ROBOTICS CURRICULA

Ink and Metal

WHAT IS FIRST?

FIRST is a robotics organization that hosts competitions and events in order to draw attention to the robotics as a whole.

ROBOTICS, FIRST TECH CHALLENGE

- Robotics requirements
  - Software, hardware understanding
  - Computer-aided design (CAD) software skill
  - Task-management if in leading position

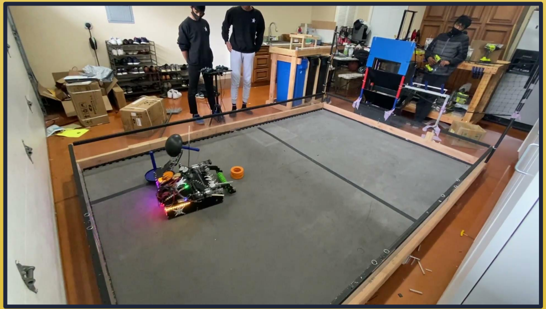
- FTC
  - Middle competition in series: FIRST Lego League (FLL), FIRST Tech Challenge (FTC), FIRST Robotics Competition (FRC)
  - Robot game changes yearly

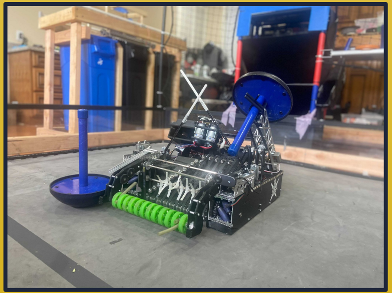
- Right: robot from 2020-2021 Ultimate Goal season

FIRST LEGO LEAGUE

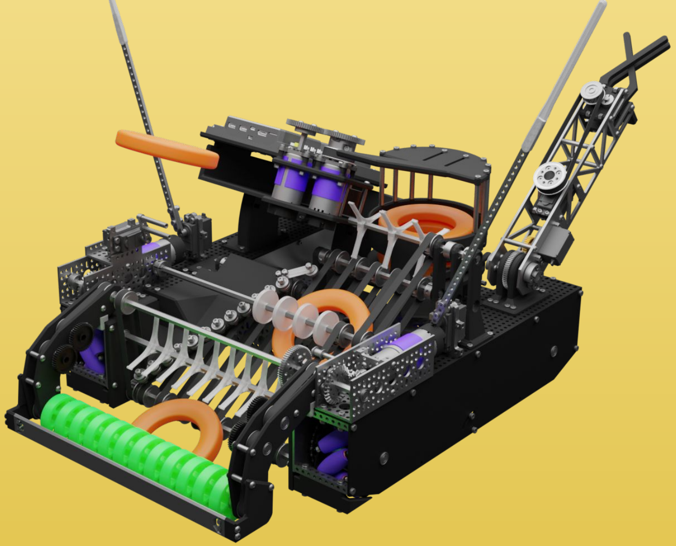
FIRST TECH CHALLENGE

FIRST ROBOTICS COMPETITION



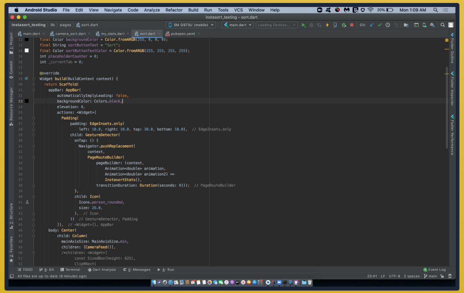


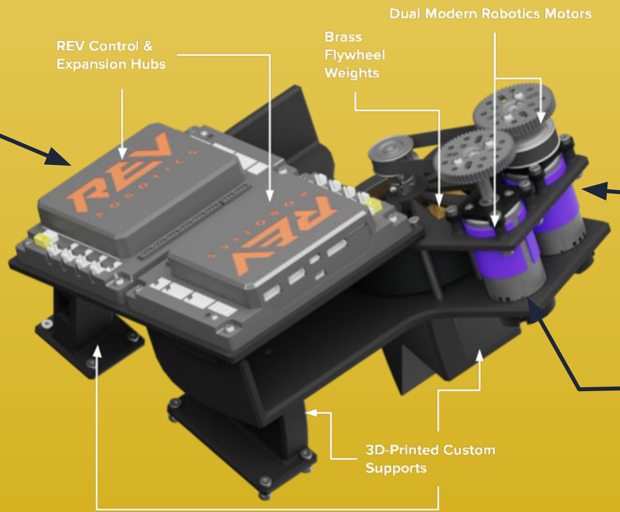
OUR FTC ROBOT



Software

- Use Roadrunner libraries
- Program



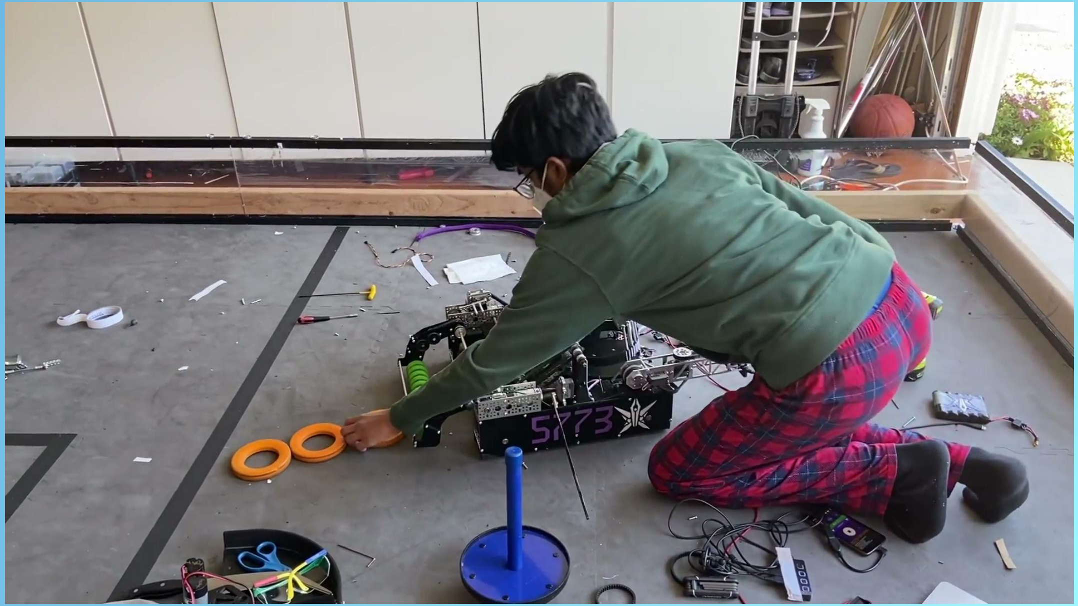


Hardware

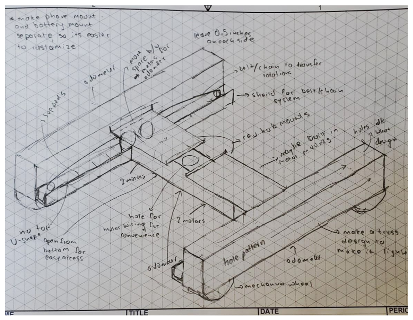
- Servos, senors, motors, etc.
- Follow build system - goBilda, REV, etc.

