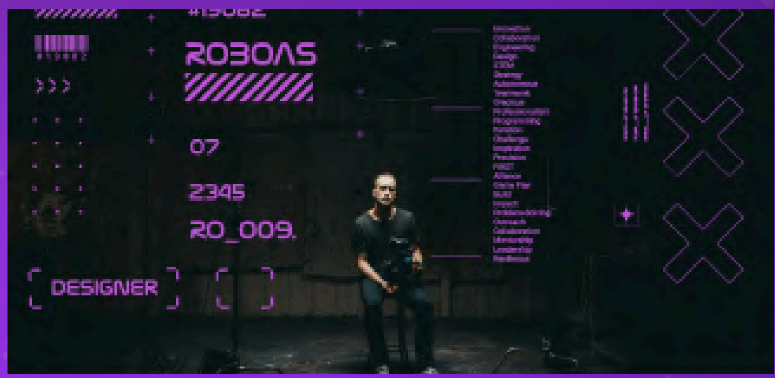
MARKETING PORTOFOLIO

Public relations (PR) plays a crucial role in shaping the identity and success of any group, including a robotics team. Through the team's journey in PR, members have developed a range of invaluable skills that extend beyond the technical aspects of robotics.

The team has gained a deeper understanding of branding, securing sponsorships, using design tools, and implementing effective marketing strategies. Each of these elements has contributed to individual and collective growth, reinforcing the importance of maintaining a strong public presence.

One of the most significant insights gained from PR efforts has been the art of brand creation. A brand is more than just a catchy name or an eye-catching logo—it represents the team's values, mission, and personality.

By establishing a strong and consistent brand identity, the team has been able to stand out in competitions and on social media. Developing a compelling visual and narrative identity has demonstrated how effective branding shapes public perception and creates new opportunities for growth and recognition.



Securing sponsorships has been another essential aspect of the team's PR journey. Attracting sponsors is vital for sustaining the team's operations, as it relies on financial and material support for competitions and development. Team members have learned how to research potential sponsors, write persuasive sponsorship proposals, and effectively communicate the benefits of sponsorship partnerships. This experience has helped refine negotiation and networking skills, demonstrating the value of persistence and professionalism in securing funding and resources.

Through PR initiatives, the team has also developed a deeper understanding of team identity, which encompasses branding, values, and community engagement. Maintaining a clear and unified identity has strengthened internal team cohesion while also enhancing its reputation within the robotics community. A well-defined identity has made the team more appealing to sponsors and supporters, further contributing to its long-term

Finally, exploring various marketing strategies has helped promote the team effectively. Whether through social media campaigns, event organization, or community outreach, the team has leveraged multiple platforms to expand its reach and increase awareness of its accomplishments.

Strategic use of social media, email newsletters, and public engagement has demonstrated the power of effective communication in fostering connections and strengthening the team's presence.
Through these experiences, the team has seen firsthand how strong PR efforts can significantly impact success, proving that a well-managed public image is just as important as technical performance in the world of robotics.

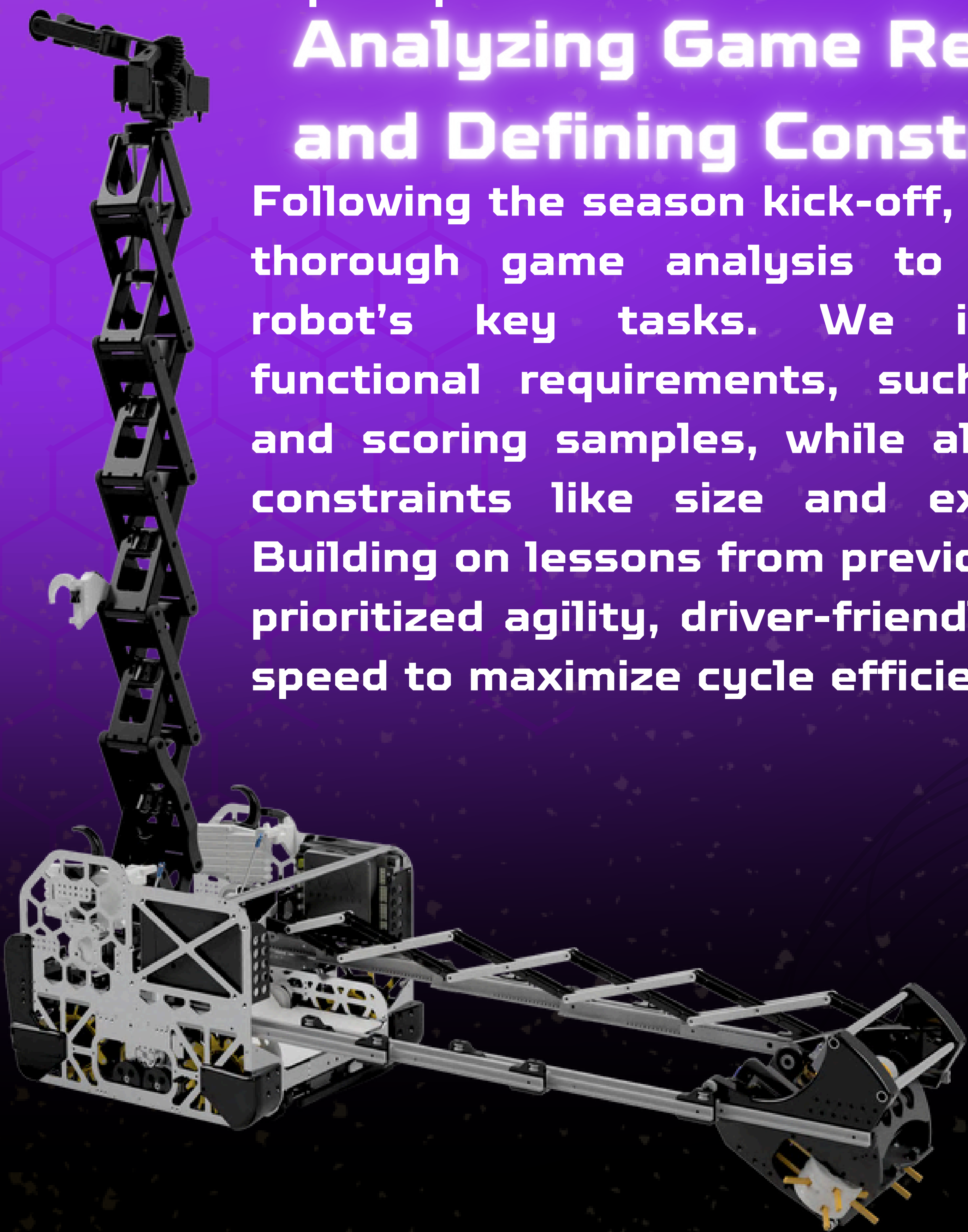
ENGINEERING PORTOFOLIO

I. Engineering design process

Genesis is a high-performance competition robot featuring a compact, belt-driven mecanum drivetrain for fast and stable movement. It utilizes an active intake mounted on an extendable mechanism to collect samples and specimens, which are then transferred to a 3-axis arm lifted by a custom scissor mechanism for precise scoring. Additionally, it boasts a rapid level 3 ascent for peak performance.

Analyzing Game Requirements and Defining Constraints

Following the season kick-off, we conducted a thorough game analysis to determine the robot's key tasks. We identified core functional requirements, such as collecting and scoring samples, while also establishing constraints like size and extension limits. Building on lessons from previous seasons, we prioritized agility, driver-friendly controls, and speed to maximize cycle efficiency.



Brainstorming and Concept Exploration

To explore various design possibilities, we developed a design matrix comparing multiple mechanism options for each task. For instance, we considered several intake methods, including claws, vertical brushes, and rubber rollers. After evaluating the strengths and limitations of each, we narrowed our options to two main configurations:

A pivoting extendo with a claw and computer vision.

An active intake on an extendable mechanism with a lift.

Detailed Design Analysis and Selection

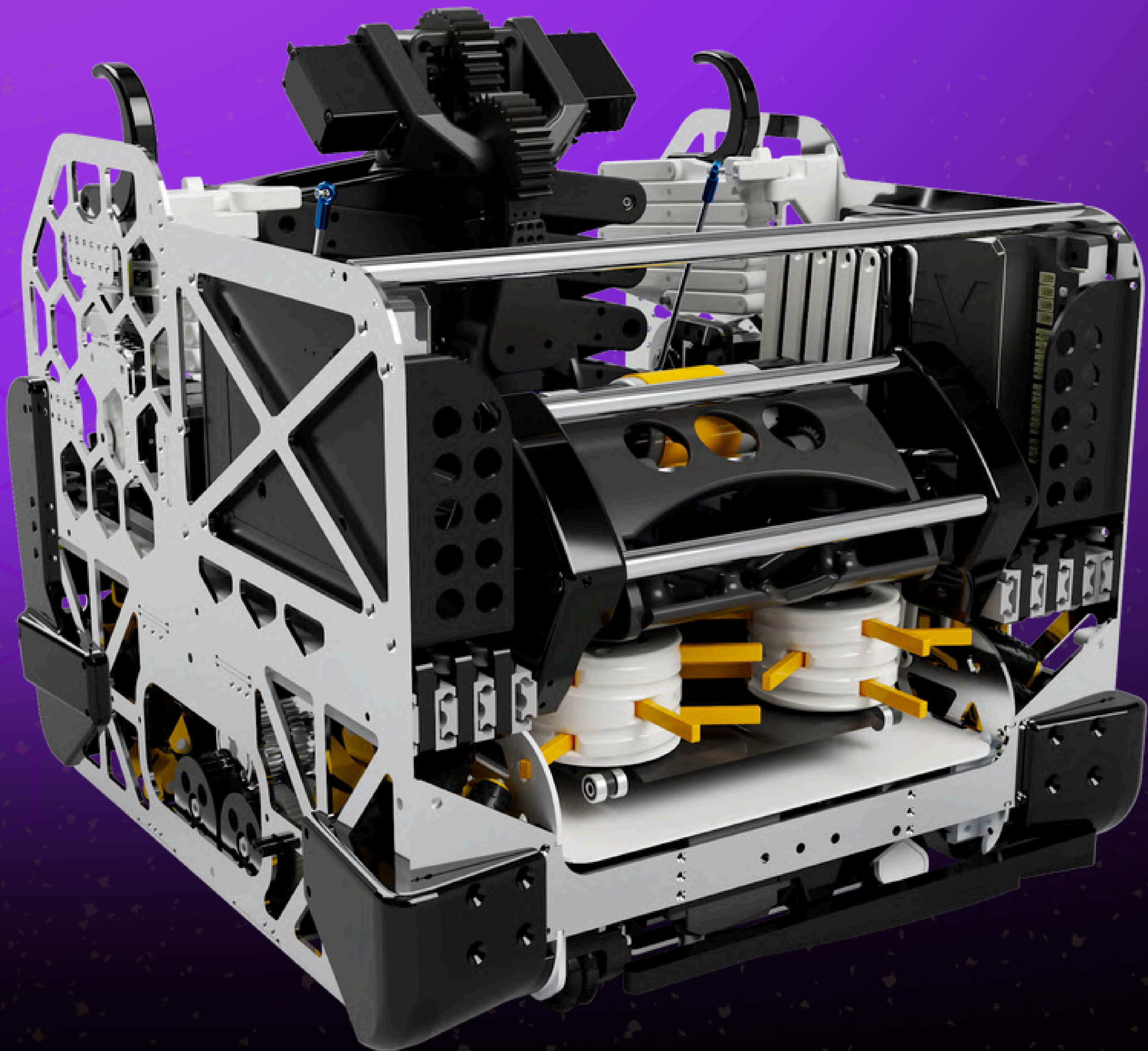
Each concept underwent detailed analysis, including feasibility assessments and design sketches. This process involved calculations, such as determining the number of slider modules required for the extendo and optimizing the claw shape for sample collection. Ultimately, we selected the active intake design due to its versatility—it could collect both samples and specimens while requiring less precision from the driver. This made it the optimal choice for speed, reliability, and ease of use.

CAD Design and Prototyping Approach

Using Autodesk Fusion, we created detailed CAD models to refine our design. We conducted structural stress tests on the aluminum chassis to ensure durability while opting for fully 3D-printed subsystems. This approach allowed for rapid prototyping, enabling quick modifications as we refined strategies and improved design solutions.

Iterative Prototyping and Testing

Our design process followed an iterative approach, leveraging 3D printing for continuous improvement. The intake system underwent seven redesigns, while the arm and lift were refined four times each. For every iteration, we followed a cycle of printing, testing, and modifying components until they met our performance standards. This rapid iteration process allowed us to optimize each system efficiently, ensuring peak functionality and reliability.



II. The chassis

Requirements Met

Our robot's design meets a set of critical engineering requirements to ensure optimal performance, durability, and efficiency during competition.

Drivetrain Compatibility

The structure is specifically optimized for a belt-driven mecanum drivetrain using GoBilda GripForce wheels. This setup enhances maneuverability, allowing for smooth omnidirectional movement while maintaining precise control. (FIG 1)

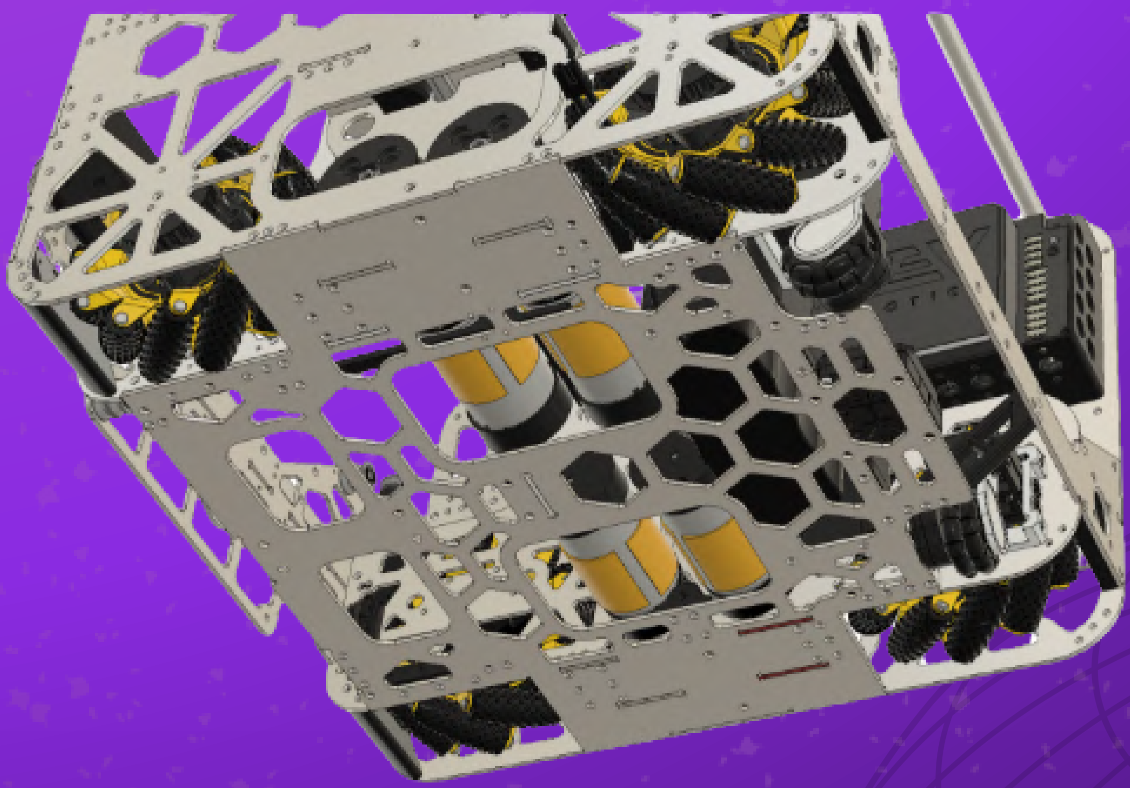


FIG. 1

Lightweight Design

Weight optimization was a key priority to improve acceleration and reduce power consumption, particularly during ascent. By minimizing unnecessary mass, the robot achieves faster cycle times while maintaining efficiency.

Structural Rigidity

To ensure durability under competitive conditions, the frame is engineered to evenly distribute stress across its structure. This high-rigidity design allows the robot to withstand impacts without compromising performance. (FIG 2)

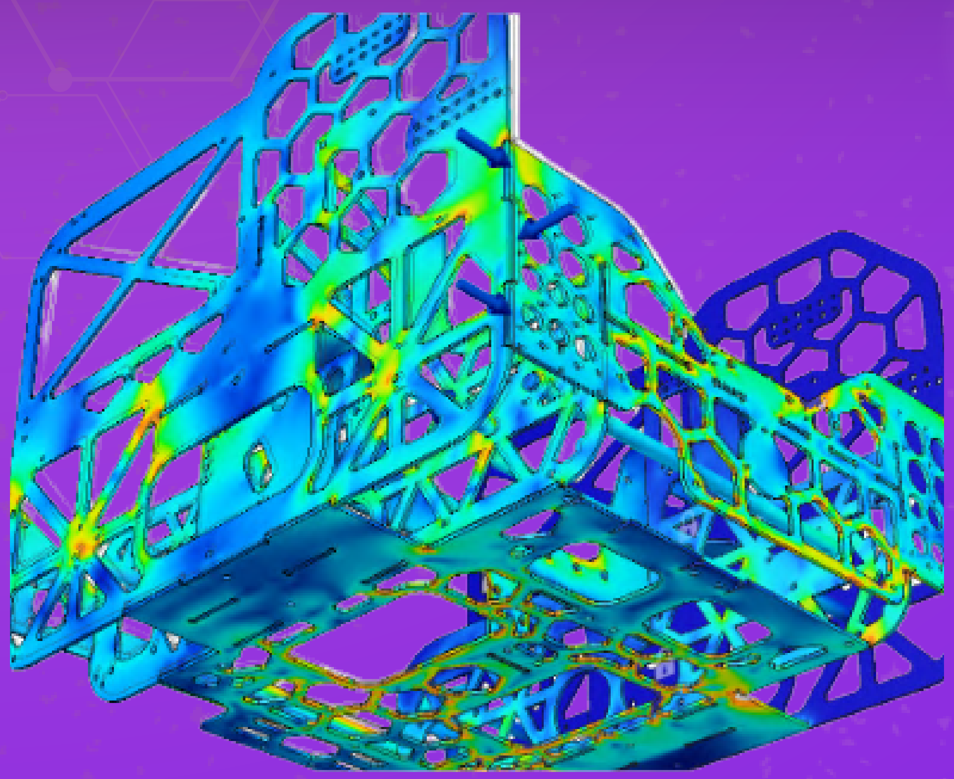


FIG 2

Seamless Component Integration

The chassis is designed to securely house all essential systems, including the extendo mechanism, motors, and electronics. Special attention was given to efficient cable routing and management, reducing clutter and improving reliability.

Compact and Agile

With a space-efficient design, the robot maintains a compact footprint for easy maneuverability while also optimizing for a smooth and effective level 3 ascent.

Low Center of Mass

By strategically placing heavy components lower in the structure, the robot benefits from improved stability and a reduced risk of tipping, especially during rapid movement and scoring.

Odometry Integration

The chassis accommodates the GoBilda odometry/Pinpoint system, enabling precise positioning and navigation. This feature enhances autonomous performance and ensures accurate movement throughout the match.

Power Take-Off (P.T.O.) System

The design includes a Power Take-Off (P.T.O.) mechanism, allowing the ascent system to share power with the drivetrain motors. This efficient power transfer minimizes energy loss and ensures a smoother, more controlled ascent. (FIG 3)

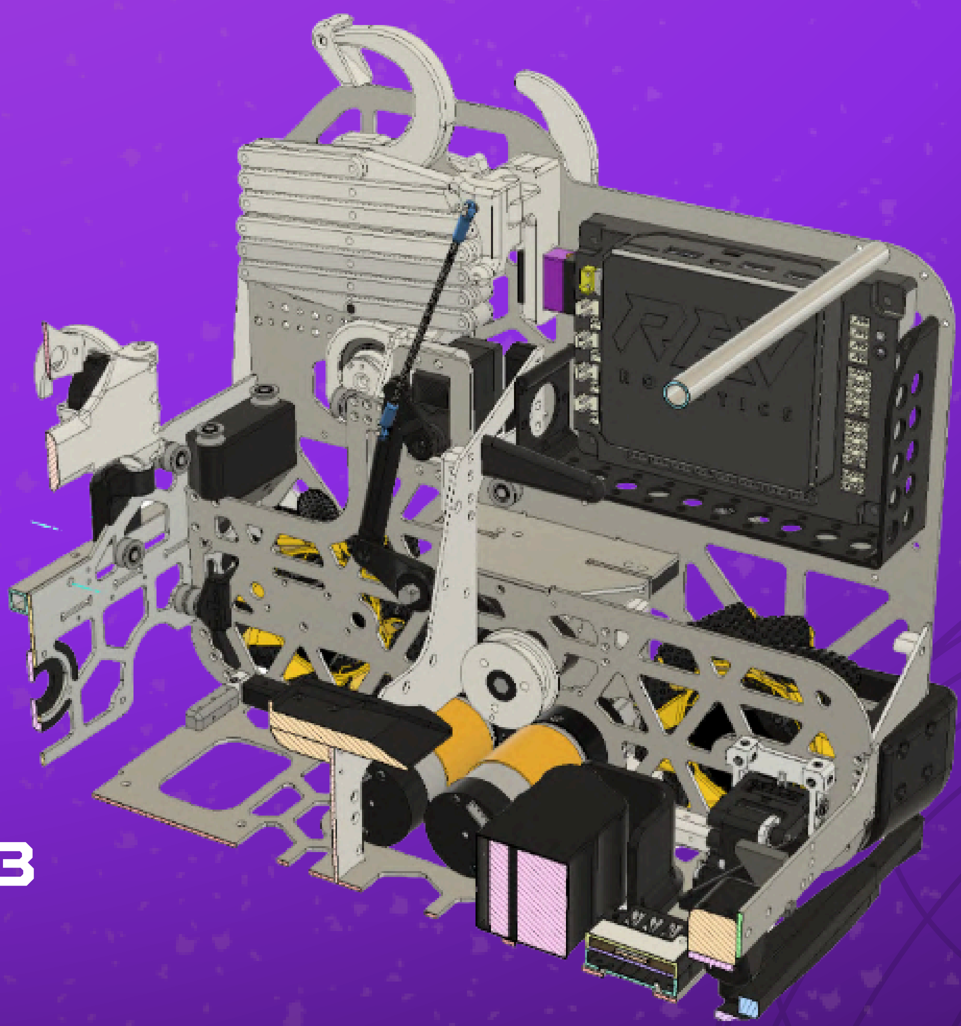


FIG 3

By meeting these key requirements, our robot achieves a balance of speed, durability, and precision, making it a high-performing contender in the competition. Let me know if you'd like further refinements!