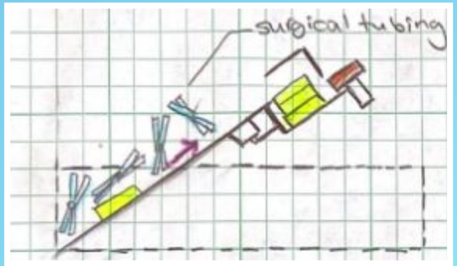
STEPS TO APPROACH ROBOTICS PROJECT

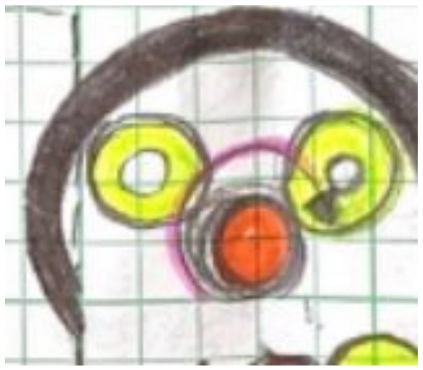
GENERAL STEP	FTC
DEFINE THE PROBLEM	Discuss the season’s game and the appropriate types of mechanisms ○ E.g. Ultimate Goal season ■ Game: intake and shoot rings ■ Mechanisms: grippy rollers, flywheel, ring carriage

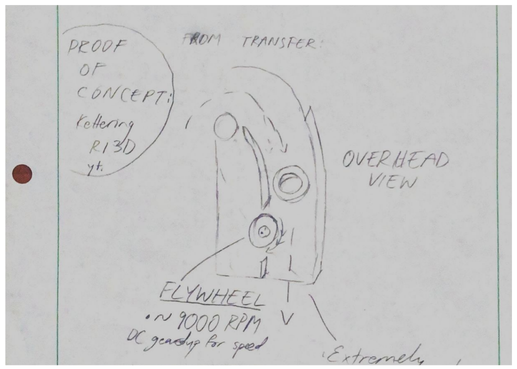


GENERAL STEP	FTC
GENERATE CONCEPTS	● Each team member - sketch exact mechanism idea ● Hold meeting to decide upon initial mechanism versions







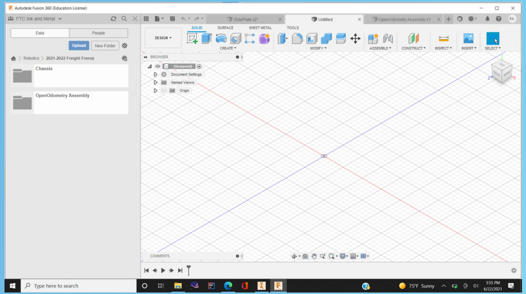


GENERAL STEP

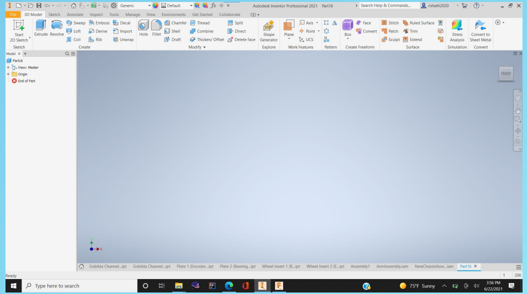
DEVELOP THE SOLUTION (INTO A CAD DESIGN)

FTC

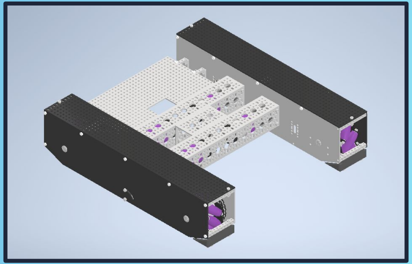
- CAD mechanism
  - Software: Autodesk Inventor, Autodesk Fusion360, Onshape, SOLIDWORKS



Autodesk Fusion360 UI

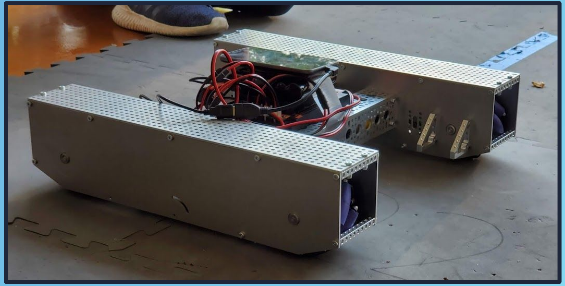


Autodesk Inventor UI

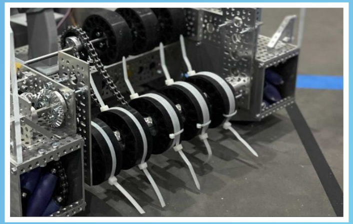


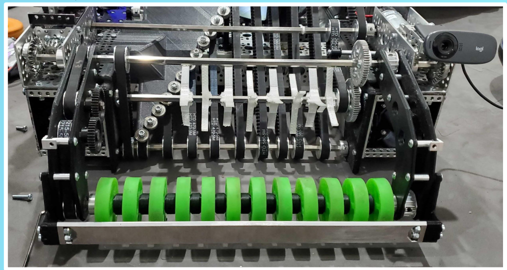
CADded Robot Chassis

GENERAL STEP	FTC
BUILD THE SOLUTION	• Build mechanism

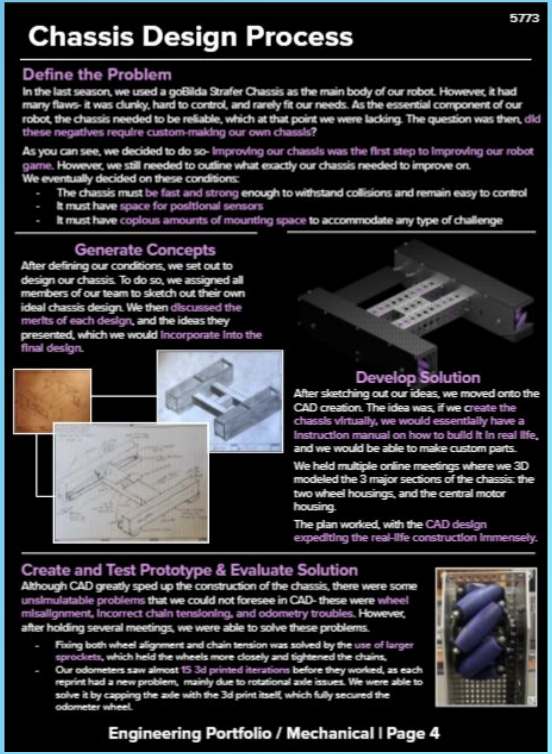


GENERAL STEP	FTC
EVALUATE THE SOLUTION	• Determine all problems in-person and redesign CAD - then rebuild and keep iterating





GENERAL STEP	FTC
PRESENT THE FINAL SOLUTION	• Present the product in Engineering Portfolio



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Chassis Design Process

Define the Problem

In the last season, we used a goBilda Strafer Chassis as the main body of our robot. However, it had many flaws- it was clunky, hard to control, and rarely fit our needs. As the essential component of our robot, the chassis needed to be reliable, which at that point we were lacking. The question was then, did these negatives require custom-making our own chassis?

As you can see, we decided to do so- Improving our chassis was the first step to improving our robot game. However, we still needed to outline what exactly our chassis needed to improve on.
We eventually decided on these conditions:

- The chassis must be fast and strong enough to withstand collisions and remain easy to control
- It must have space for positional sensors
- It must have copious amounts of mounting space to accommodate any type of challenge

Generate Concepts

After defining our conditions, we set out to design our chassis. To do so, we assigned all members of our team to sketch out their own ideal chassis design. We then discussed the merits of each design, and the ideas they presented, which we would incorporate into the final design.

Develop Solution

After sketching out our ideas, we moved onto the CAD creation. The idea was, if we create the chassis virtually, we would essentially have a instruction manual on how to build it in real life, and we would be able to make custom parts.

We held multiple online meetings where we 3D modeled the 3 major sections of the chassis: the two wheel housings, and the central motor housing.

The plan worked, with the CAD design expediting the real-life construction immensely.

Create and Test Prototype & Evaluate Solution

Although CAD greatly sped up the construction of the chassis, there were some unsimulatable problems that we could not foresee in CAD- these were wheel misalignment, incorrect chain tensioning, and odometry troubles. However, after holding several meetings, we were able to solve these problems.

- Fixing both wheel alignment and chain tension was solved by the use of larger sprockets, which held the wheels more closely and tightened the chains,
- Our odometers saw almost 15 3d printed iterations before they worked, as each reprint had a new problem, mainly due to rotational axle issues. We were able to solve it by capping the axle with the 3d print itself, which fully secured the odometer wheel.

Engineering Portfolio / Mechanical | Page 4

LET'S PRACTICE!

Problem:

One Problem that we have found a solution to is the cross-contamination of trash in society.

Solution:

We have built a mechanized TrashSorter and TrashSorter App to scan and detect waste and sort it in compost, recycling, or landfill.

If you have an iPhone, you can go to the App Store and download the **Instasort** app to see the solution in greater detail. We are also working to release this app on the Play Store.

Think of a problem that is negatively affecting the world.

Think of a solution to that same problem that you brainstormed. Keep in mind factors such as cost, feasibility, and effectiveness.

SESSION ENDED

SEE YOU ON THURSDAY @ 5 PM!

ROBOTICS COURSE - GRADE 6,7,8

Week 1, Day 2

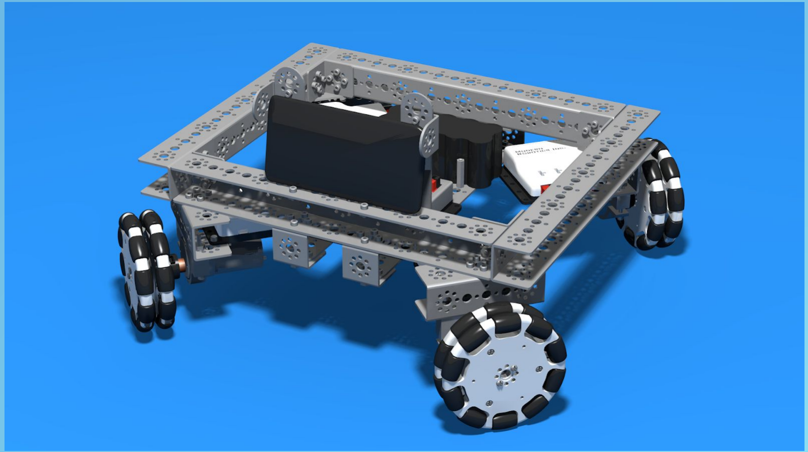
JOIN THE GOOGLE CLASSROOM

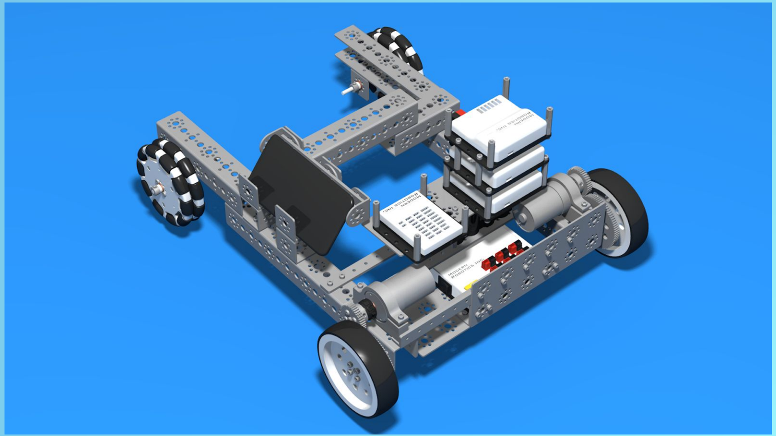
Invite passcode: ddzfggq

CHASSIS DESCRIPTION

CHASSIS

- A frame of some sort that usually holds the body + motor of a vehicle





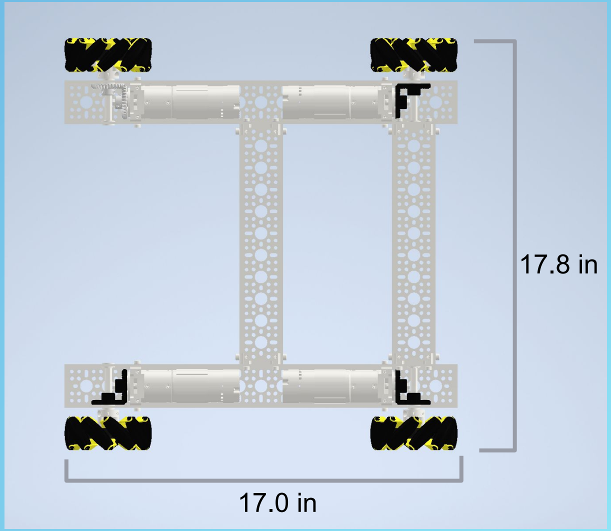
BUILD SYSTEMS

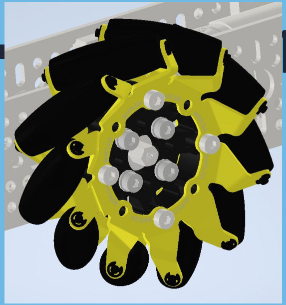
Companies partnered with FIRST

- Gobilda
- Andymark
- REV Robotics
- And many more!

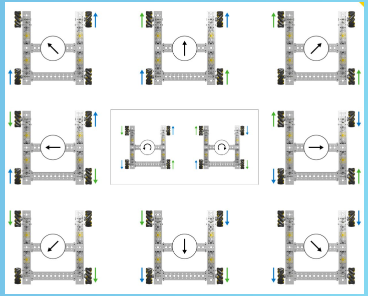
goBilda Strafer Chassis

- Uses mecanum wheels that allow for diagonal movement
- 17 x 17.8 in
- Requires goBilda Yellow Jacket motors that are fitted within the channels
- :1 gear ratio





Strafing

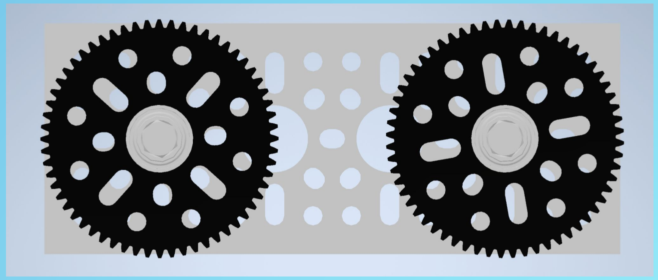


goBilda Strafer Chassis Advantages

- Lightweight
- Motors are conveniently hidden and out of the way
- Can easily move in all directions
- Space to build intake, outtake, and other mechanisms