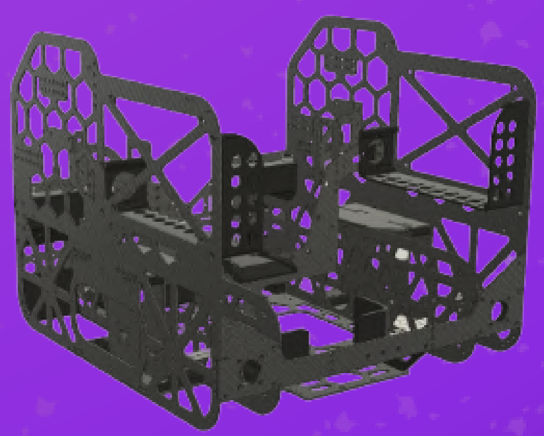
Chassis Design and Material Selection

In designing our chassis, we aimed to balance strength, weight efficiency, and cost-effectiveness while meeting all performance requirements.

Initially, we considered using carbon fiber plates due to their lightweight properties (FIG 4). However, after conducting a cost-benefit analysis, we determined that the €500 investment for a mere 500g weight reduction was not a practical trade-off. Instead, we opted for 2mm aluminum plates (FIG 5), which provided a strong and cost-efficient alternative without compromising durability.

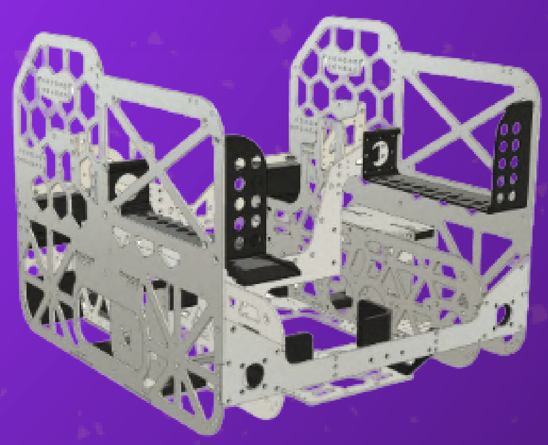
WITH CARBON PLATING

FIG 4



WITH ALUMINUM PLATING

FIG 5



The final chassis design meets all structural and functional requirements while maintaining a compact footprint of 35cm x 31cm x 27cm and a lightweight build of just 1.5 kg. It effectively integrates all key systems, ensuring proper fit and accessibility.

To enhance stability and maneuverability, the motors and battery are positioned close to the ground, lowering the center of mass and reducing the risk of tipping. Despite using thin 2mm aluminum, the interlocking plate design maximizes structural rigidity, distributing stress efficiently and ensuring high durability under competition conditions.

This carefully engineered chassis provides the ideal balance of strength, weight, and cost, making it an optimal foundation for our high-performance robot.

Interlocking Plate Design

To achieve a lighter yet structurally superior chassis, we conducted an in-depth analysis of traditional designs. Our findings revealed that much of the weight in standard chassis structures comes from inefficient construction, requiring thick 3mm plates, heavy steel standoffs, and M4 screws for rigidity. This issue was evident in last year's design. (FIG 6)
Our redesigned interlocking plate system eliminates 90% of metal standoffs and M4 screws, resulting in a 30% weight reduction compared to a standard chassis. The plates feature integrated tabs that interlock like puzzle pieces, bracing the structure across all three dimensions. This design effectively distributes loads and impacts evenly, maintaining exceptional rigidity without the need for excessive hardware.

The strength of the interlocking mechanism is so effective that the chassis can almost hold together without screws. To secure everything in place, we use lightweight 3D-printed brackets and small 2mm self-tapping screws. Since the plates bear the entire structural load, the screws experience no stress, unlike the Figure 4 design, where rigidity depends on the strength of heavy standoffs.

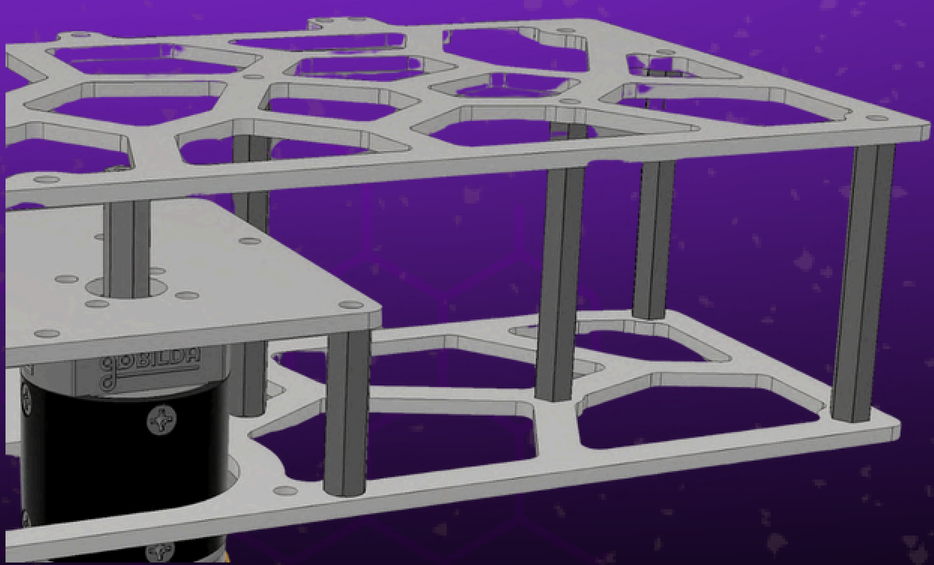


FIG 6

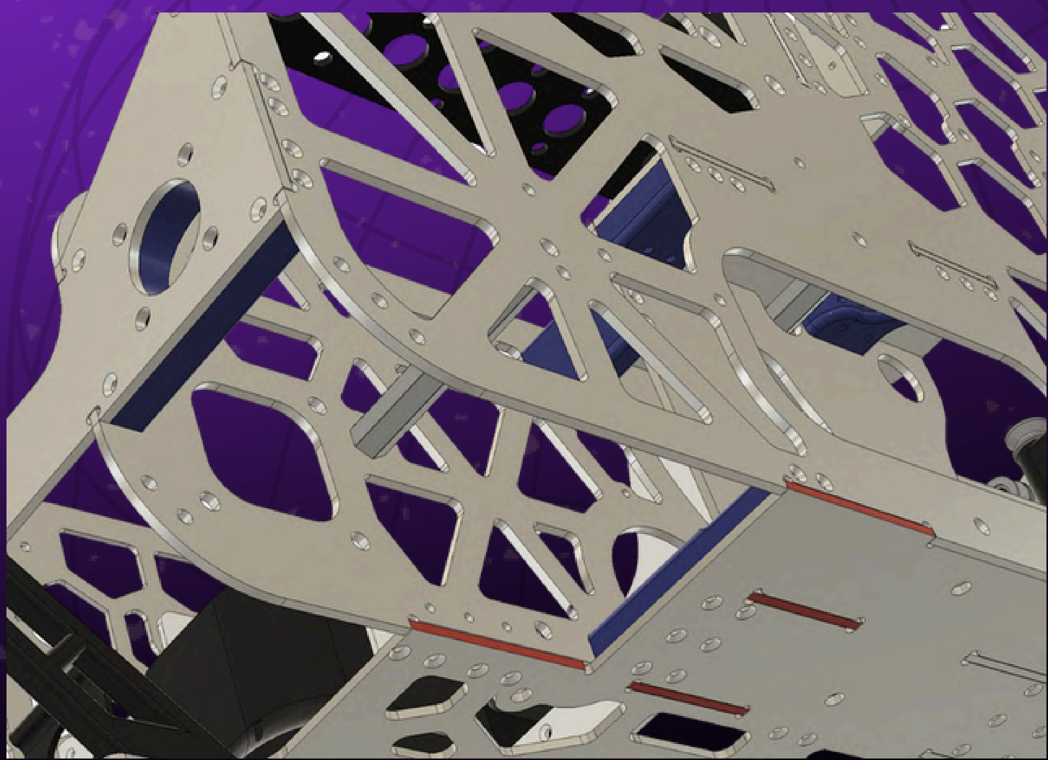
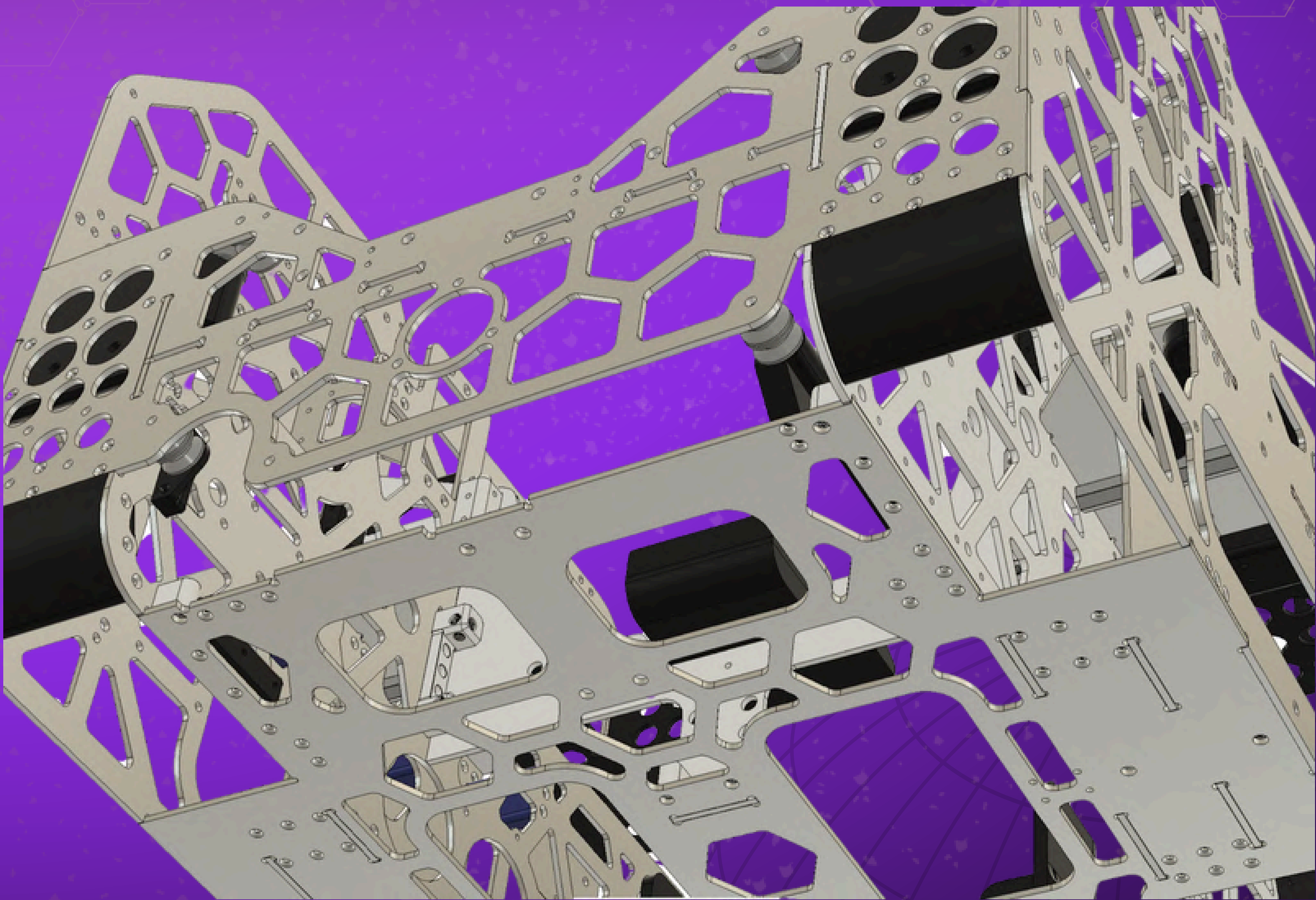
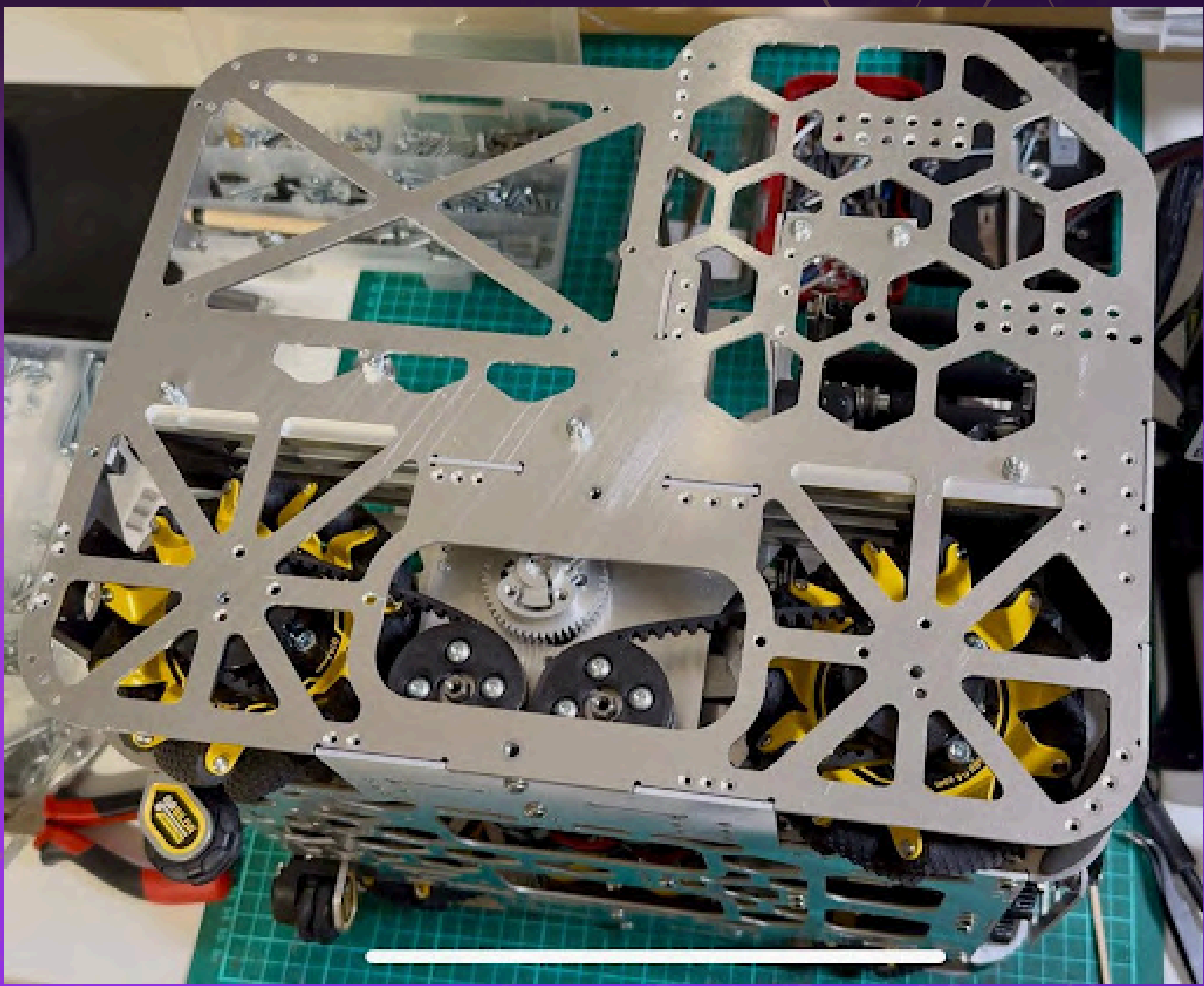


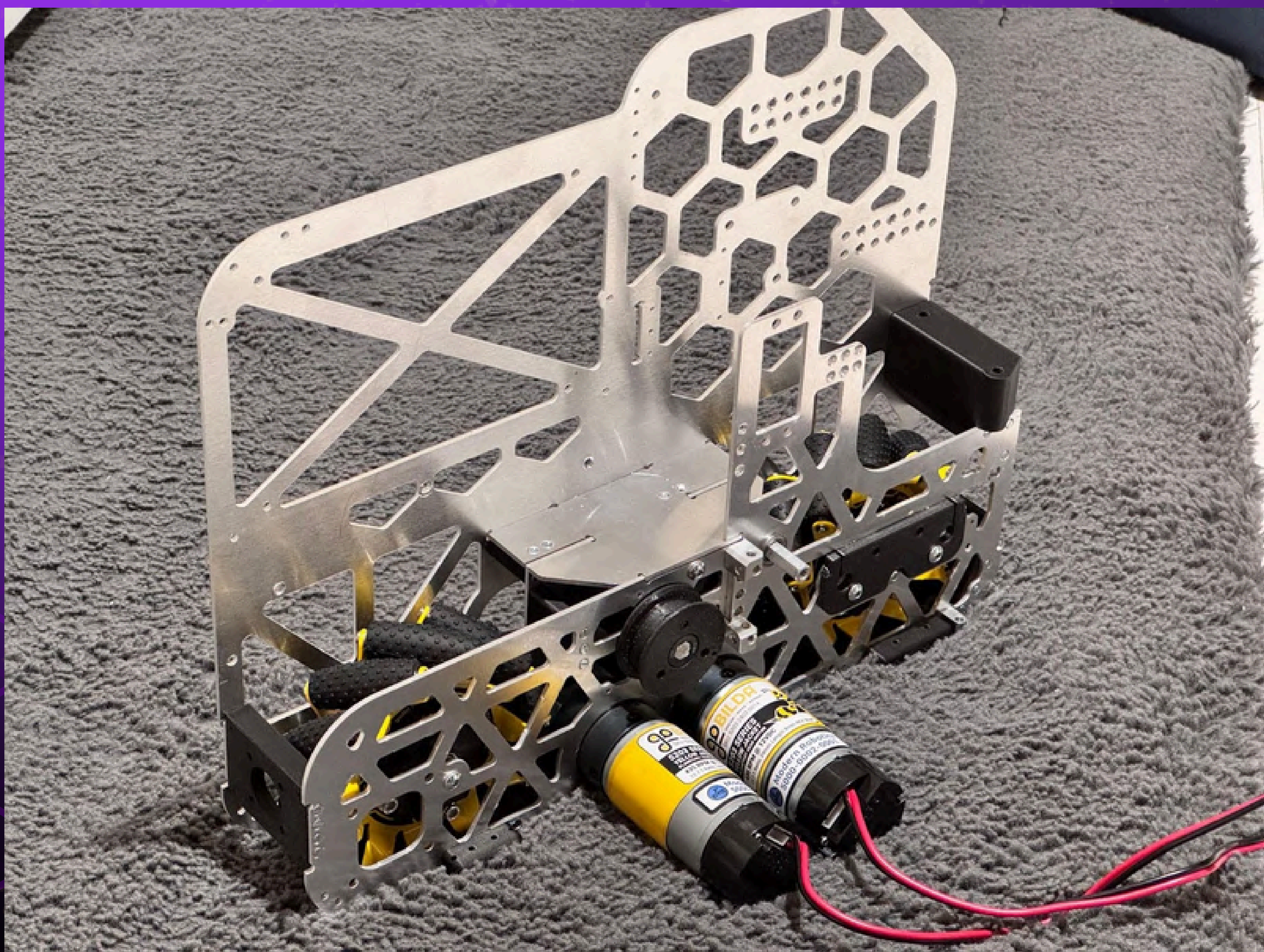
FIG 5

As shown in Figure 5, the interlocking tabs (highlighted in red) and plastic brackets (in blue) work together to create a lightweight, durable, and highly efficient chassis, ensuring maximum strength with minimal weight.