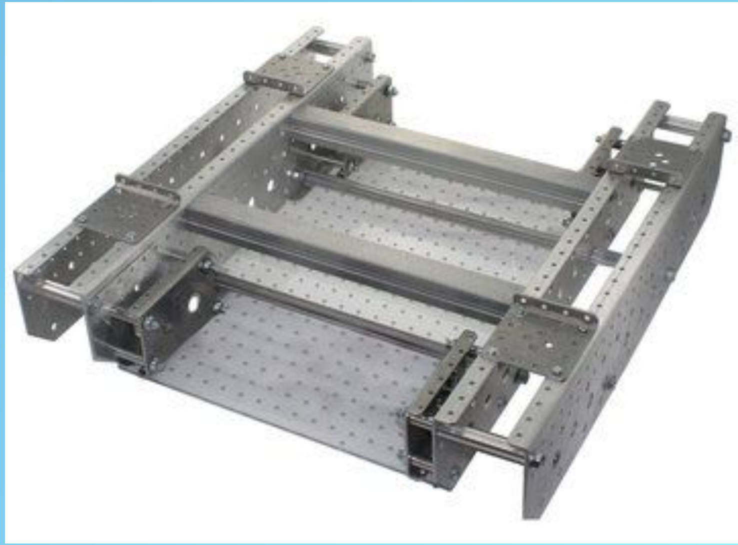
GOBILDA STRAFER CHASSIS DISADVANTAGES

- Using a 1:1 gear ratio can prevent increased speed
- Wheels are exposed on the sides
- Beam in the back may obstruct building of certain mechanisms such as intake and outtake



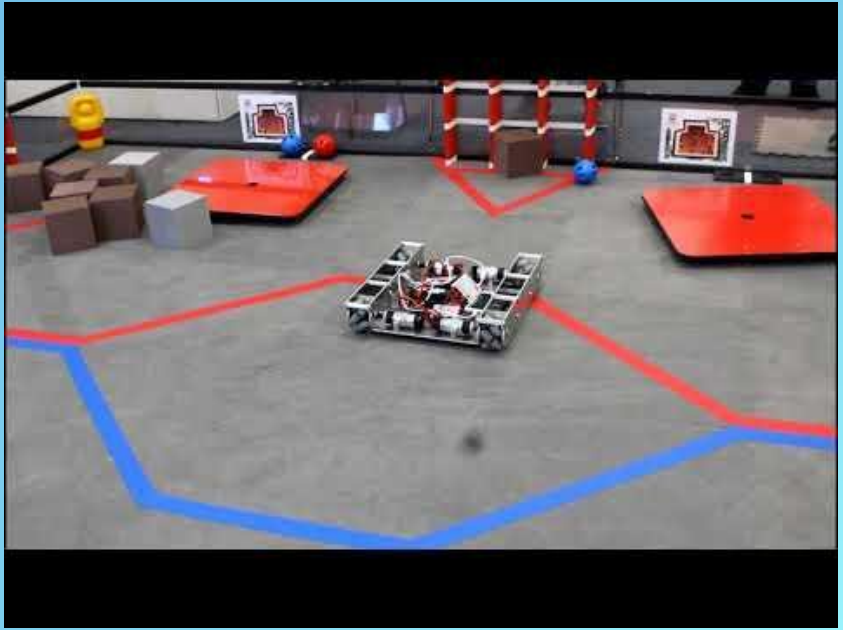
ANDYMARK TILE RUNNER CHASSIS

- Uses mecanum drive
- Includes side and bottom plates
- Uses AndyMark parts with different hole pattern on the bottom



ANDYMARK TILE RUNNER ADVANTAGES

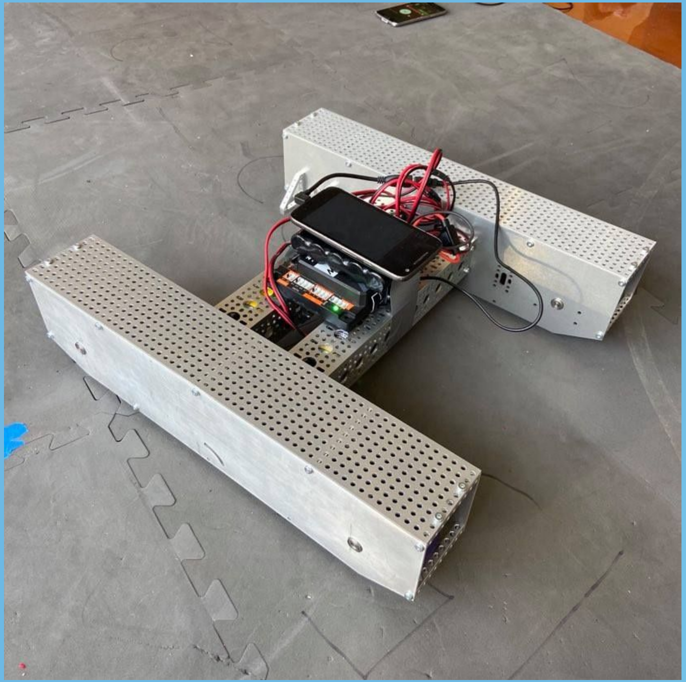
- Durable due to plating along the sides
- Can build on top of the side plates using the hole pattern
- Easy mounting on the bottom due to base plate

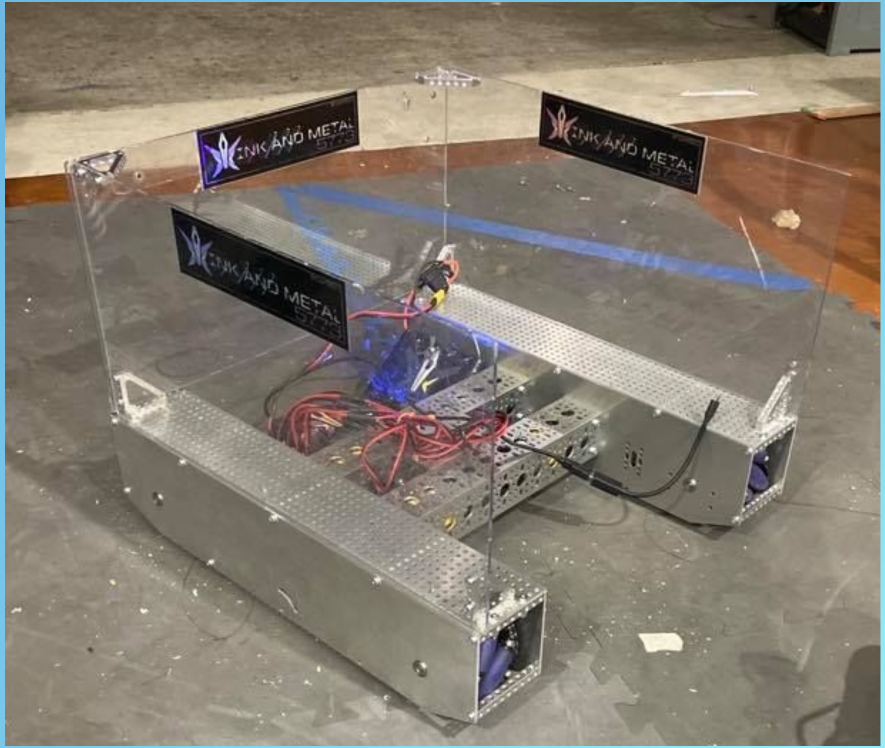


AndyMark Tile Runner: Disadvantages

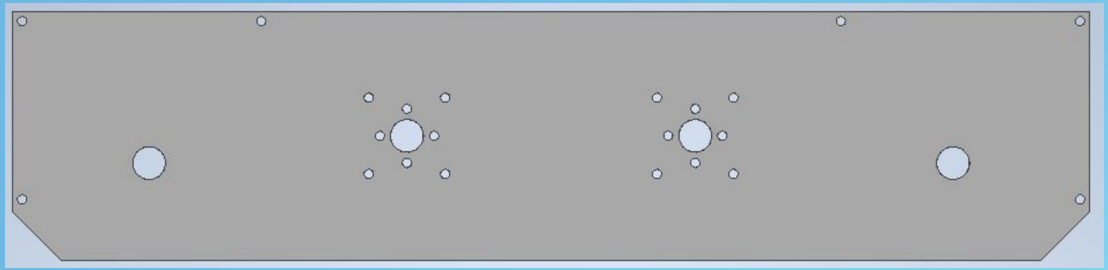
- Much heavier
- Based on parts used, hole pattern may require adapters
- Less space overall due to placement of beams and side plates