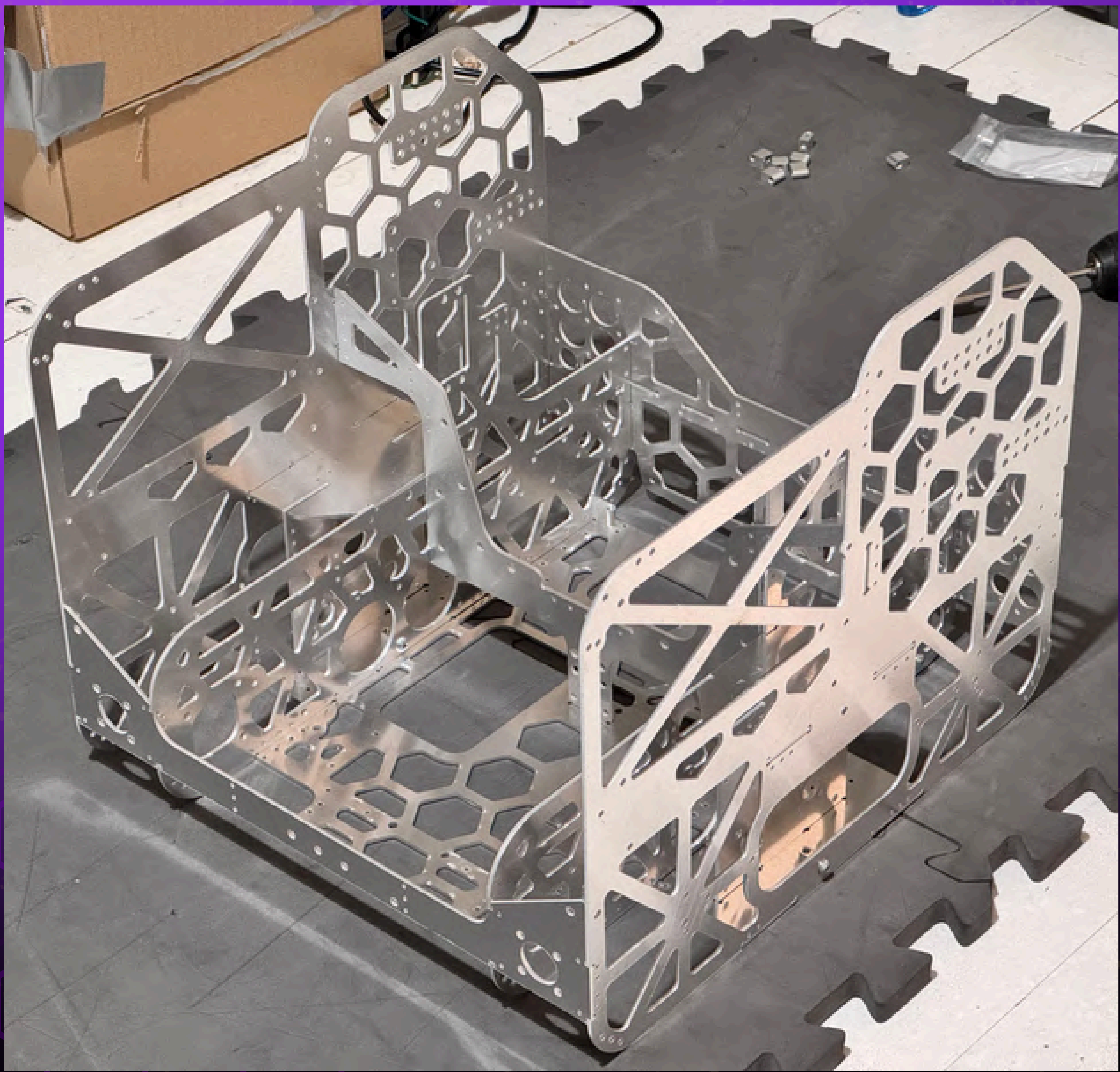


This innovative approach allows us to maintain rigidity, reduce weight, and simplify assembly, giving our robot a significant advantage in speed, efficiency, and durability during competition.





The chassis plates hold themselves together through a precisely engineered interlocking design, where each plate features tabs and slots that fit together like puzzle pieces, ensuring stability across all three dimensions. This mechanical locking system distributes stress evenly throughout the structure, preventing twisting, bending, or separation even under impact. The tight tolerances create a high-friction fit, meaning external forces actually push the plates tighter together rather than pulling them apart. Additionally, the strategic load distribution eliminates reliance on heavy fasteners, making the chassis both lightweight and structurally rigid. While 3D-printed brackets and small self-tapping screws provide extra alignment security, the chassis remains structurally sound even without them, showcasing a highly efficient and innovative assembly method.



III. The Intake

Intake Mechanism Design

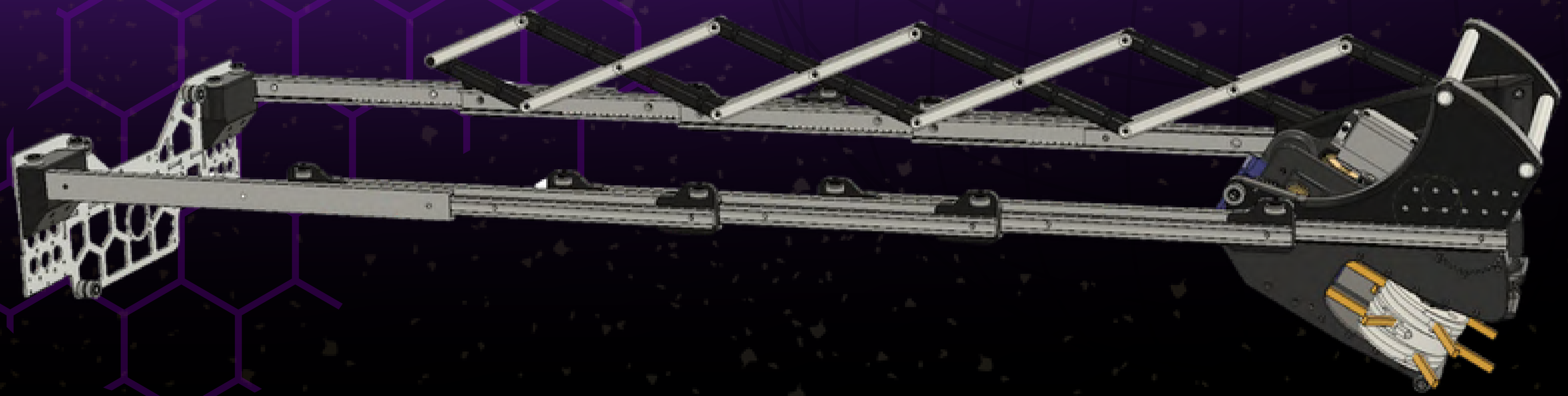
The intake mechanism is composed of two key components: the intake system and the extendo mechanism. This carefully engineered system ensures smooth sample collection, secure handling, and reliable performance in competition.

Extendo Mechanism

The extendo utilizes four Misumi slider modules connected in series, capable of extending up to 72 cm but intentionally limited to 65 cm for operational efficiency. It incorporates a scissor mechanism cable holder along with a reinforced structure, which serves two crucial functions.

1. Protecting the intake system from damage during deployment and retraction.
2. Ensuring continued operation even in the event of a cable failure, as the design prevents complete system loss.

To maintain smooth cable routing, we integrated multiple pulleys, each equipped with compact 3D-printed cable guards, minimizing interference and ensuring durability throughout repeated use.



Shape-Shifting Guide

To guide samples into the intake in the correct position, the mechanism features a spring-loaded four-bar system. When a specimen clip collides with the guide, it automatically retracts, allowing the clip to pass through. This feature ensures that the intake system can handle both samples (FIG 13) and specimens (FIG 14) reliably, adjusting dynamically to different object types.

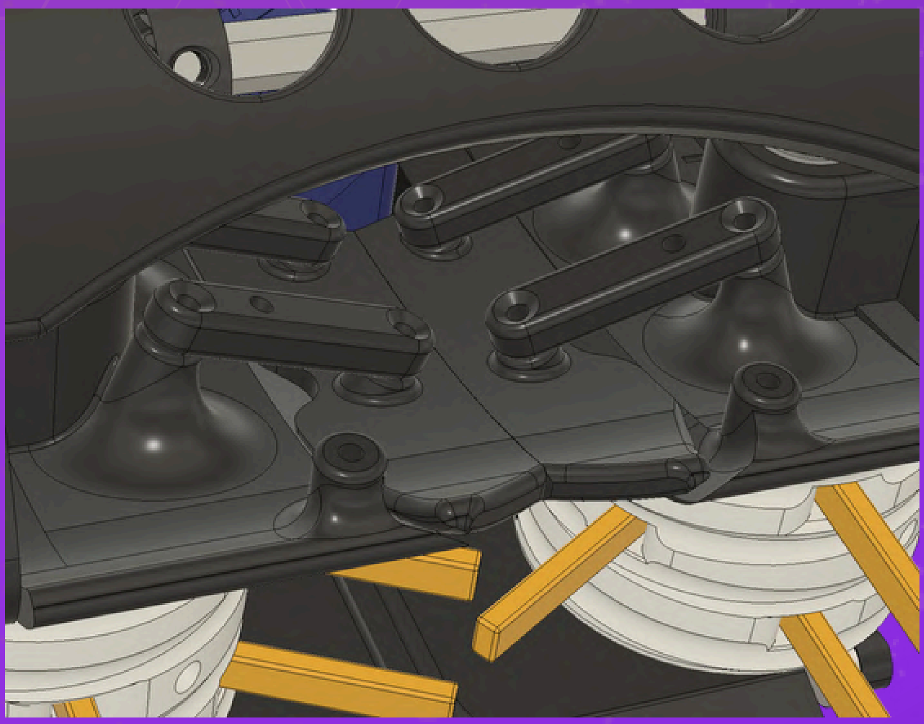


FIG 13

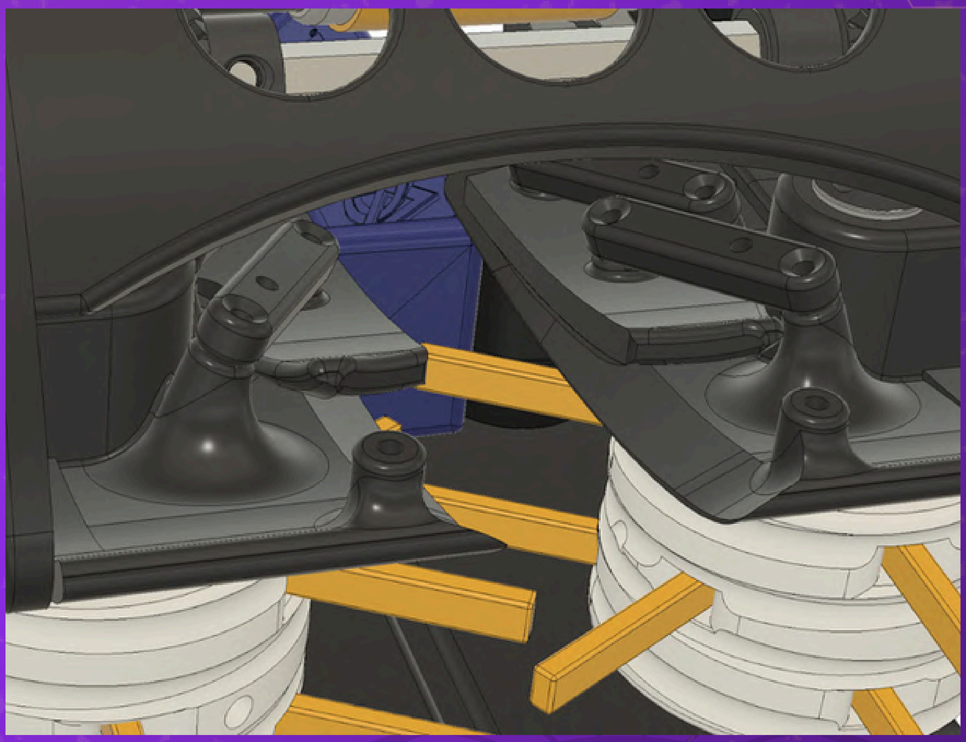


FIG 14

Tilt Servo

The tilt servo plays a crucial role in adjusting the intake angle (FIG 15). By precisely lowering the brushes into the submersible, it ensures effective sample collection, improving overall efficiency and reducing collection errors.

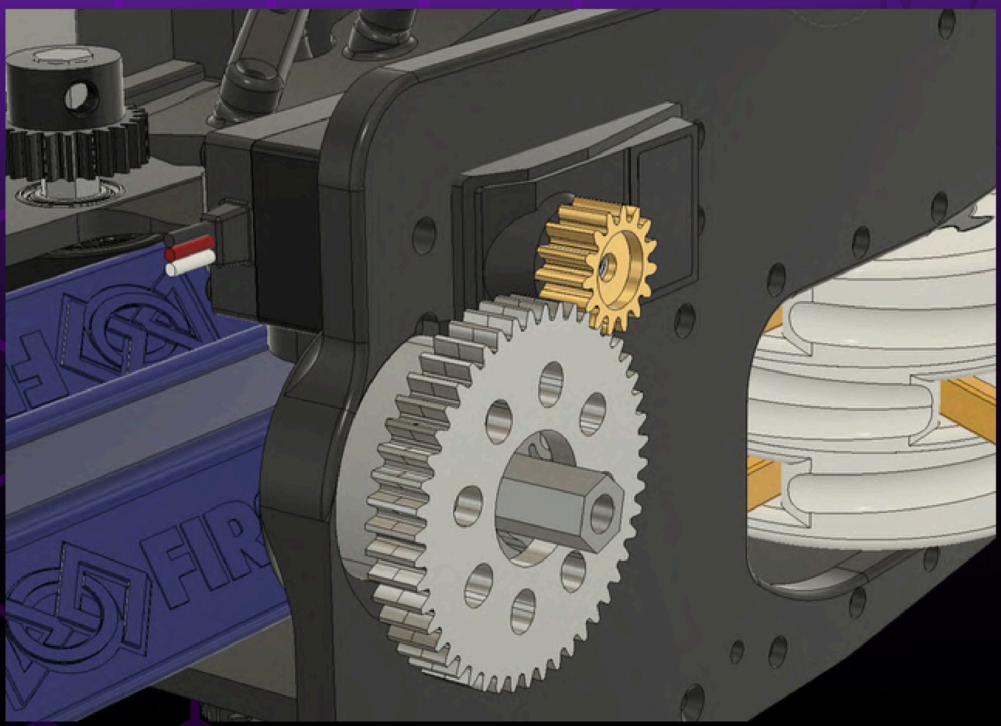


FIG 15

Main Brush System

The main brush, powered by a motor positioned at the top of the intake, efficiently picks up both samples and specimens. It consists of:

- A PLA-constructed structure reinforced with a flexible TPU insert on the axle (FIG 16; FIG 17;).
- Rubber bristles that actively pull in the sample for reliable intake.
- A hard outer shell with spiral channels, which ensures proper alignment of samples before further processing.

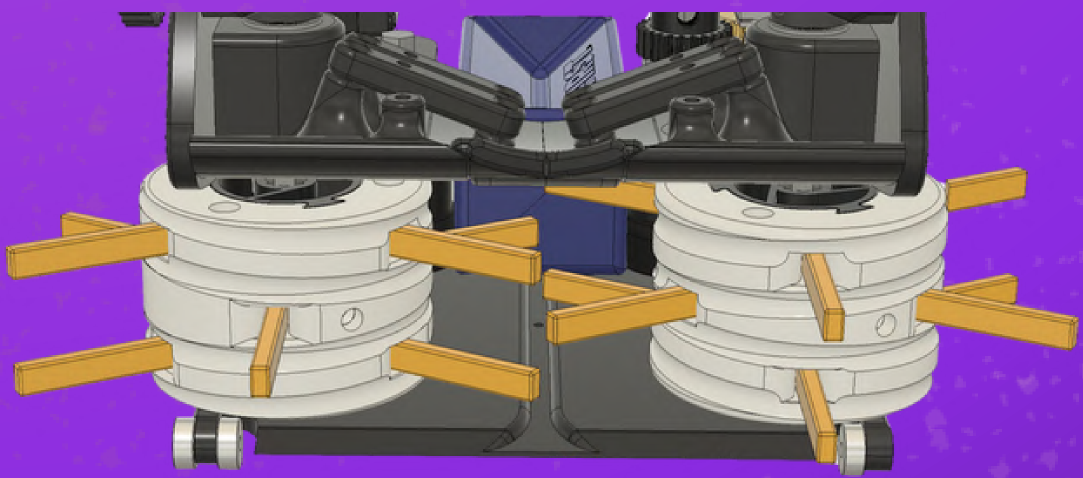


FIG 16

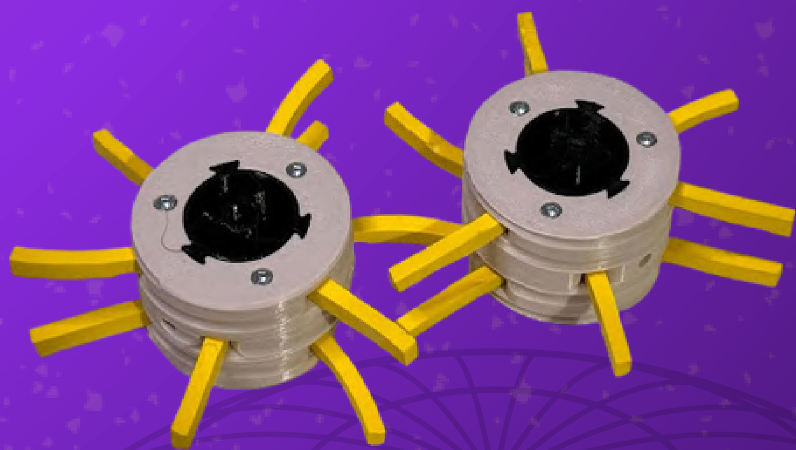


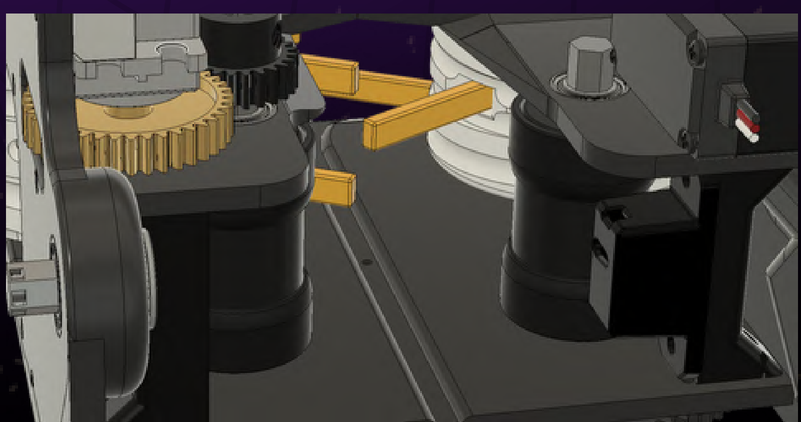
FIG 17

TPU Control Rollers

The control rollers, attached to a continuous rotation servo, enhance the system's ability to (FIG 18):

- Align samples or specimens within the intake.
- Lock them in place securely to prevent unwanted movement.
- Eject samples forward or backward, depending on sorting requirements.

FIG 18



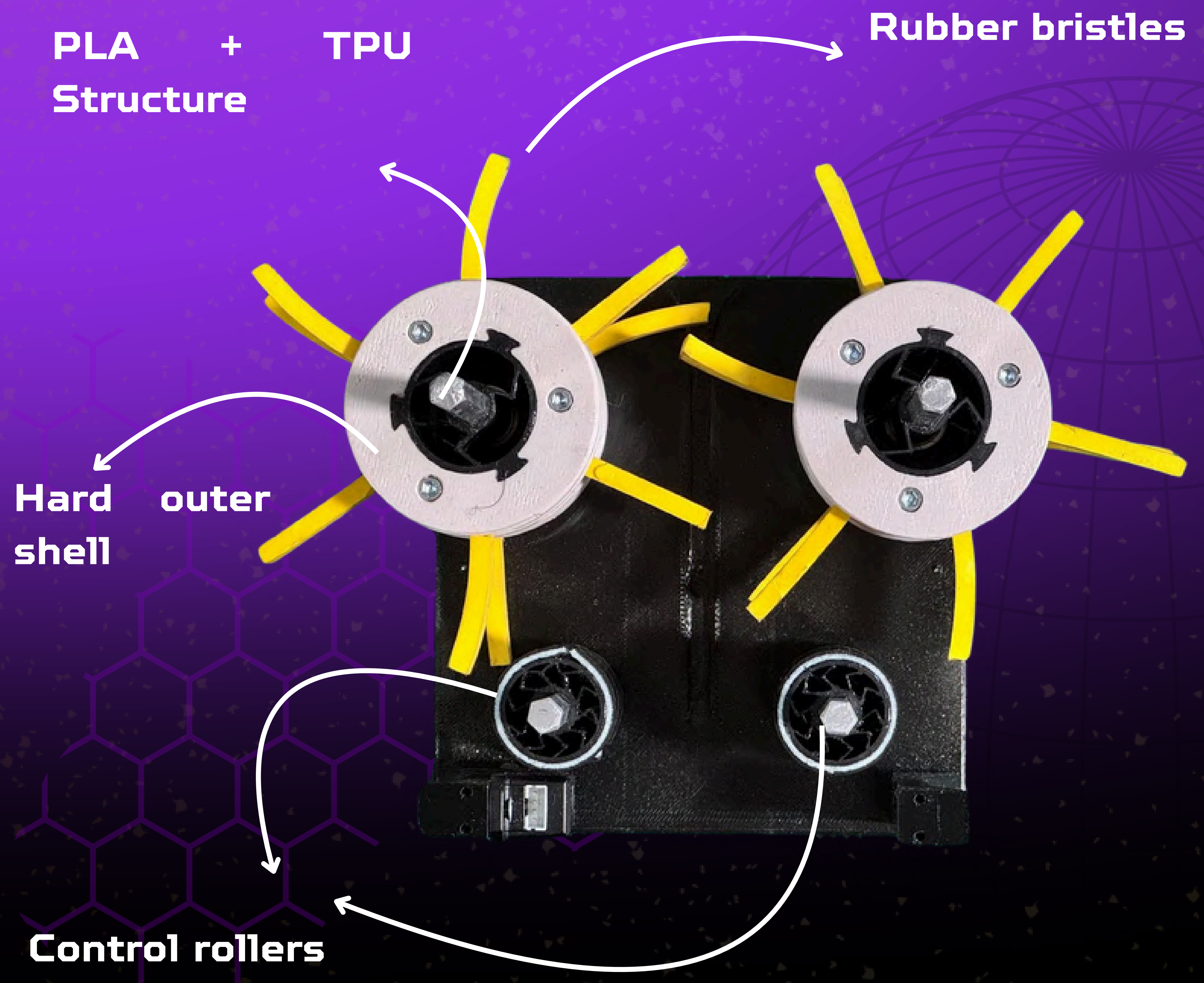
Automated Sample Sorting with Color Detection

A sensor detects the sample's color and works in coordination with the TPU control rollers to execute precise sorting actions. If the detected color matches the desired criteria, the rollers lock the sample inside the intake. If the color is incorrect, the system ejects the sample backward, making space for the next incoming sample.

Optimized for Performance

This intake and extendo mechanism ensures high reliability, adaptability, and efficiency. The combination of:

- Interlocking structural reinforcements
- Smart cable management
- Dynamic sample positioning
- Automated sample sorting

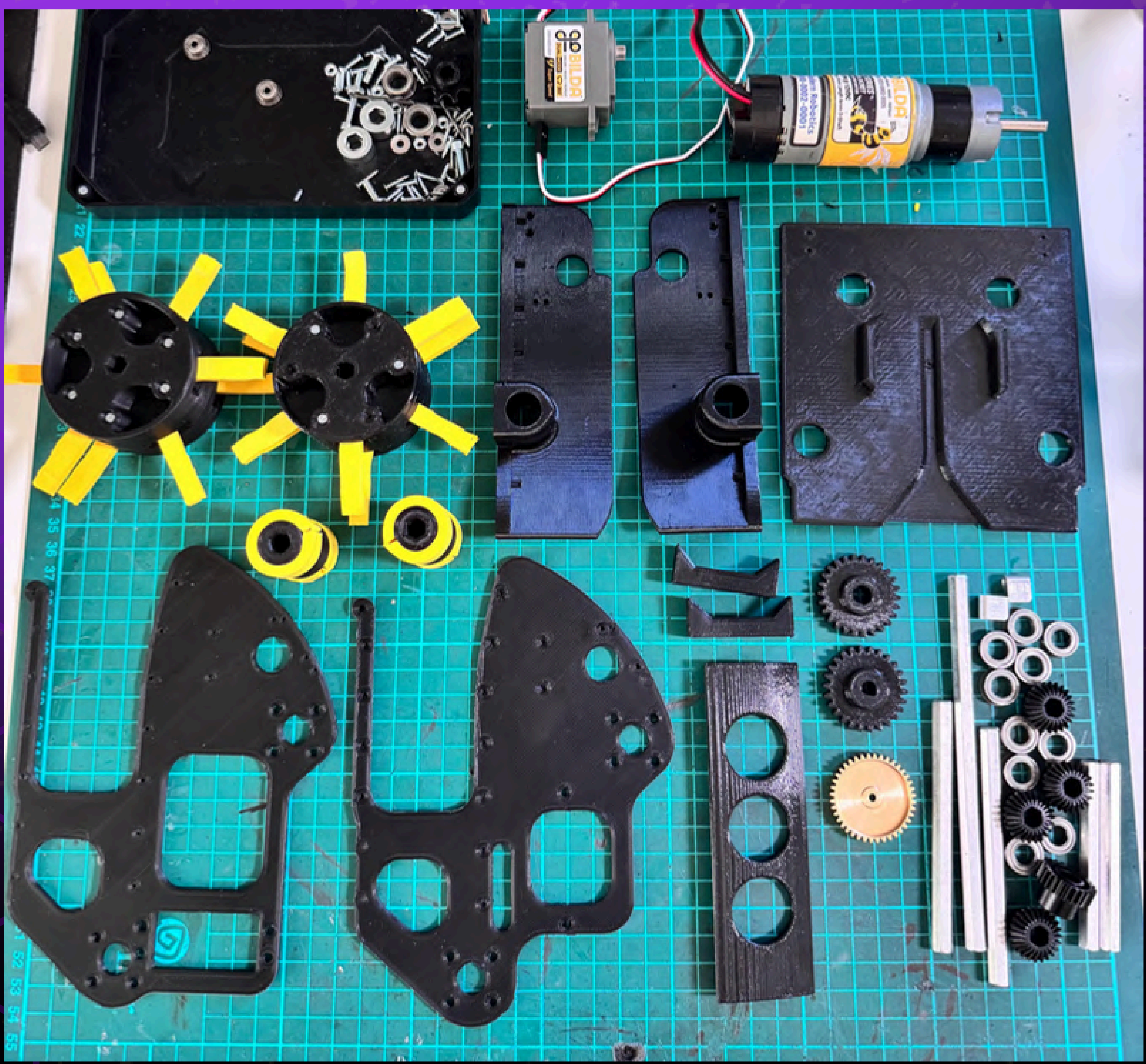


These are the prototypes for the intake and extendo mechanisms, showcasing the iterative design process that led to the final high-performance system. Each version was tested and refined to improve efficiency, durability, and adaptability, ensuring the intake could reliably collect samples and specimens under competition conditions. From early experimental designs to the fully optimized final version, these prototypes highlight the engineering challenges we tackled, including weight reduction, structural reinforcement, and cable management, ultimately resulting in a fast, reliable, and precise intake system.

First prototype

Second prototype

Third prototype



Lift Mechanism Design Approach

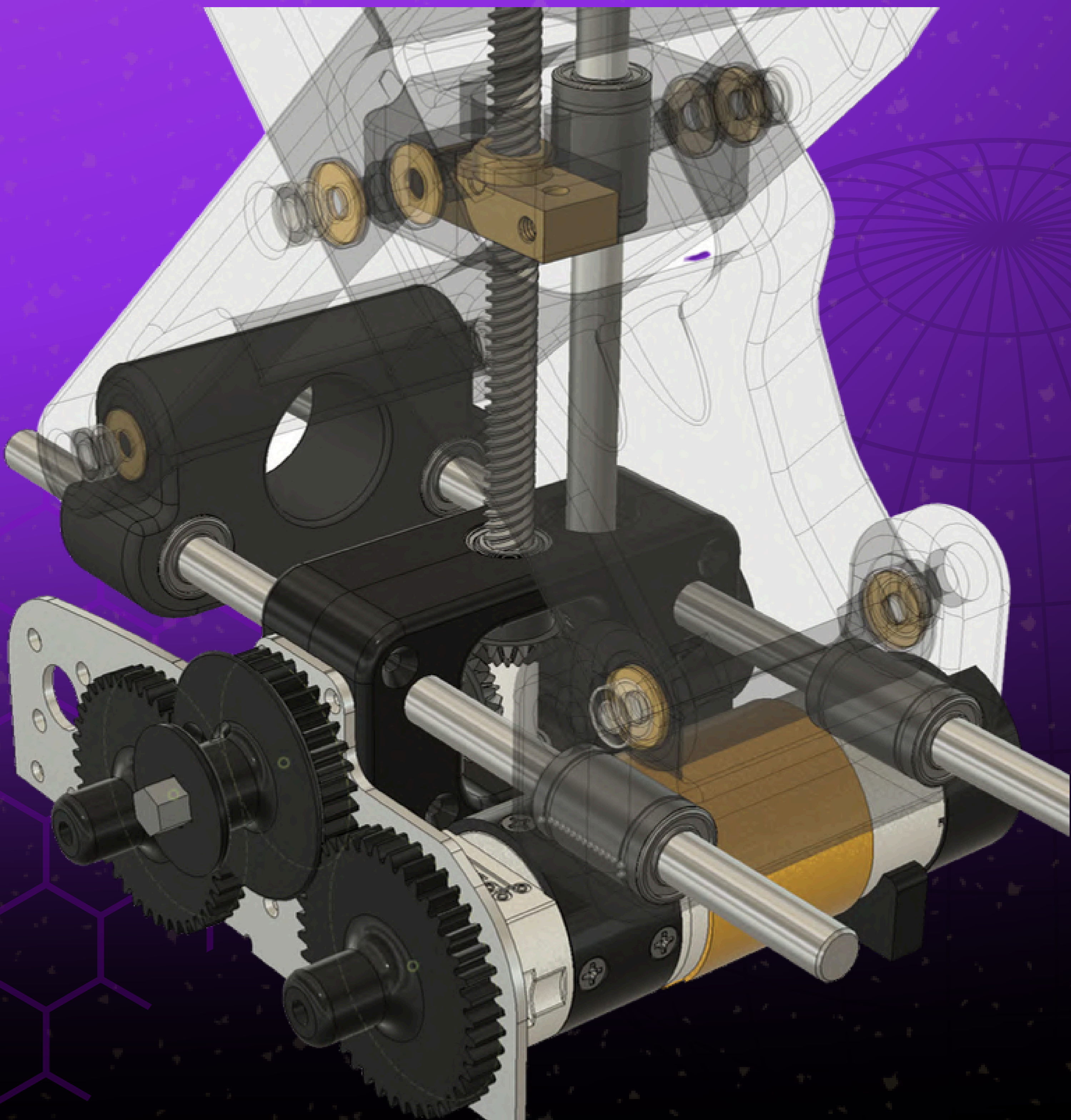
When designing the lift mechanism, we initially considered using sliders similar to those in the extendo system. However, after working extensively with Misumi sliders in the previous season, we wanted to explore a more innovative and unique solution. This led us to develop a scissor lift system, which provided significant advantages in weight, reliability, and maintainability.

How It Works

The scissor lift operates on simple mechanical principles, but achieving consistent and reliable performance required extensive optimization.

The primary challenge was efficiently converting the motors' rotational motion into linear movement. As shown in Figure 8, this was accomplished using a combination of spur gears, bevel gears, and a lead screw. This system transforms the high-speed, low-torque output of the two 1150 RPM motors into a powerful 800N linear force.

The gear ratio was carefully calculated to achieve the optimal balance of torque and RPM, maximizing lifting speed without compromising power. The detailed calculations for this optimization can be found on page 11.

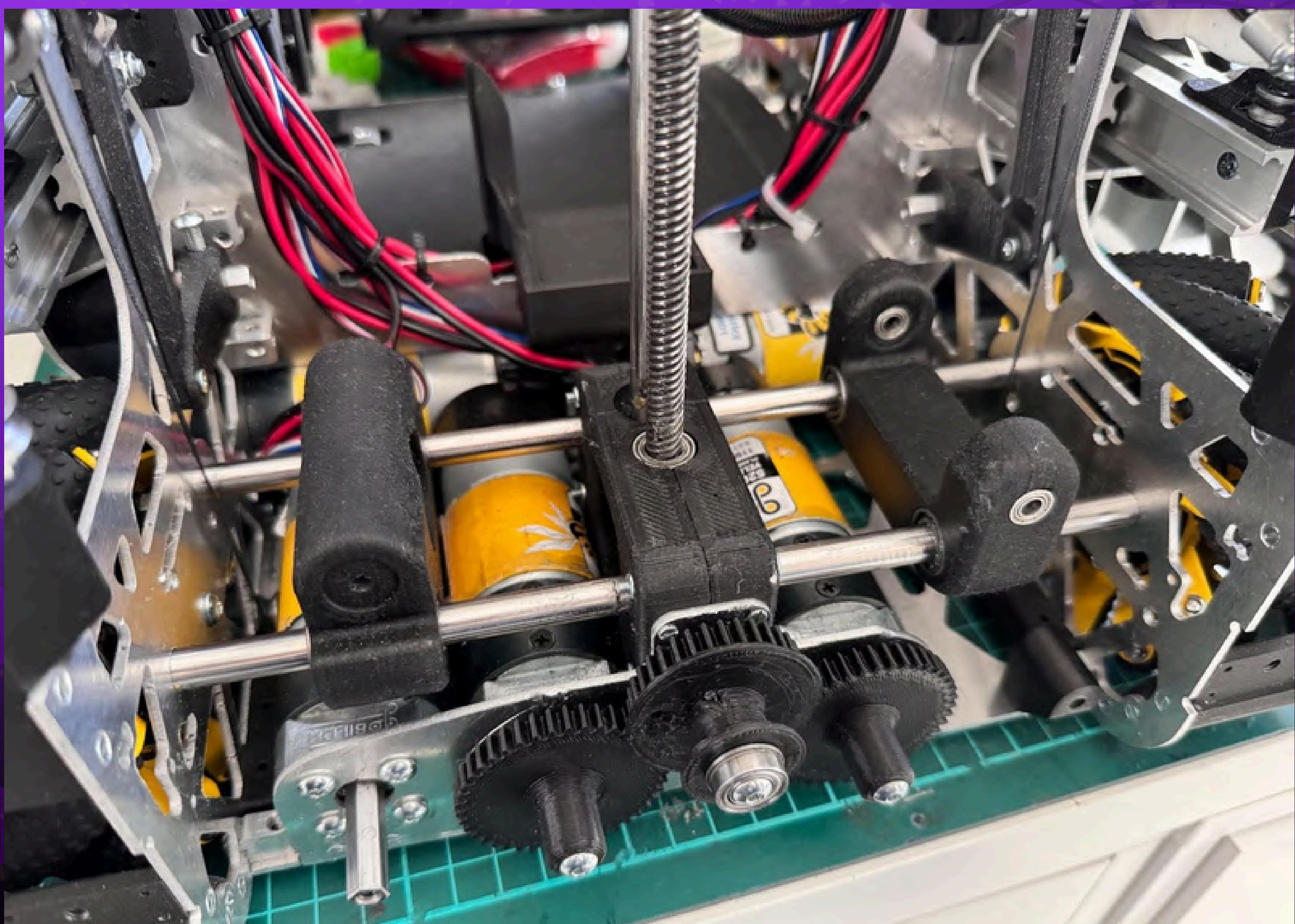


To ensure stability and smooth movement, the scissor mechanism is securely mounted to the chassis using three 8mm polished steel beams with linear bearings. This configuration provides support across all three axes, minimizing unwanted movement or misalignment.

Scissor Mechanism Design

The scissor lift is constructed using 3D-printed components, with different materials selected based on their structural demands:

- Inner modules are printed in PETG, offering flexibility and impact resistance.
- Outer modules are printed in CF-PLA, providing enhanced rigidity and strength.



For smooth operation, the modules are connected using ball bearings and metric screws secured with embedded nuts.
To optimize weight distribution, component sizes and infill density decrease toward the top, where less force is required. Additionally, strong counterbalance springs are installed between modules, counteracting gravity and maximizing lifting speed.
This fully optimized mechanism weighs under 1kg and is capable of lifting a sample to basket height in just 0.6 seconds. Additionally, it features capabilities for the Level 2 ascent (more details on page 10).

Scissor Lift vs. Misumi Sliders

We conducted a comparative analysis between our scissor lift and traditional Misumi slider mechanisms, evaluating their advantages and trade-offs.

Advantages of the Scissor Lift:

- The lifted parts are approximately 500g lighter compared to an equivalent-length slider mechanism.
- The elimination of strings enhances reliability, removing risks of tangling or snapping.
- Easier repairs due to its accessible structure and modular 3D-printed design.
- Provided a better learning experience, as it was a new engineering challenge for our team.

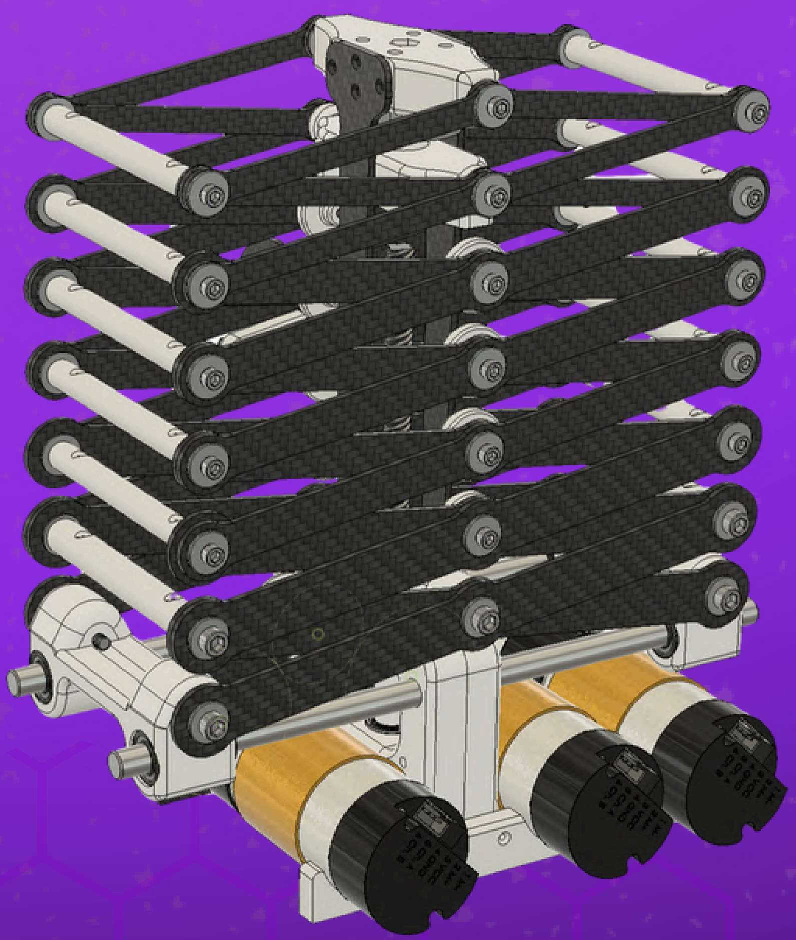
Advantages of Misumi Sliders:

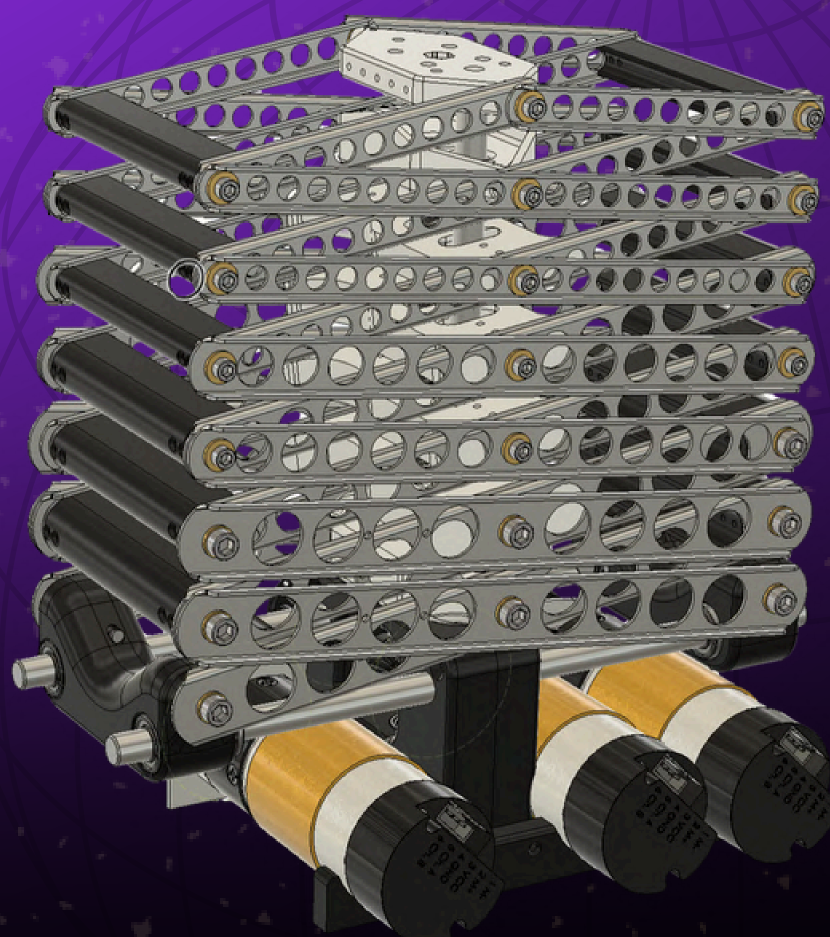
- Slightly faster movement when used efficiently.
- Higher rigidity at lower extensions, providing a more stable base.
- More accessible, requiring no specialized knowledge in 3D printing.
- Dual functionality, as they can also serve as a Level 3 ascent mechanism.