INK AND METAL CUSTOM CHASSIS

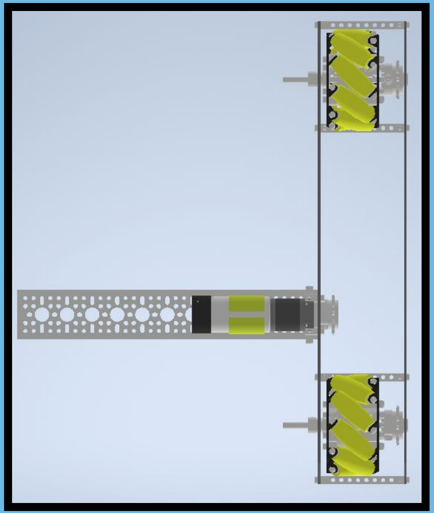


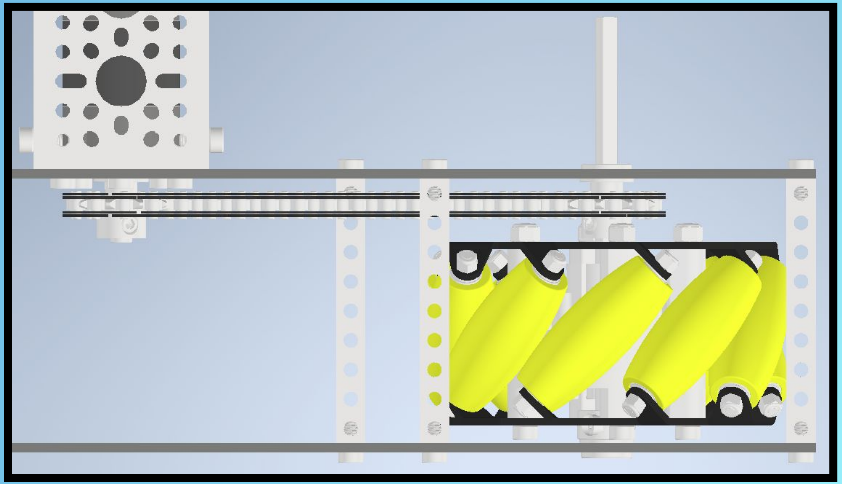


INK AND METAL CUSTOM CHASSIS



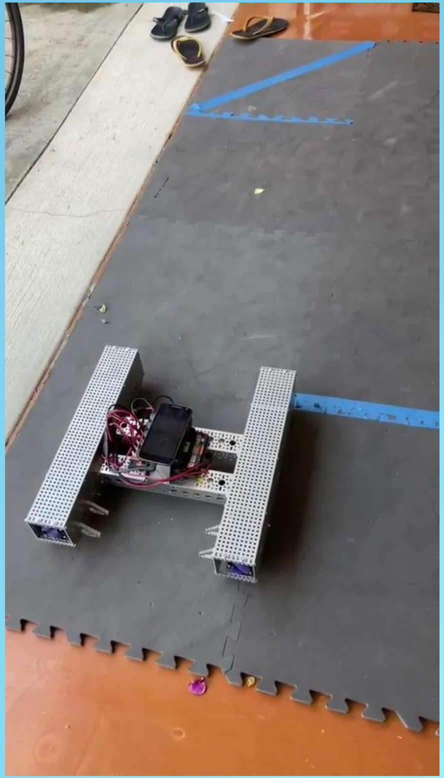
- Connects using a 1:1 chain and sprocket ratio
- Motors are tucked into the middle beams



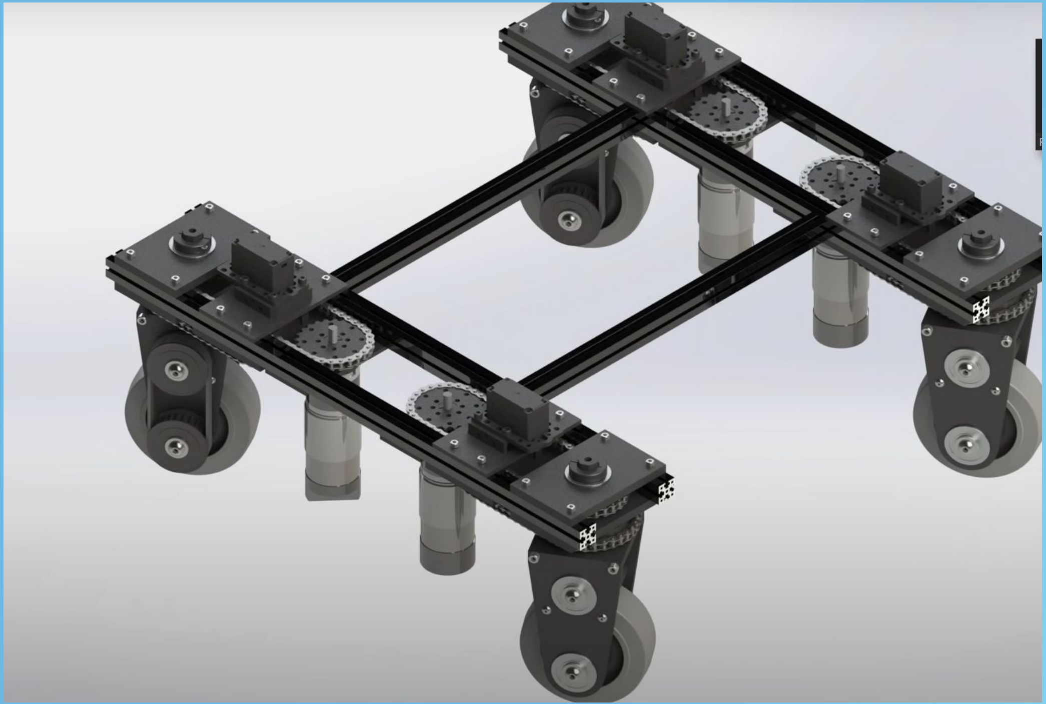


INK AND METAL CHASSIS: ADVANTAGES

- Motors are out of the way allowing for more space
- Mechanisms can be mounted on top of the grid plates
- Lightweight, but durable chassis

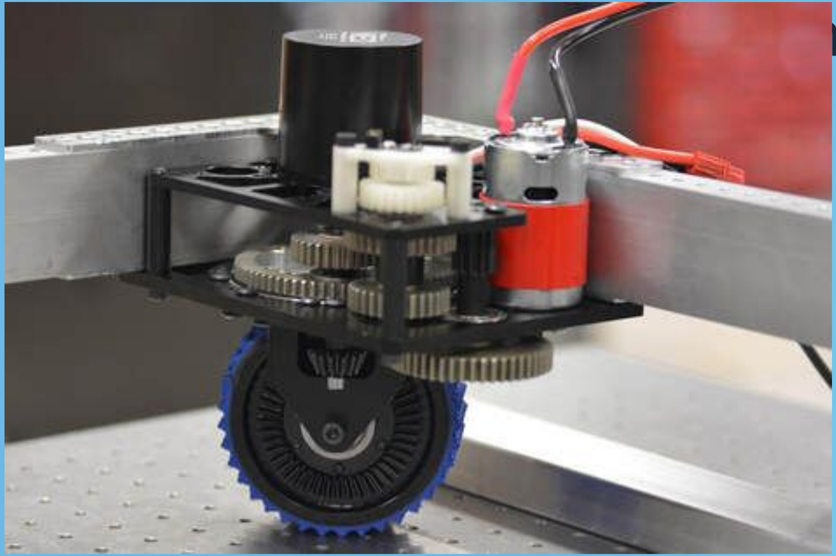


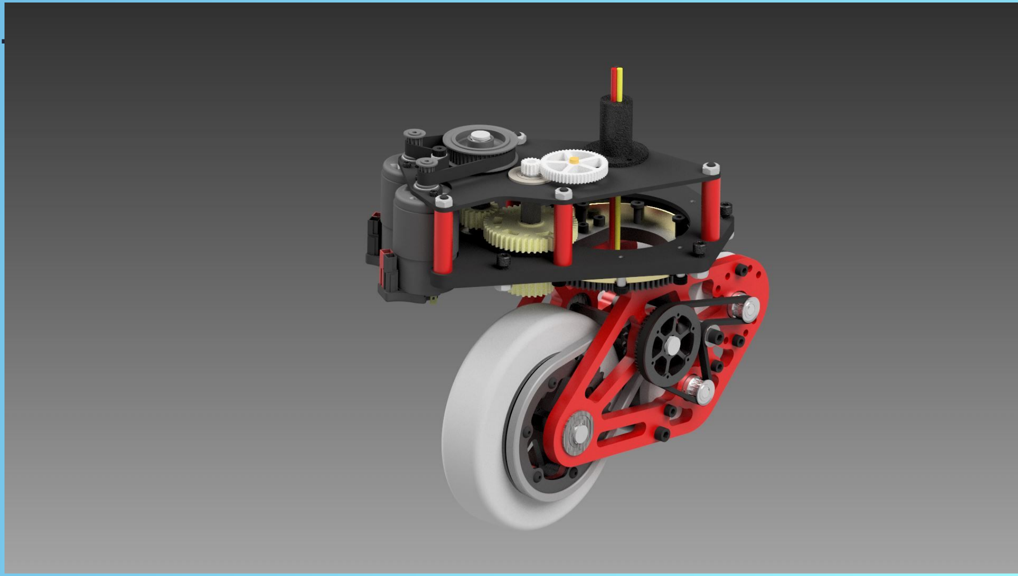
SWERVE DRIVE



SWERVE DRIVE ADVANTAGES

- Can move in any direction no matter the robot orientation



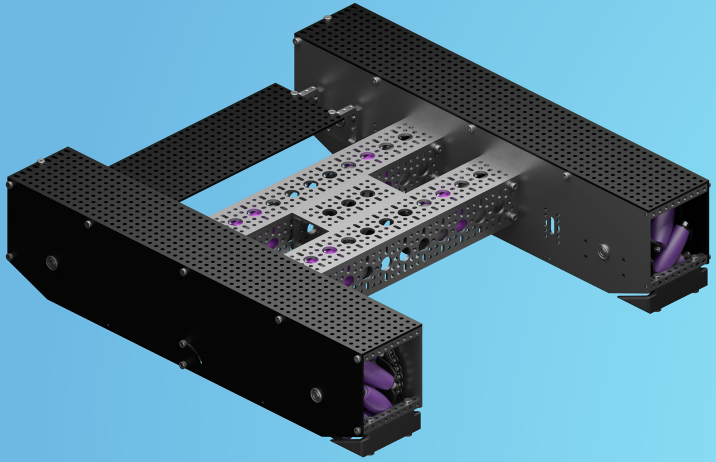


SWERVE DRIVE DISADVANTAGES

- More difficult to do code because you need to figure out orientation of robot and move all wheels accordingly
- More difficult to maintain since it is a more complex system that is hard to redesign/rebuild
- Takes up more space overall
  - Brings about the question of whether space is more important than maneuverability.

PREVIOUS SESSION REVIEW

EXAMPLE PROBLEM: ROBOT CHASSIS



General Step	FTC
Define the Problem	Yearly challenge: design a robot to move circular and spherical elements from one corner of a playing field to the other corner • In a meeting, list all of the requirements of the challenge

GENERAL STEP	FTC
GENERATE CONCEPTS	• Each team member - sketch exact mechanism idea • Hold meeting to decide upon initial mechanism versions

GENERAL STEP	FTC
DEVELOP THE SOLUTION (INTO A CAD DESIGN)	• ~~CAD mechanism~~ ◦ ~~Software: Autodesk Inventor, Autodesk Fusion360, Onshape, SOLIDWORKS~~ • Sketch mechanism ideas with annotations • When you get feedback in the EVALUATE THE SOLUTION step, come back to this step and create new design sketches with the improvements

GENERAL STEP	FTC
BUILD DESIGN	• Build mechanism

GENERAL STEP	FTC
EVALUATE THE SOLUTION	• ~~Determine all problems in person and redesign CAD then rebuild and keep iterating~~ • Discuss the design with everyone in the main session, get feedback

GENERAL STEP	FTC
PRESENT THE FINAL SOLUTION	• Present the product in a slideshow page

SESSION ENDED

SEE YOU ON TUESDAY @ 5 PM!

ROBOTICS COURSE - GRADE 6,7,8

Week 2, Day 1

REVIEW OF PREVIOUS CLASSES

- The first two classes we talked about FIRST and the Chassis.
- We talked about the design process and how it works
- We talked about different types of chassis's
- Week 1 Day 2 we did a activity involving the design process and our knowledge about the different types of chassis

GEAR DESCRIPTION

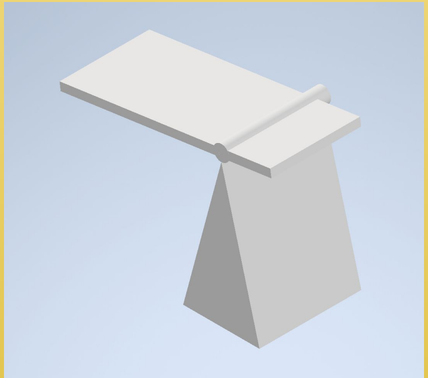
- Circular wheels with teeth that mesh with other gears
- Allows circular motion transfer between axles

GEAR RATIO

- Two gears of different sizes are meshed to allow mechanical advantage

MECHANICAL ADVANTAGE, GEAR RATIO

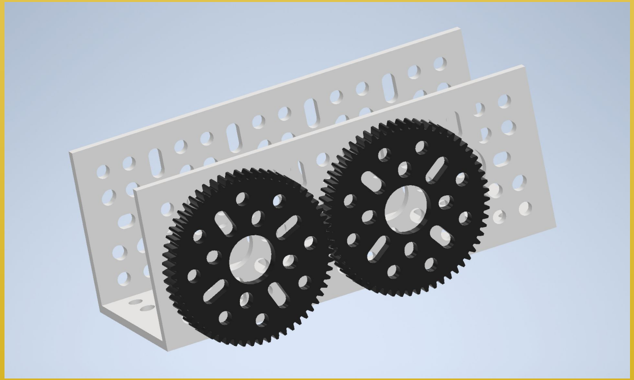
Mechanical advantage - constant energy



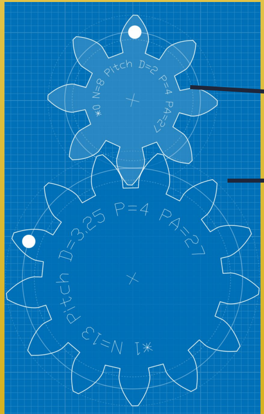
high torque, low speed

$$\frac{Torque_{\ in}}{Torque_{\ out}} = \frac{Teeth_{\ in}}{Teeth_{\ out}}$$

low torque, high speed



Gear ratio formula:



8 teeth, Input torque: 10 Nm

13 teeth, output force = ?