Design and Development Process

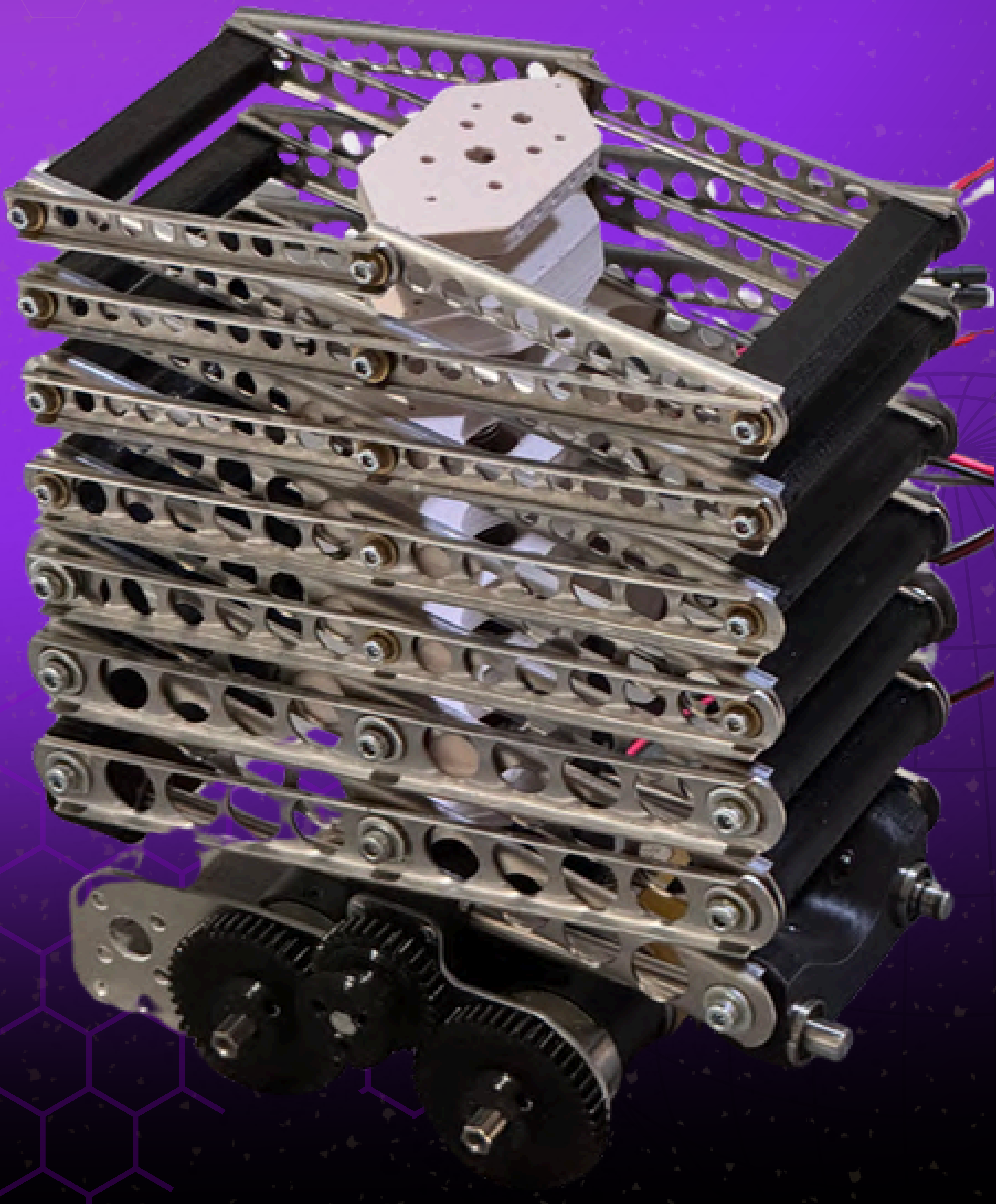
The development of this lift system posed several challenges. Initially, we planned to use carbon fiber plates, but due to budget constraints, we switched to stainless steel. However, the steel version was too flexible, which compromised performance.

This led us to develop a fully 3D-printed version. After multiple iterations, the second version successfully met all design requirements, balancing weight, strength, and reliability.





The stainless steel lift version was an early attempt to create a strong and durable lifting mechanism, but despite its promising material properties, it ultimately proved to be too flexible and structurally inefficient. The main issue arose from the inherent properties of stainless steel—while it is strong and resistant to deformation, it also has a tendency to bend under load when used in thin sections. Because the lift relied on long, narrow beams, the steel would flex unpredictably, reducing precision and making the system unreliable for consistent lifting.



Conclusion

By adopting the scissor lift system, we achieved a lightweight, highly reliable, and easy-to-maintain lift mechanism. The decision to explore alternative solutions beyond traditional sliders not only enhanced our robot's performance but also provided a valuable learning experience for our team.

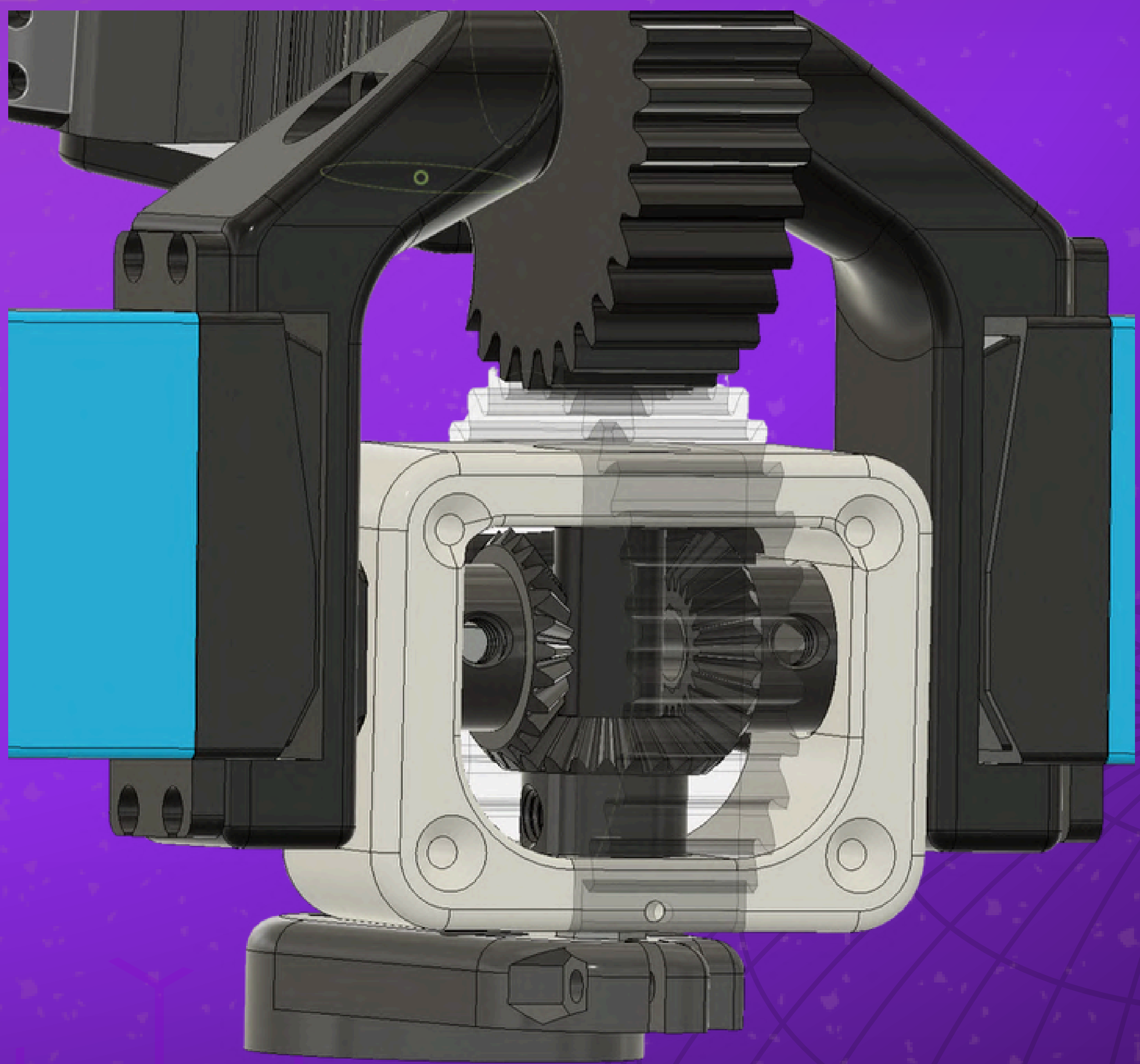
This carefully engineered lift is a key component of our robot's success, ensuring fast, precise, and efficient scoring capabilities throughout the competition.

The Arm

The robotic arm is designed to grab samples or specimens from the intake and score them either in the high basket or on the high rung. Its lightweight construction allows for faster lift speeds and rapid pivoting, achieving a 60-degree rotation in just 0.12 seconds. Through motion profiling, it operates efficiently without requiring a servo power module, ensuring that the servos are not overstressed.

Differential Mechanism

The arm incorporates a differential system that secures the middle gear to the base while linking the side gears to the servo axles. This setup enables two-axis movement, allowing the arm to precisely align itself using the robot's gyroscope. Additionally, it combines the power of both servos for backward pivoting, achieving full range of motion with just two servos instead of three, making the design more efficient and compact.



Spur Gear System

A spur gear mechanism enables the arm to pivot 300 degrees around the lift, ensuring collision-free movement. The 1:2 gear ratio enhances servo speed and range, allowing the arm to move smoothly and responsively.

A unique feature of this system is its ability to extend in the idle position but shorten when pivoted backward, ensuring it remains within extension limits while maintaining flexibility and efficiency in its movement.

Claw Mechanism

The claw system consists of two long fingers that are linked by spur gears, ensuring synchronized movement. A micro servo located on the left finger controls the closing motion, allowing the claw to grip samples or specimens securely.
To prevent servo stress and overheating, the servo is connected to the right finger via a bent 1mm steel beam that acts as a spring mechanism. This ensures a firm grip while absorbing excess force, increasing both reliability and longevity.

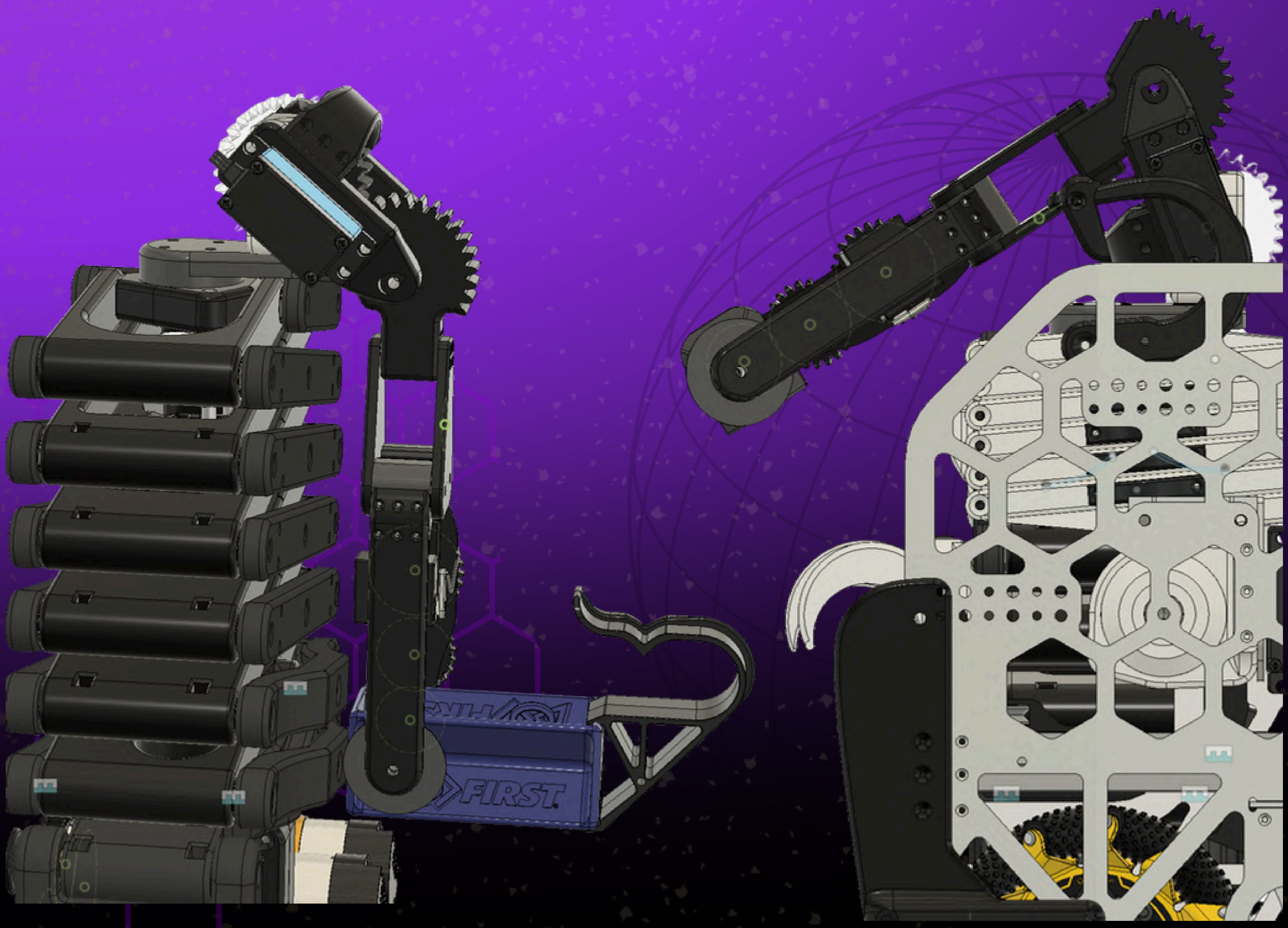
Wrist Mechanism

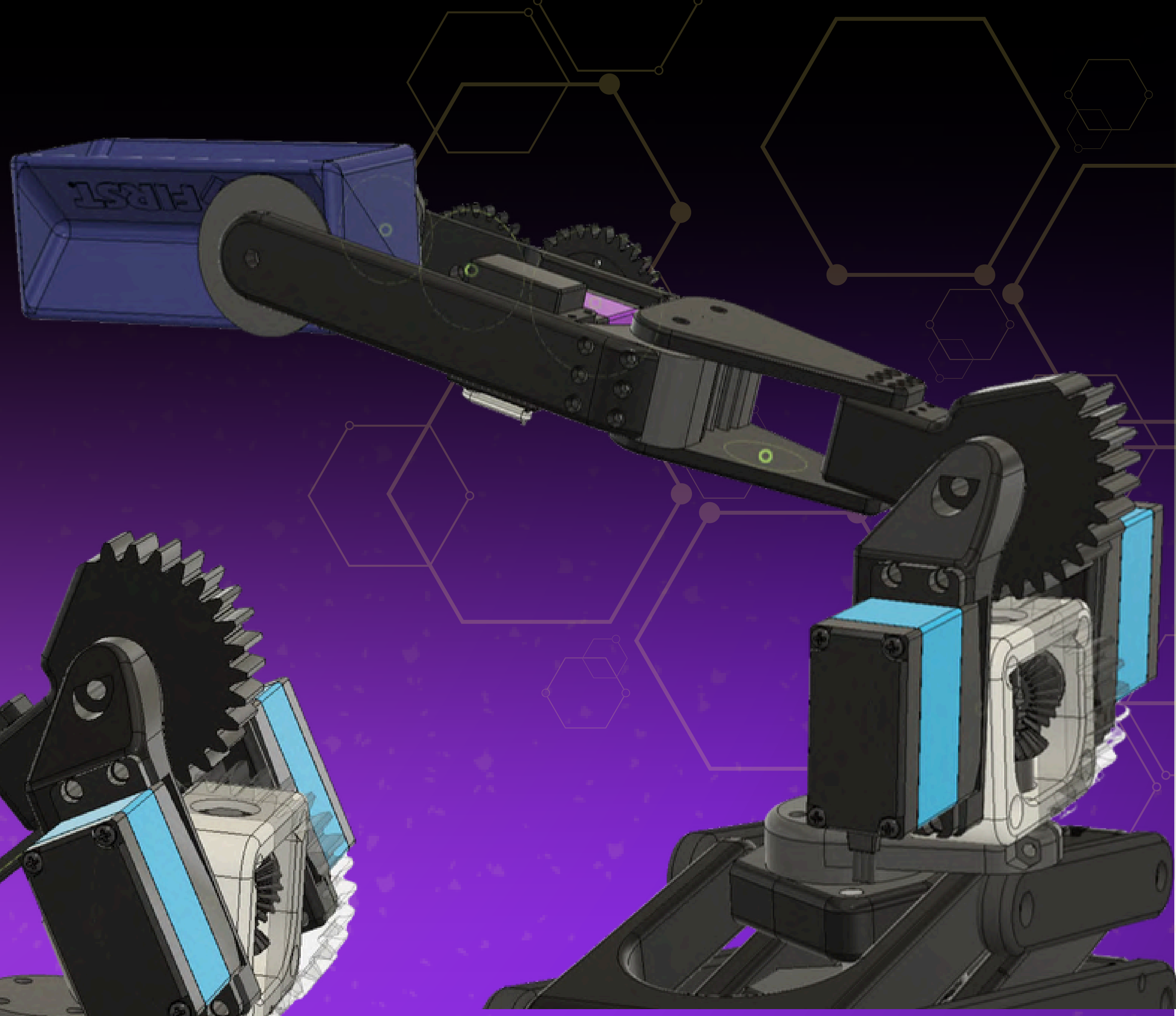
The right finger of the claw serves as a third axis, allowing the gripping mechanism to pivot using a micro servo connected through three spur gears. This enables the arm to adjust the scoring element's orientation by up to 230 degrees, with the pivot point centered through the middle of the element for precise placement.

Arm Positions

The arm operates in four primary positions, each designed for a specific function:

- Idle Position: The arm remains at rest, waiting to grab a scoring element from the intake.
- Basket Position: Used for scoring in both high and low baskets, ensuring smooth and accurate placement.
- Specimen Scoring Position: This position endures the highest stress, positioning the arm at its sharpest angle for maximum stability when handling specimens.
- Backup Specimen Collection Position: Although specimens are primarily collected using the intake, the arm has a secondary position for retrieving specimens off the wall when necessary.





Optimized for Performance

This lightweight, high-speed arm design ensures efficient sample collection, precise scoring, and reliable operation in all match scenarios. By integrating differential gearing, a synchronized claw, and a three-axis wrist mechanism, the system delivers maximum versatility while minimizing weight and servo load.

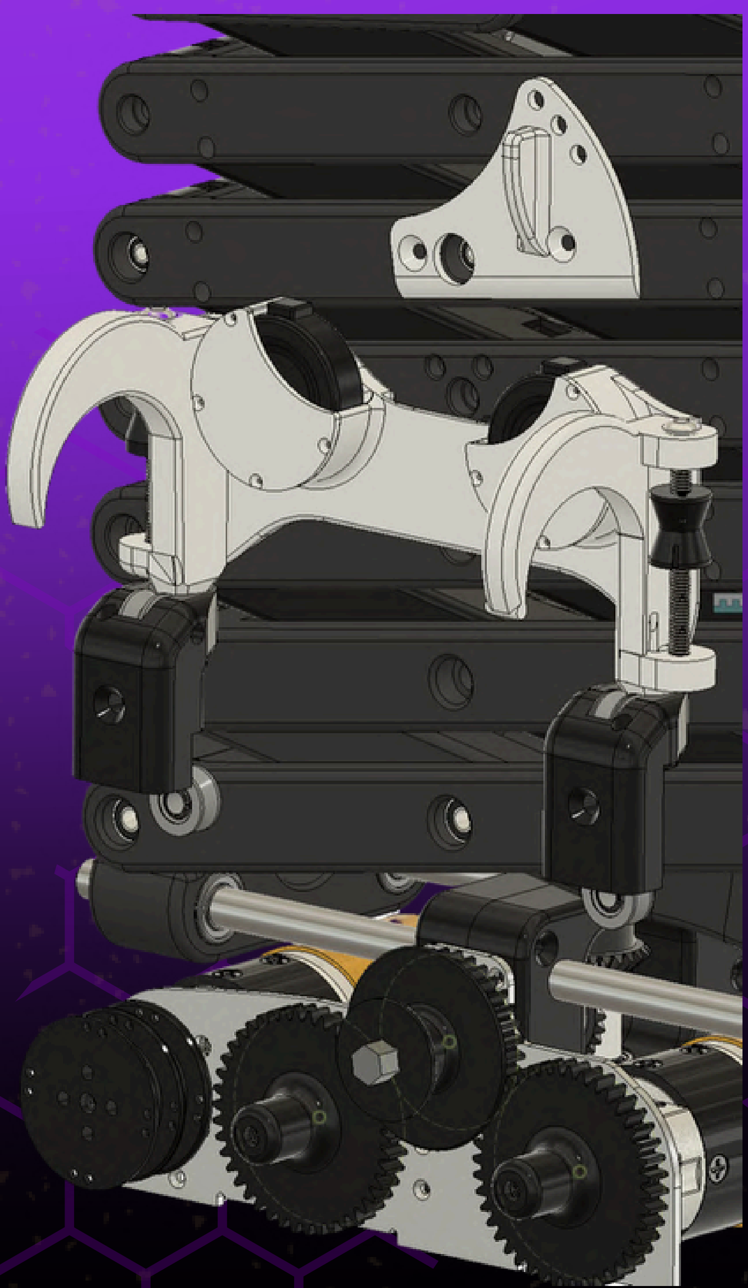
With its fast actuation, adaptive gripping, and multi-position flexibility, this arm plays a crucial role in the robot's overall success, ensuring smooth, accurate, and rapid scoring.

The Level 3 Ascent

This robot is equipped with a level 3 ascent capability, utilizing two independent hanging mechanisms. The first system is designed for level 2 ascent, while the second system, detailed below, is one of two identical mechanisms optimized for level 3 ascent.