Practice:

SPUR GEARS

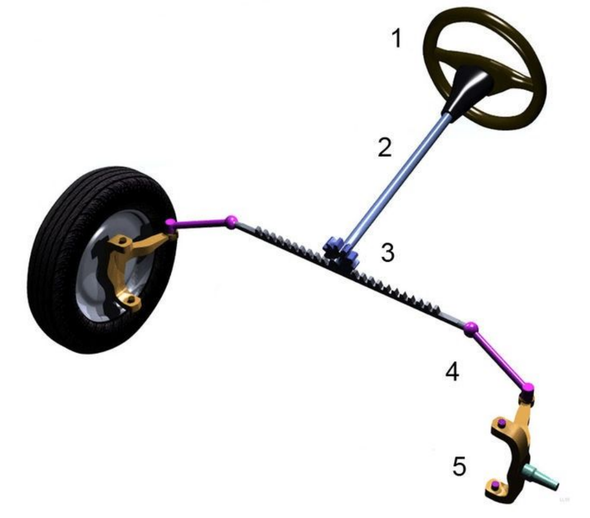
- Most common gear
- Used to increase or decrease output speed or torque of the mechanical system
- Ex. washing machine, clothes dryers, blenders

HELICAL GEARS

- Slanted tooth traces
- Larger contact ratio
    - Less vibration
    - Can exert force on larger area → greater pressure
- Greater manufacturing time

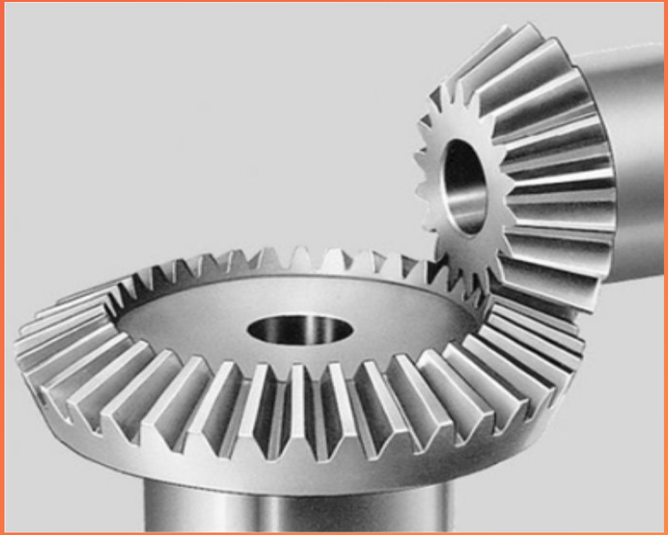
RACK AND PINION

- Used to convert a rotational gear motion into a linear motion
- Very simple to use
- Ex. Steering wheels of cars.



BEVEL GEARS

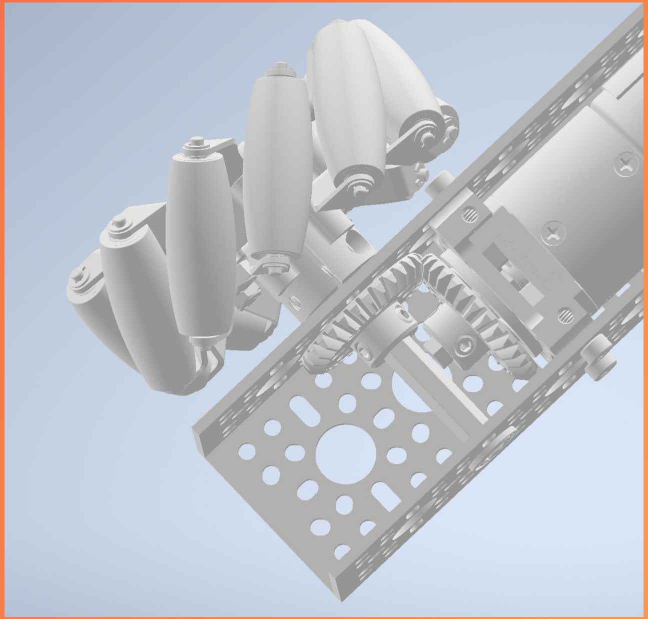
- Used when the axes of two shafts intersect
- Usually used for 90 degree angles.
  - Gears an be designed for other angles too
- Ex. Hand drills, cars, and garage doors.



MITER GEARS

- They are bevel gears with 1:1 gear ratio

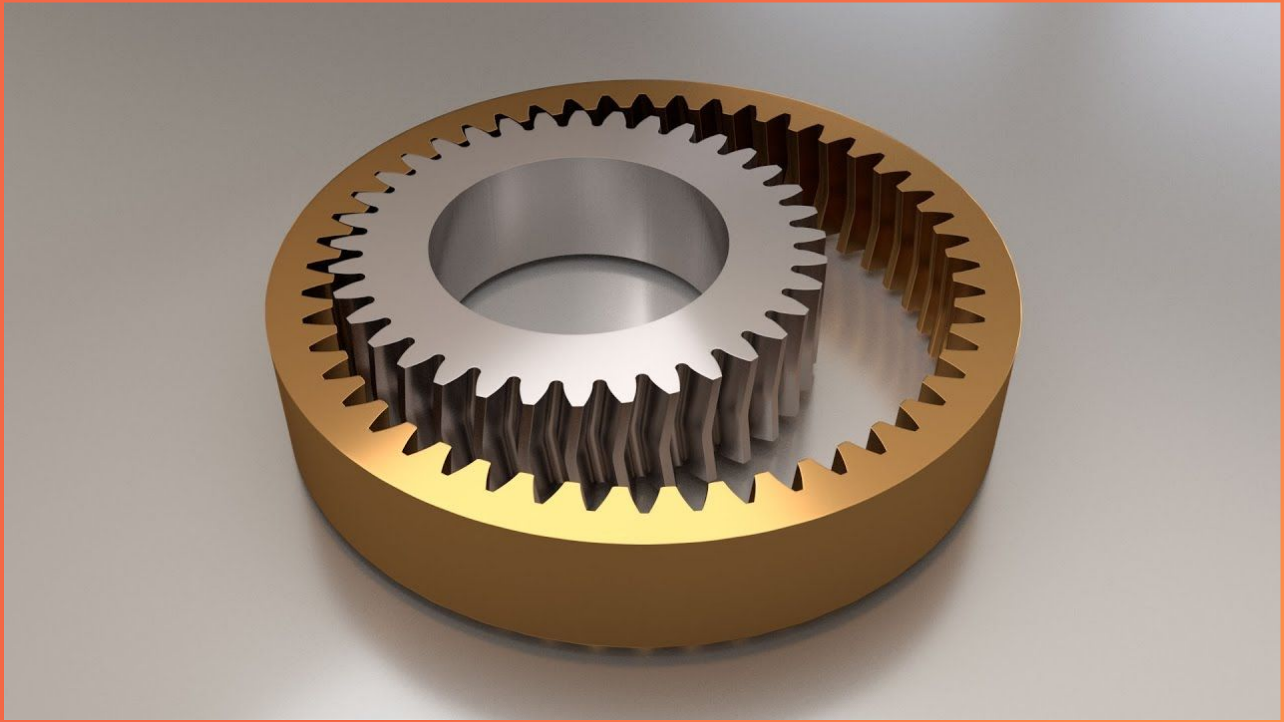
90 degree intersection



WORM GEARS

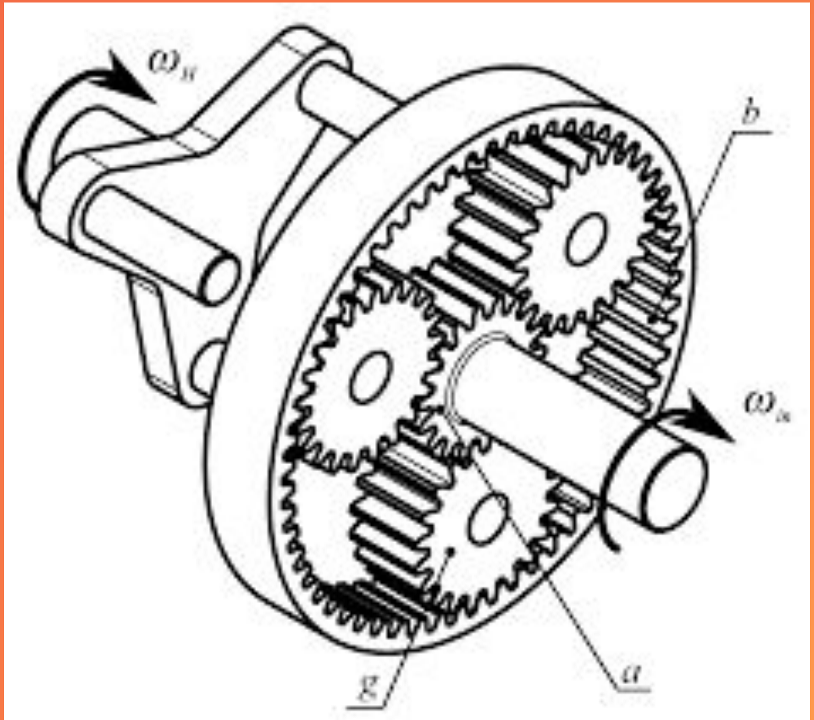
- Extremely high torque
- Extremely slow speed
- Worm gear can drive spur gear, but the opposite is not true
- Used in car jack - high torque, low distance

INTERNAL GEAR



PLANETARY GEARBOX

- Complex system of internal and spur gears that reduce or increase the speed of an axle without using much space
- Are prone to failure because of their complexity
- Provide great load bearing due to the greater teeth that spread the forces among each gear



EXAMPLE PLANETARY GEARBOX

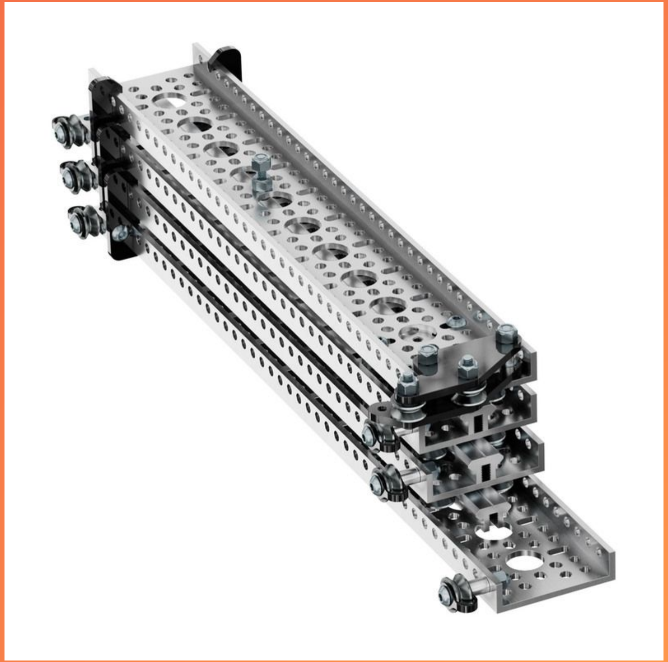
GEAR SIMULATION - COOL RESOURCE

Link:
https://geargenerator.com/#200,200,100,6,1,3,0,4,1,8,2,4,27,-90,0,0,0,0,0,0,16,4,4,27,-60,0,0,0,0,1,1,12,1,12,20,-60,0,0,0,0,2,0,60,5,12,20,0,1,0,0,0,0,0,3,-515

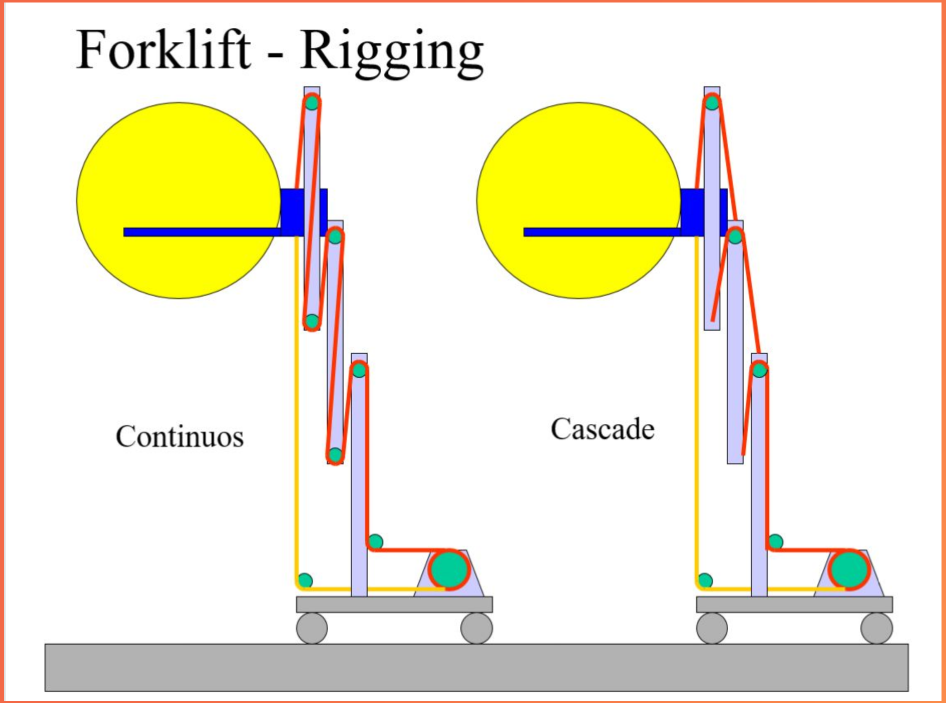
WHAT ARE LINEAR SLIDES?

- Linear slides are two rails joined together that collapse and extend based on the tension of a rope/string pulling on it
- They can retract back into a small form factor with the use of elasticity from something like rubber bands