Level 2 Ascent Mechanism

This system employs two 3D-printed hooks attached to high-strength cables, which wind around a spool mounted on the lift's main axle. To ensure smooth and controlled ascent, the hooks are integrated with retractable rollers that assist in their precise deployment.
The spool size is carefully calculated to lift the hooks to the bar's height of 53cm when the lift is fully extended to 108cm. This ensures optimal mechanical advantage, enabling the robot to lift itself efficiently while maintaining high lift speeds



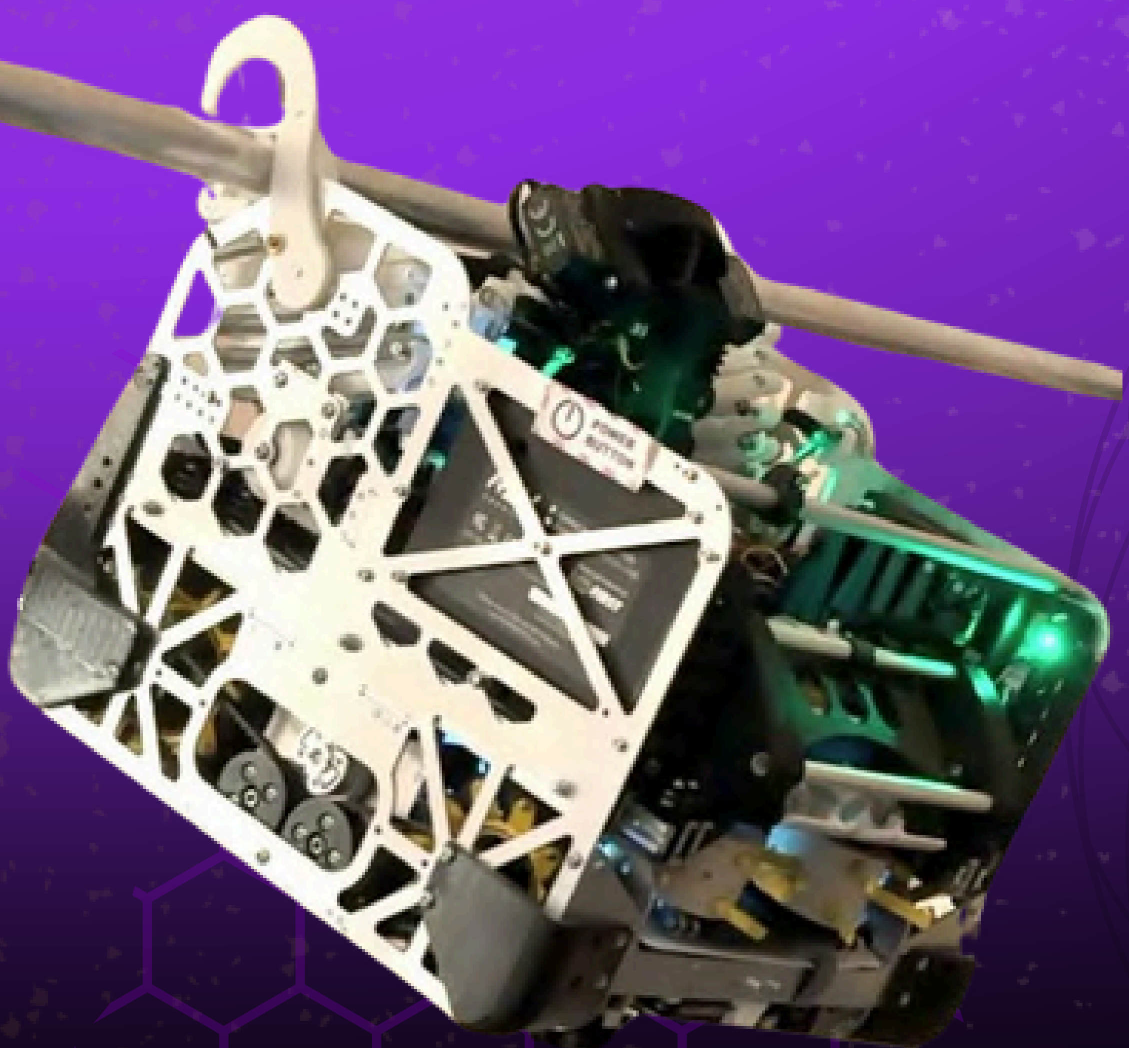
Level 3 Ascent Mechanism

For level 3 ascent, a spring-loaded 3D-printed scissor lift is utilized. When triggered, the scissor lift rapidly deploys upwards, placing the hook onto the second bar.

A key feature of this design is that the scissor lift bears no load during the hang. Instead, the hook is pulled down by a cable, allowing the scissor mechanism to naturally compress back into its original position while the robot remains securely suspended.

Hook Design

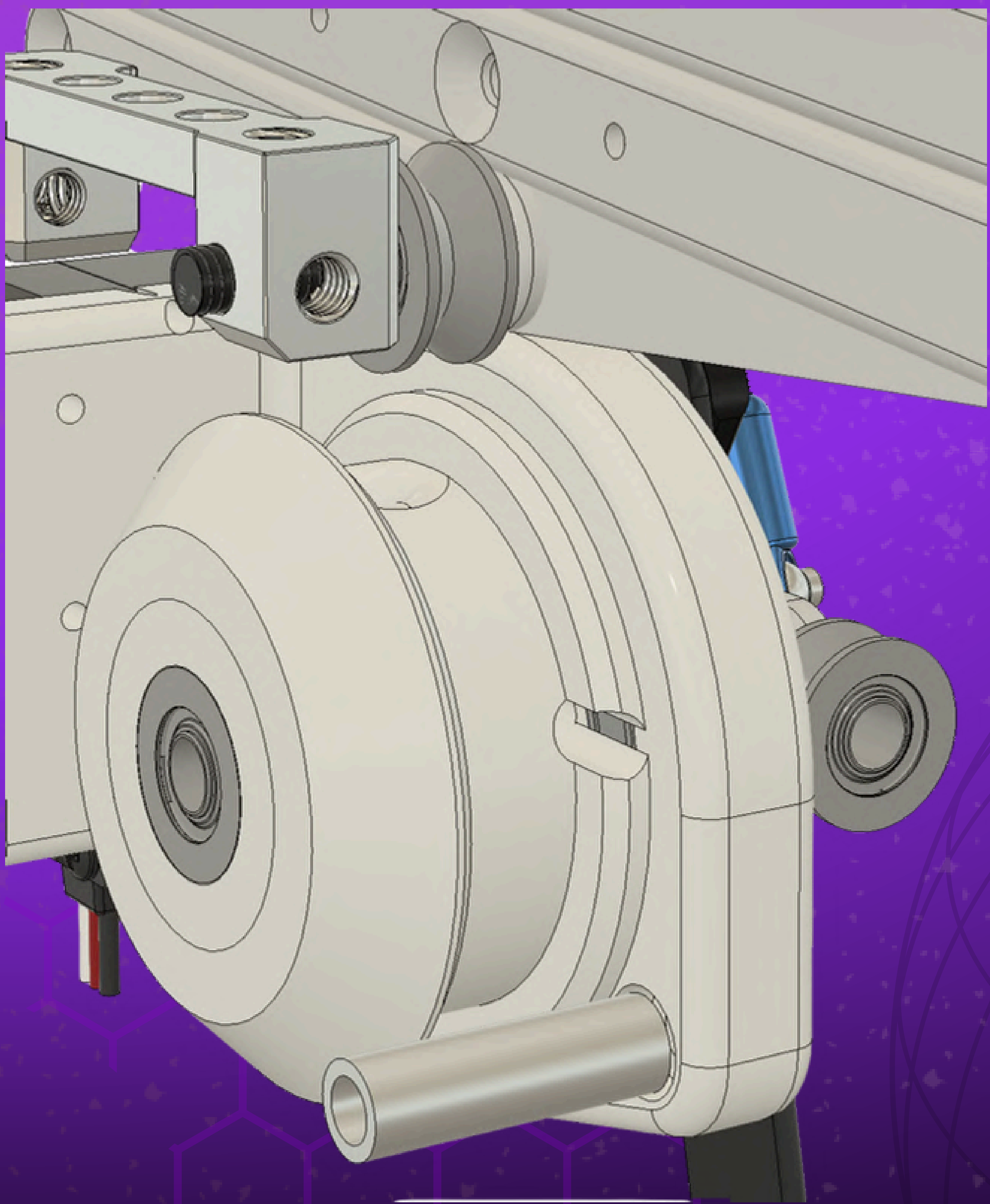
The hook is a 3D-printed component with a spring-loaded locking clip, ensuring secure attachment to the bar once engaged. This locking mechanism prevents accidental detachment, maintaining a reliable and stable hang throughout the ascent.

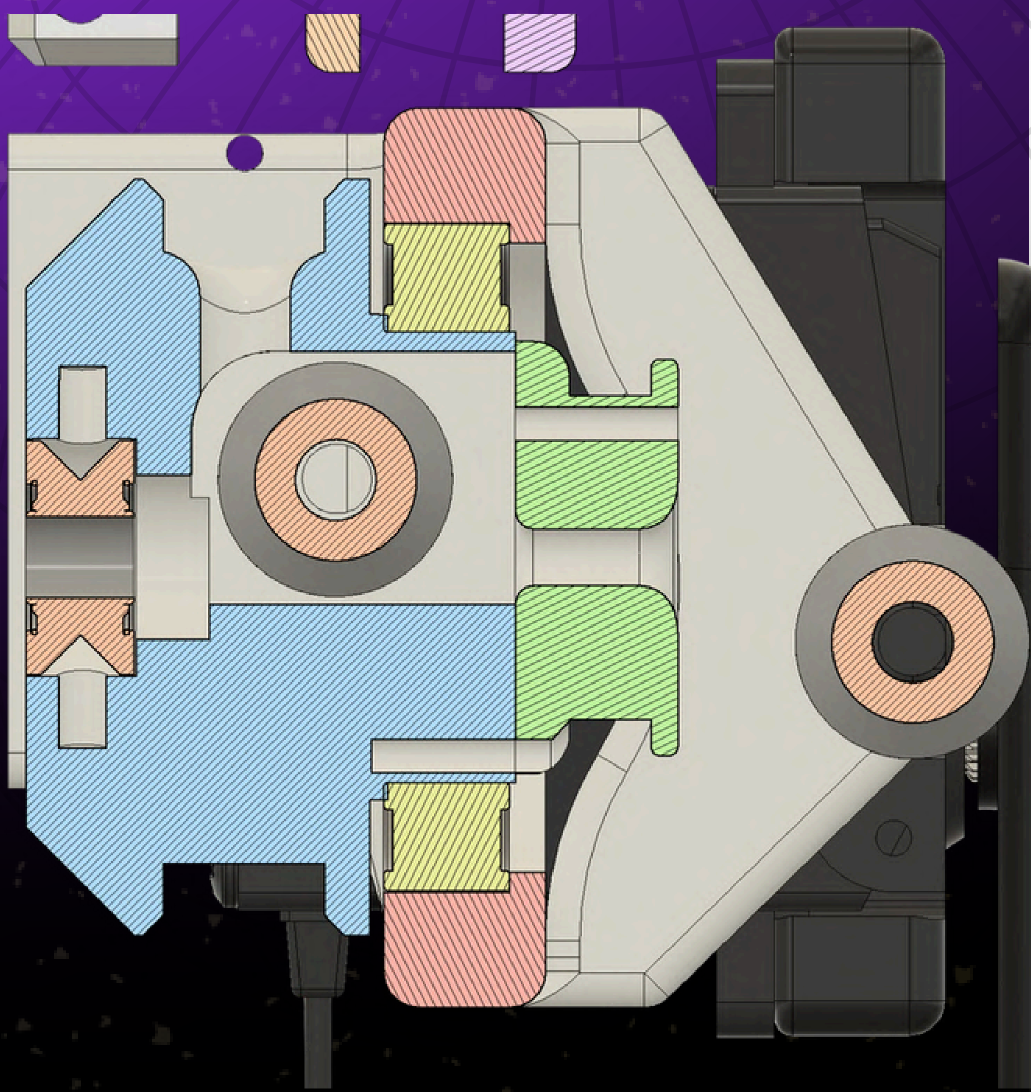


Automatic String Reloader

To streamline the resetting process after an ascent, the robot is equipped with a 3D-printed automatic string reloader. This internal spool and pulley system allows the ascent cable to pass through completely, enabling seamless reloading.

A weak counterclockwise spring continuously rotates the spool, ensuring that once the scissor extension is recompressed, the extra cable is automatically wound onto the spool, fully resetting the system for the next climb.





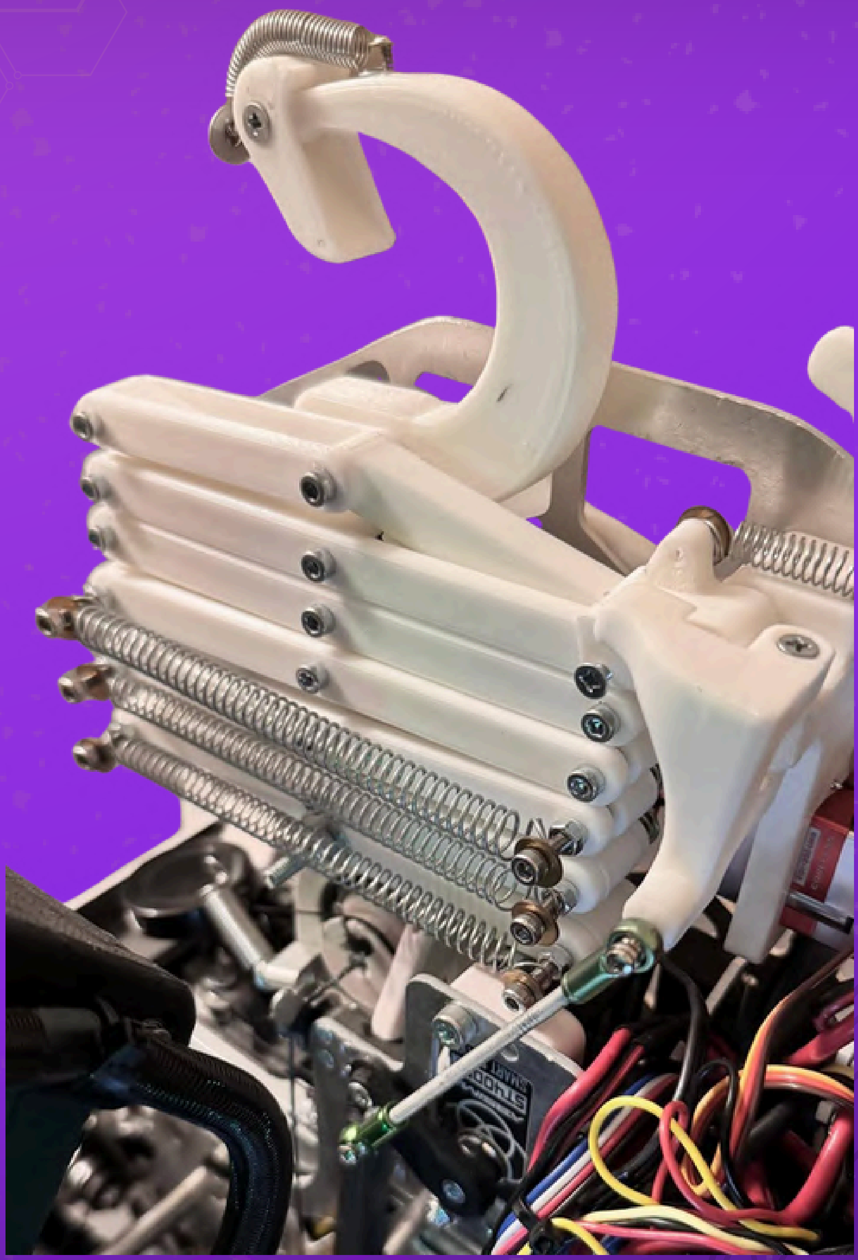
Powered Take-Off System (PTO)

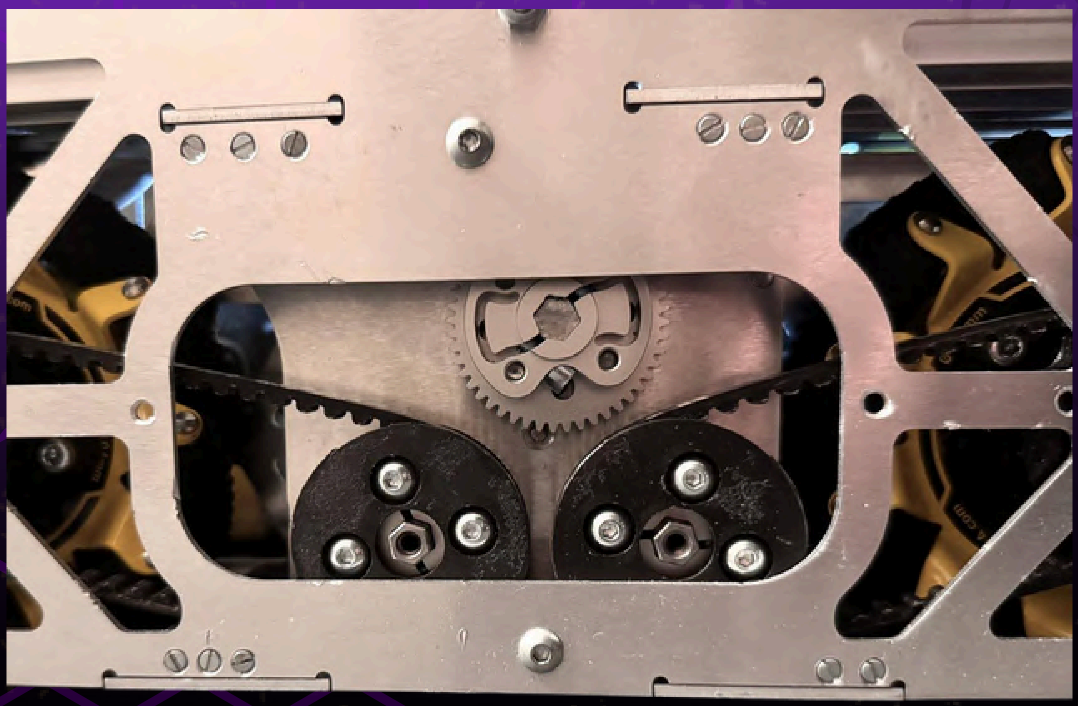
Each ascent mechanism is powered by two chassis motors, utilizing a total of four motors to maximize climbing speed. This is achieved through a mechanically coupled system, where a gear with a spool is linked to two chassis motor gears via a servomotor.

The cable is routed downward beneath the motors, using the robot's own weight to press the gears together. This self-tightening design ensures that as cable tension increases, the gear meshing becomes more secure, preventing slippage and optimizing power transfer.

Optimized for Speed, Strength, and Reliability

This dual-mechanism ascent system allows the robot to quickly and efficiently reach level 3, combining high-speed motorized climbing, secure hooking, and automatic resetting features. The integration of spring-loaded mechanisms, carefully calculated gear ratios, and a self-tightening drive system ensures a fast, reliable, and repeatable ascent in every match.

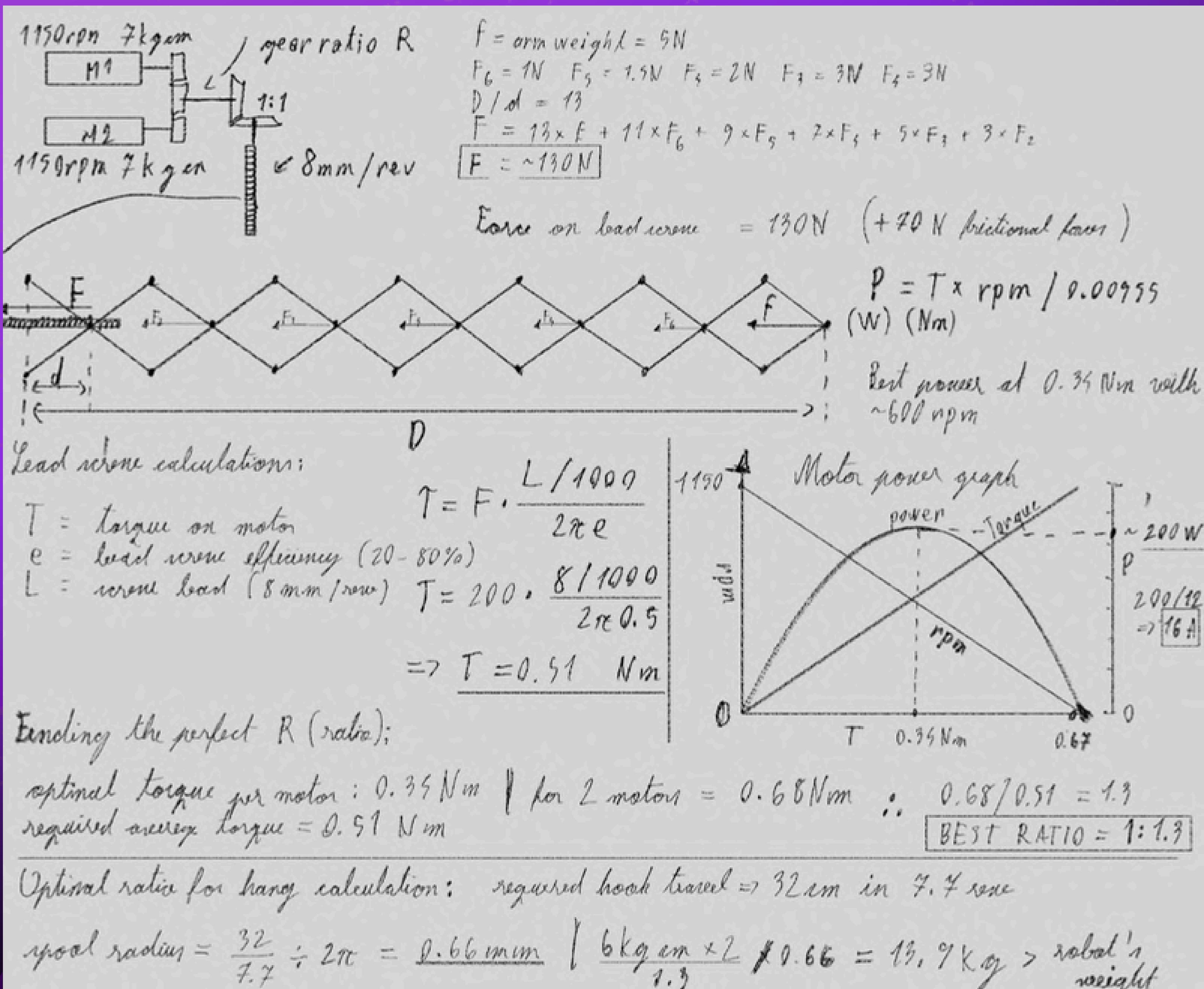




Mathematical Analysis Behind the Robot Design

Building this robot required extensive calculations and engineering analysis.

While not every computation can be covered here, we'll focus on some of the most interesting and impactful examples, particularly the scissor lift calculations and stress simulations.



Scissor Lift Calculations

The scissor lift mechanism needed to efficiently convert motor rotation into linear motion to raise the robot's arm and scoring system. The calculations, sketched in the accompanying notebook image, break down as follows:

Step 1: Determining the Force on the Lead Screw

To calculate the force required to raise the lift, we needed to consider:

- The weight of each lift module.
- The mechanical advantage provided by the scissor structure.
- The weight of the arm.
- By summing the products of (module weight × mechanical advantage) for all modules and adding the weight of the arm, we determined that the lead screw must handle 130N of force.

However, real-world systems always include friction. Based on estimates, we accounted for an additional 70N of frictional forces, bringing the total required lifting force to 200N.

Step 2: Calculating the Required Torque

The next step was to calculate the torque needed to generate this 200N of linear force using the lead screw formula:

$$T = \frac{F \cdot d}{2\pi \cdot \eta}$$

where:

- T is the required torque.
- F=200NF = 200N (force needed to lift the mechanism).
- d is the lead screw pitch diameter.
- η is the efficiency of the lead screw.

Plugging in the known values, we determined that 0.51 Nm of torque is needed to generate this lifting force.

Step 3: Optimizing Motor Power and Gear Ratio

DC motors are notoriously inefficient, delivering the most mechanical power at a specific balance of torque and RPM. The power output curve (approximated in our sketches) shows that peak mechanical power occurs at about 50% of the stall torque and 50% of the no-load speed.
Using this principle, we calculated:

- Target torque per motor: 0.34 Nm (half of the stall torque from motor specs).
- Total torque from two motors: 0.68 Nm.
- Comparing this to the required 0.51 Nm, we computed the optimal gear ratio between the motors and the lead screw:

This means the most efficient gearing configuration should have a 1:1.3 ratio, where the lead screw rotates 1.3 times for every full motor rotation.

$$\frac{0.68}{0.51} = 1.3$$

Step 4: Verifying Power Efficiency

To confirm these calculations, we used the mechanical power formula:

$$P = T \times \omega$$

where:
P is mechanical power.
T is torque.
ω\omega is angular velocity.

This gave us an estimated 200W of mechanical power output. Given that the maximum power consumption is 240W and that DC motors operate at about 80% efficiency, this aligns perfectly with our predictions.

Lift Axle Spool & Level 2 Ascent

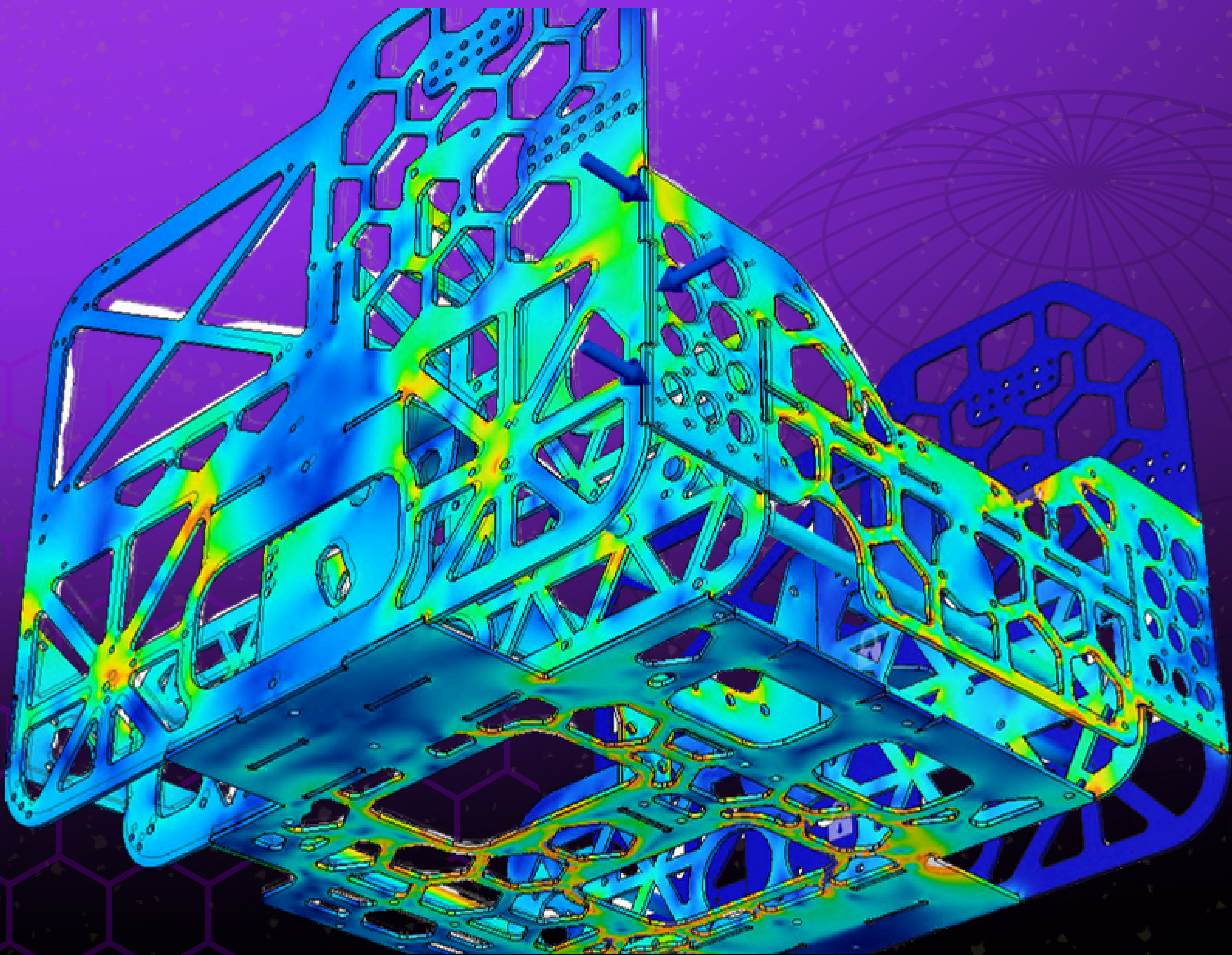
Another key verification was ensuring that the spool mounted on the lift axle had enough torque for the level 2 ascent mechanism. After calculating the spool diameter, force transmission, and motor power, we confirmed that the torque output was sufficient for a reliable ascent.

Stress Test Simulations

While developing the robot chassis, we ran multiple structural simulations using Fusion 360 to analyze potential weak points and optimize material usage.

One of our biggest concerns was whether pocketing (weight reduction cutouts) would cause excessive stress concentrations. To test this, we conducted a simulation where a strong impact force was applied to the rear left corner of the chassis.

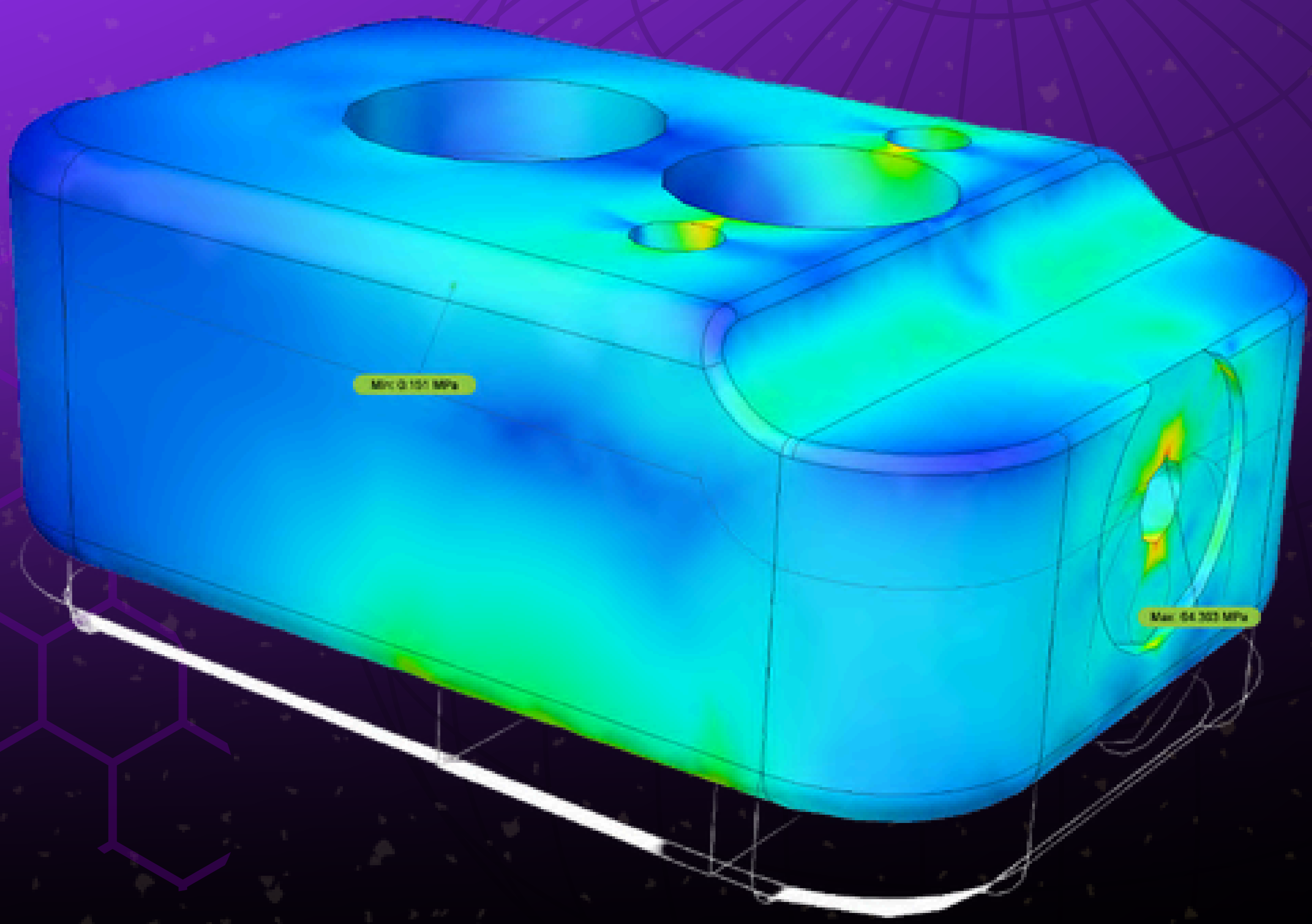
The results showed that the stress was evenly distributed, proving that our puzzle-like interlocking plate design was structurally sound. Importantly, this simulation was conducted without accounting for screws, standoffs, or brackets, meaning that in real-world conditions, the structure is even more robust.



Conclusion: The Most Fascinating Engineering Challenges

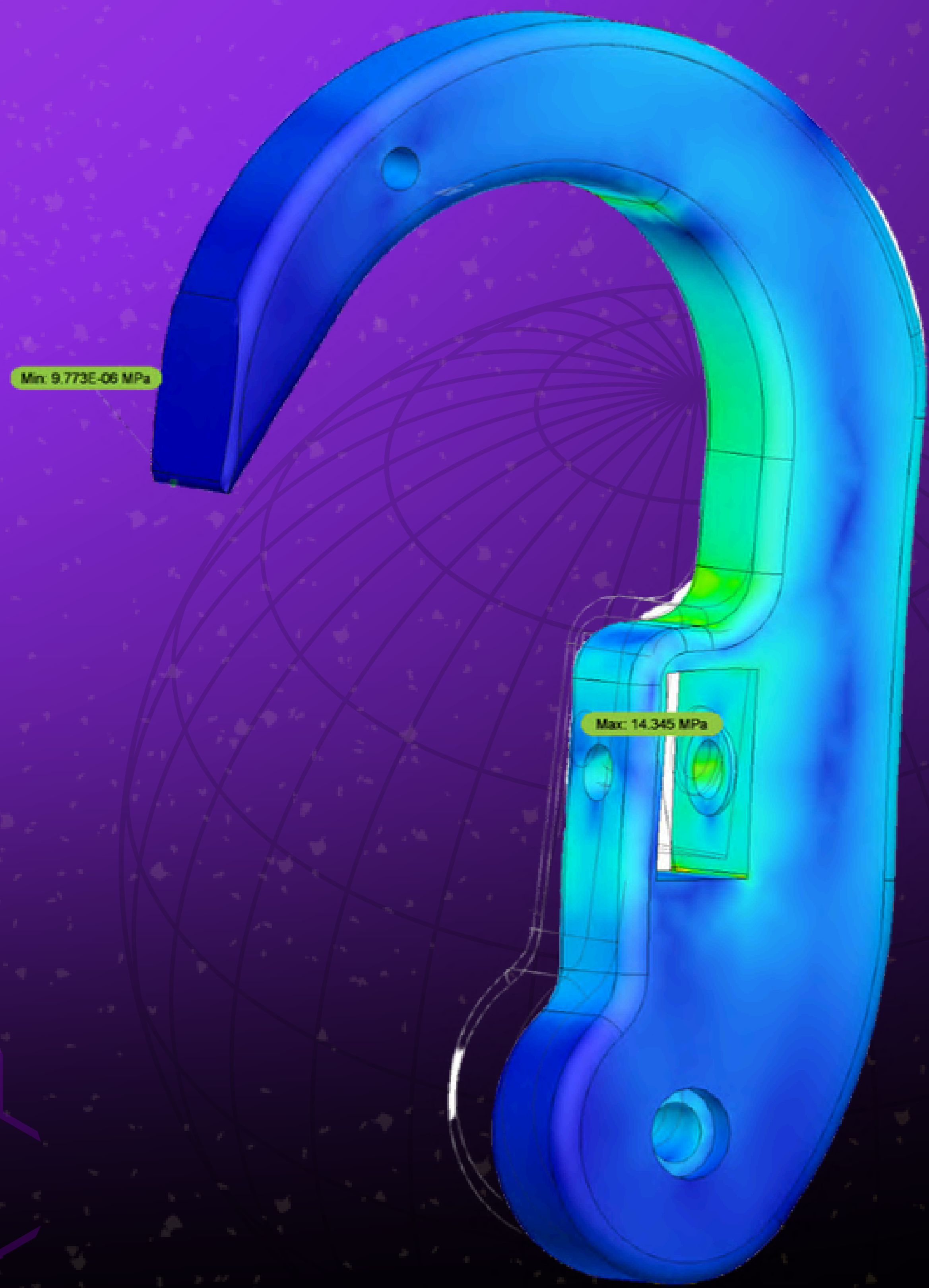
These calculations are just a small fraction of the math and physics behind our robot. Other key analyses included:

- *Tipping speed calculations to determine stability with the lift fully extended.*
- *Force calculations for the level 3 ascent to ensure reliable climbing.*
- *Torque analysis for the arm to verify that it could pivot efficiently without overloading the servos.*



While many calculations weren't documented in full detail, these scissor lift and structural stress simulations represent some of the most interesting and complex mathematical challenges we tackled during the design process.

By combining mechanical power optimization, efficient gearing, and structural analysis, we created a highly efficient, lightweight, and reliable competition robot, capable of handling extreme forces while maximizing performance.



Programming

I.Driver-Controlled Period

Software Design Approach

During the driver-controlled period, the robot's software is optimized for a single driver. Using Command-Based programming, we implemented multiple automation strategies to make the robot as easy to operate as possible. Additionally, we designed multiple controls for a more intuitive but also foolproof operation.

Controls for enhanced game strategy

To adapt to various game strategies, the driver can select which sample color the robot is allowed to intake. A gamepad lighting system provides visual feedback on the selected option. The 3 available options are:

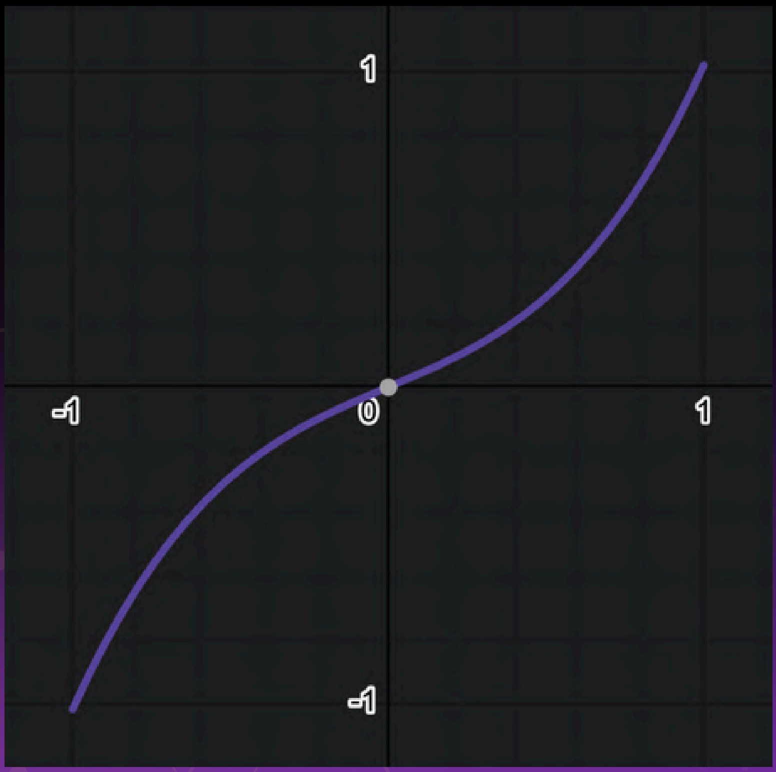
Both Neutral and Alliance-Specific Samples: The robot intakes both but ejects opponent alliance samples. The gamepad remains unlit.

Alliance-Specific Samples Only: The robot ejects both neutral and opponent alliance samples. The gamepad lights up red or blue, matching our alliance color.

Neutral Samples Only: The robot ejects both alliance-specific samples. The gamepad lights up yellow.

Controls for enhanced robot motion

To achieve smoother, more precise control of the Extendo and Chassis mechanisms, their speeds are dynamically adjusted using the following cubic polynomial function:



$$f(x) = (x^3 + 0.7x) \times 0.6 \quad \text{where } x \text{ represents the joystick input}$$

Unlike a linear control approach, where motor power is directly proportional to joystick input, this function improves precision by creating a smoother transition between low and high speeds. Small joystick movements correspond to finer, more controlled adjustments, while higher speeds are only reached with more significant joystick input.

Fail safes

While the Intake and Claw mechanisms are fully automated and typically require no manual control, fail-safe programs have been implemented to handle potential mechanical issues during matches.

Intake Fail-Safe: If a scoring element gets stuck inside the Intake mechanism at any point during the match, the driver can eject it instantly with a button press.

Claw & Transfer Fail-Safe: If the scoring element is not transferred correctly, preventing the Claw from automatically gripping it, the driver can manually open the claw and retry the transfer. Once successful, the claw will automatically close, and the gamepad will vibrate to notify the driver that the element is ready for scoring.

Arm Rotation Fail-Safe: In case the robot gyroscope decalibrates, resulting in problematic rotations of the Arm mechanism, the driver can disable it at any time during the match. The Arm will no longer rotate, maintaining only a striaght, fixed position.

Color Sensor Fail-Safe: Through testing, we observed that the REV Color Sensor is highly unreliable and can stop transmitting input during a match. To address this issue, we implemented a fail-safe that disables the color sensor when it becomes unresponsive. In this mode, the intake system relies solely on the proximity sensor, collecting all samples regardless of color. The driver then manually decides whether to eject the sample, pass it to the human player, or transfer it to the claw for scoring. This ensures that our intake remains functional even if the color sensor fails.

Automations

The Intake mechanism and scoring element transfer are fully automated, allowing seamless control of the robot, even with a single driver. Additionally, gamepad vibrations provide real-time feedback, notifying the driver when scoring elements are ready to be scored.

Intake Mechanism

Equipped with proximity and color sensors, the intake system detects both the presence and color (red, blue, or yellow) of a scoring element. Once an element is inside:

Opponent alliance sample → Automatically ejected.

Desired sample → Retained for further processing.

Scoring Element Transfer

Once a scoring element is intaked, the Extendo retracts back inside the robot. Based on the detected color, the intake system determines the next action:

Yellow sample → Directly transferred to the outtake, where the claw closes to prepare for scoring.

Alliance-specific sample → The driver can either:

Pass it to the outtake for scoring.

Eject it to the human player for conversion into a specimen.

Once a scoring element (sample or specimen) reaches the outtake and is ready for scoring, the gamepad vibrates, alerting the driver to activate the outtake.

Arm Mechanism

The Arm mechanism rotates according to the heading of the robot in order to automatically align to the basket/chamber. More exactly, the Arm compensates for the heading of the robot. For example, if the robot's heading is 30 degrees to the right, the Arm will totate 30 degrees to the left in order to compensate. This automation allows the driver to focuss less on the alignment of the robot, making the scoring actions faster.

Command-Based Programming

Command-based programming is a modular and scalable design pattern that promotes reusability, maintainability, optimization, and—most importantly—automation. This approach structures robot control into subsystems (representing the robot's mechanisms), commands((which define actions), and command groups.
Each subsystem has dedicated commands that manage its states and actions.
Example: The Intake subsystem includes commands to adjust its angle, toggle its intake state, and activate its hardware components.

Command Groups

Comands are combined into Command Groups, allowing the robot to execute multiple actions sequentially or in parallel based on driver or sensor inputs.

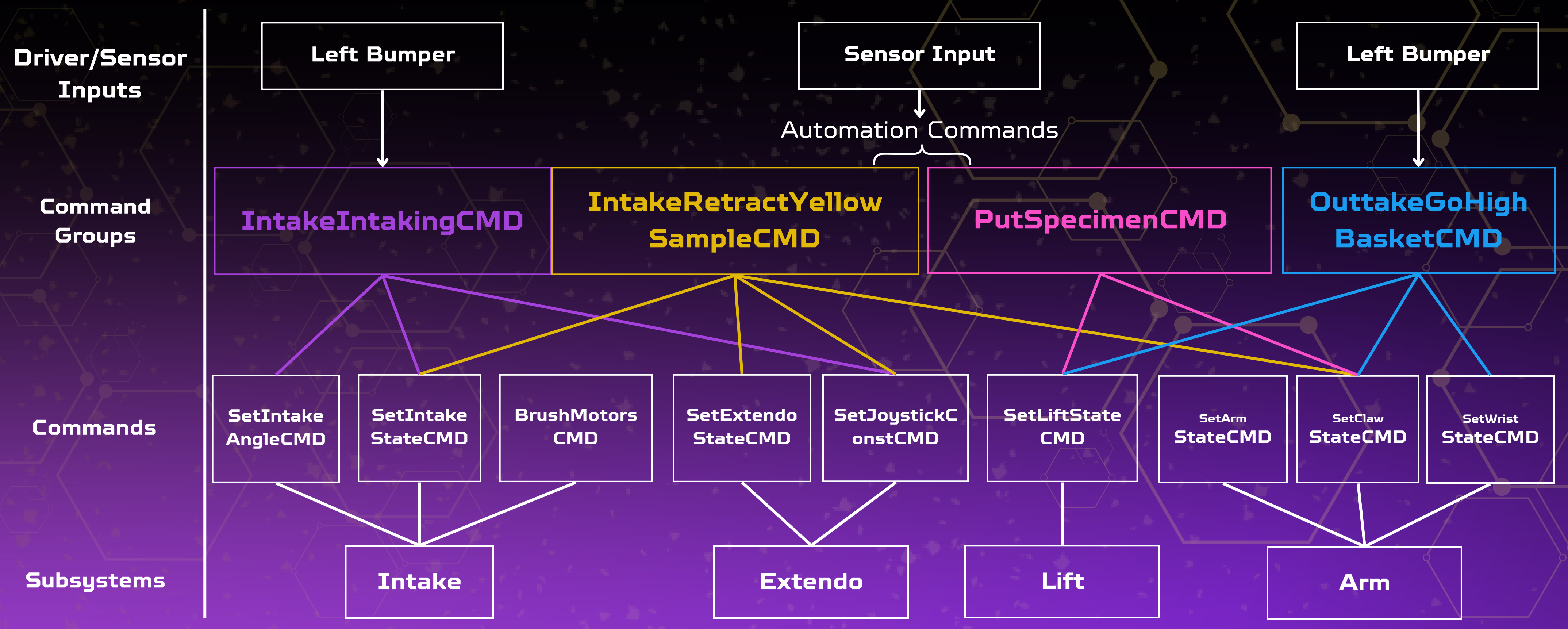


Diagram – Brief explanation of how we implemented Command-Based programming on our robot

Sequential Command Groups (for smooth mechanism coordination)

Some mechanisms require precise timing to function efficiently. By executing commands in sequence, we ensure smooth operation without interference.

Example: The Outtake mechanism consists of multiple moving parts—wrist, arm, and lift. To deposit a scoring element efficiently, we structured a sequential command group, ensuring each component moves in a controlled order with necessary delays to prevent collisions.

Parallel Command Groups (for time optimization)

Certain actions run simultaneously to maximize efficiency and reduce execution time.

Example: When the Intake mechanism activates, it adjusts its angle and spins the brushes simultaneously, reducing delays.

Parallel Command Groups (for time optimization)

Certain actions run simultaneously to maximize efficiency and reduce execution time.

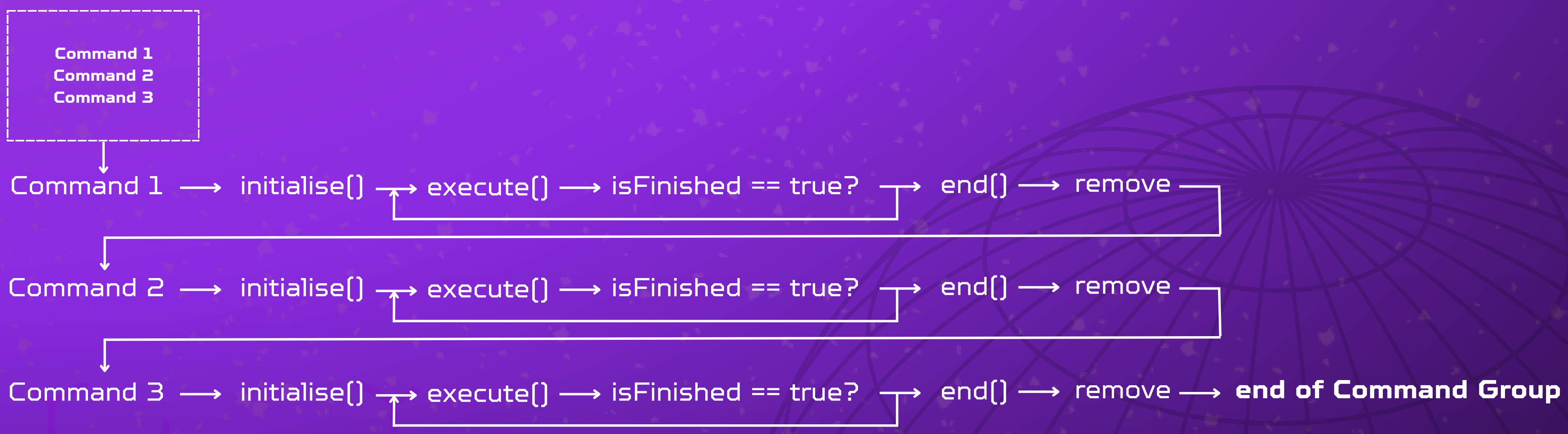
Example: When the Intake mechanism activates, it adjusts its angle and spins the brushes simultaneously, reducing delays.

How Command Groups are executed?

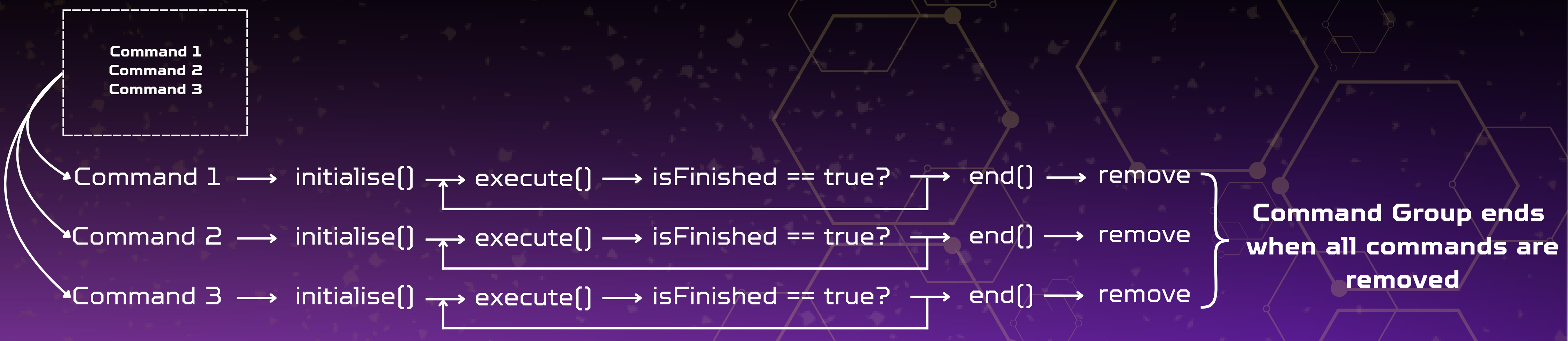
At the heart of command-based programming is the Command Scheduler, which manages the execution of commands. The scheduler operates in a continuous loop, handling the following tasks:

1. **Scheduling Commands: When a command is triggered (e.g., by a button press or an event), the scheduler adds it to the execution queue.**
2. **Executing Commands: The scheduler runs active commands by repeatedly calling their execute() method.**
3. **Handling Command Completion: When a command's isFinished() method returns true, the scheduler stops the command and removes it from the execution queue.**

Sequential Command Group



Parallel Command Group



Control Systems

PID Controllers

A PID Controller is a feedback control system used to achieve precise and stable control of a mechanism by continuously adjusting its output based on the error between the desired and actual position. We use them for Lift, Extendo, and Ascent mechanisms.

How It Works:

- **Proportional (P) – Corrects based on current error.**
- **Integral (I) – Eliminates long-term errors.**
- **Derivative (D) – Prevents overshoot and oscillations.**

The controller's output is calculated using the following formula:

$$Output = K_p \cdot Error + K_i \cdot \int Error + K_d \cdot \frac{d(Error)}{dt}$$

where: K_p, K_i, K_d are tuning constantsfor each term (P, I, and D)

Motion Profiling

Motion profiling is a technique used in robotics to generate smooth, controlled motion by carefully planning a mechanism's velocity and acceleration over time. While not a control loop itself, it works effectively alongside control systems like PID controllers to improve movement precision and stability.

Why use Motion Profiling?

We implemented trapezoidal motion profiling for the Lift and Extendo mechanisms because relying solely on PID control, even when well-tuned, resulted in movements that were too abrupt. These sudden accelerations placed unnecessary mechanical stress on the mechanisms . By incorporating motion profiling, we regulated maximum velocity and acceleration, achieving smoother motion, reducing mechanical strain, and improving long-term durability.

Motion profiling was also applied to the robot's Arm, but for a different reason. Unlike the Lift and Extendo, which use DC motors with PID control, the Arm is powered by servo motors, which operate at fixed high speeds without built-in speed regulation. This caused sudden, unpredictable movements. By integrating motion profiling, we introduced gradual transitions, ensuring greater stability.

How Trapezoidal Motion Profiling works?

A trapezoidal motion profile consists of 3 distinct phases:
Acceleration Phase → Smoothly increases speed to prevent sudden jerks.
Cruise Phase → Maintains a constant maximum velocity.
Deceleration Phase → Gradually slows down to reach the target position without overshooting.

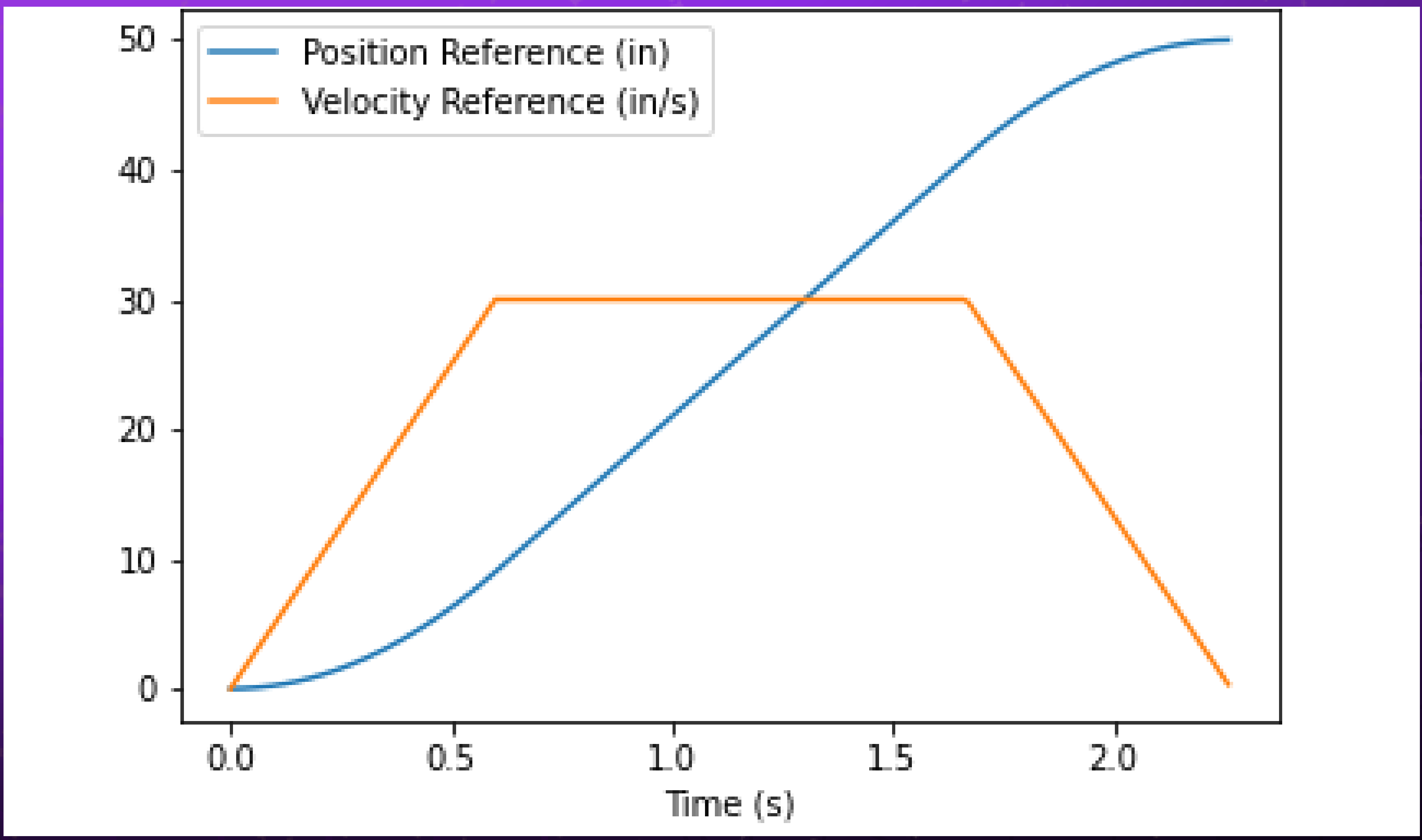


Image source: CTRL ALT FTC Control Theory guide

II. Autonomous Period

Software Design Approach

For our autonomous code, we evaluated whether to develop a custom pathing system or use an existing third-party library. Given our time constraints and the need for a highly performant and consistent autonomous program, we chose Pedro Pathing, a library developed by the mentor and alumni of FTC Team 10158 (Georgia, USA). This allowed us to focus on refining our autonomous strategy rather than building a pathing system from scratch. Additionally, we implemented fail-safes to handle field imperfections, human error, scoring elements bloackages and time constraints.

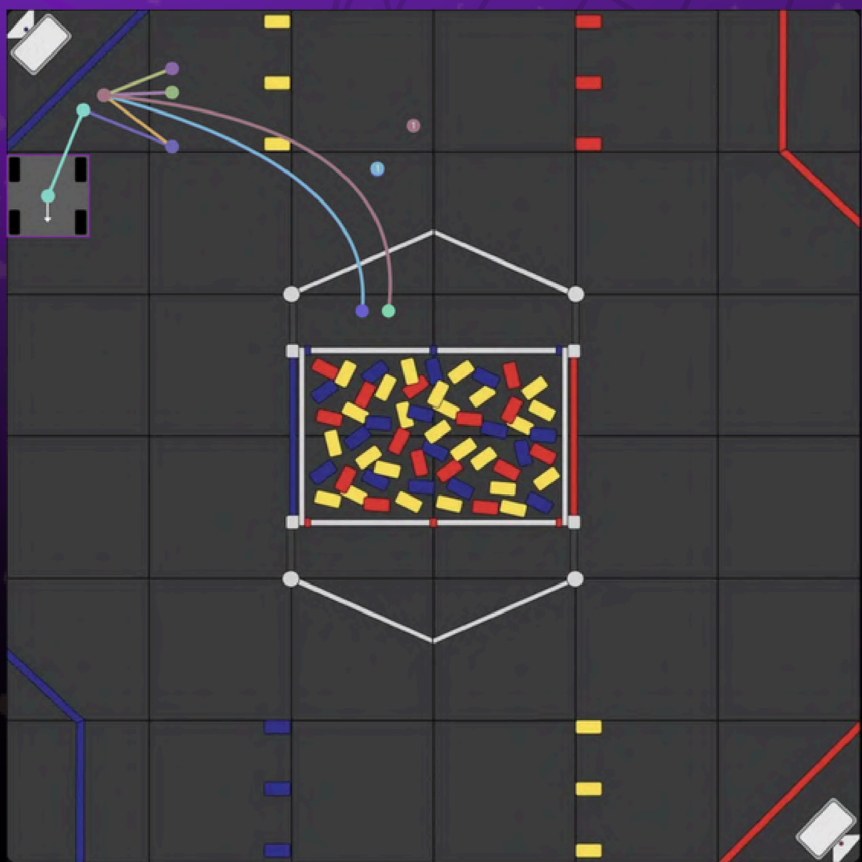
Why Pedro Pathing?

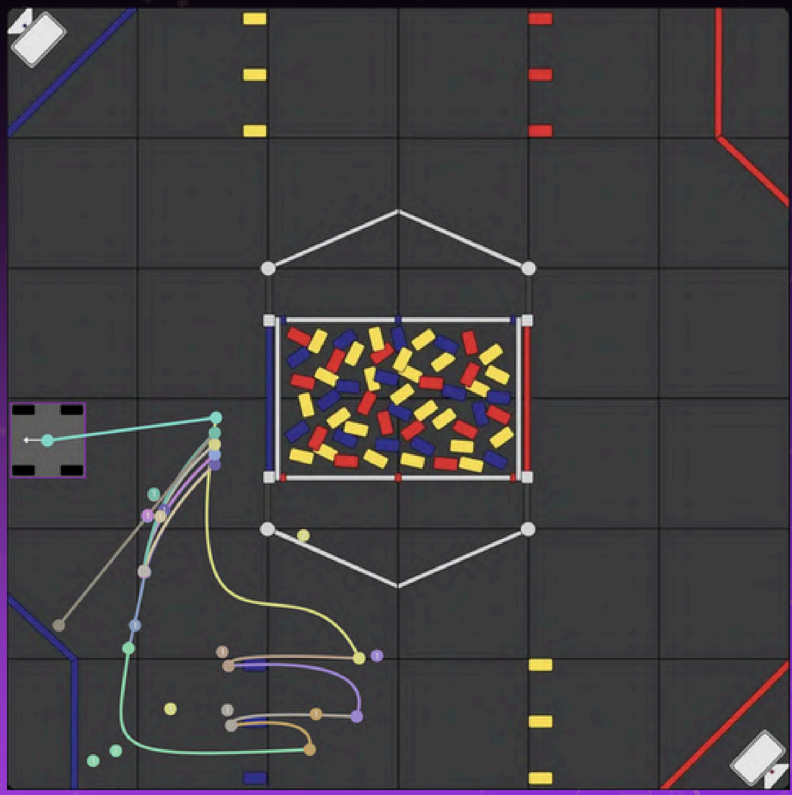
Pedro Pathing stood out due to its Bézier curve generation, which enables smoother, faster, and more efficient trajectories than traditional methods. Unlike many pathing libraries, such as Road Runner, which rely on purely kinematic models and spline-based trajectory planning, Pedro Pathing inherently optimizes for real-time corrections and fluid motion, making it a superior choice for our robot.

Strategy

Basket Autonomous - Reliable 6 Samples Scoring

The robot first scores the preload sample, followed by the 3 preset samples. It then cycles between the submersible and basket, intaking and depositing additional samples.





Fail-safes

Basket Autonomous

- **Field Imperfections:** If minor field imperfections prevent the robot from grabbing a preset sample, it will attempt to intake the sample for 1.5 seconds. If the proximity sensor detects no sample within this time, the robot moves to the next preset sample. This fail-safe applies to all three preset samples, minimizing time loss due to minor inconsistencies.
- **Time Management for Mechanism Retraction:** The robot continuously monitors a timer during autonomous. If the timer exceeds the threshold and the robot is still attempting to intake samples from the submersible, it halts the intake process, retracts the extendo, and cancels all remaining trajectories, ensuring enough time remains for robot reset at the end of the period.

Specimen Autonomous

- **Misplaced Specimen by Human Player:** If the human player misplaces a specimen, the robot attempts to intake it for 1.5 seconds. If no specimen is detected by the proximity sensor, the extendo retracts for 2 seconds to allow repositioning, then retries to intake. This process repeats for all 4 specimens.
- **Specimen Blockage in Intake:** Although blockages were very rare during testing, we wanted to ensure we are prepared in case one occurs during a match. If a specimen is physically stuck in the Intake, a current spike is detected due to increased current draw. We monitor this via the control hub's voltage sensor. If the voltage exceeds 5 amps, the robot ejects the specimen, retracts the Extendo for 2 seconds, and retries the intake after repositioning.
- **Time Management for Mechanism Retraction:** The robot tracks time throughout autonomous to avoid running out of time with active mechanisms. If the time threshold is exceeded and no scoring trajectory is in progress, the robot cancels remaining trajectories and retracts its mechanisms. If a scoring trajectory is active, the robot completes it, then retracts its mechanisms and halts immediately after.

Pretty Smart Software Improvements

Arm Angle Adjustment

Because the robot can rotate around its own axis multimple time during the match, we needed to find a way to keep adjusting the Arm angle according to the robot current heading, no matter the accumulated heading.
Thus we needed to monitorize the acumultated heading and keep correcting the Arm angle exclding the acumulated angle.

This is how we do it: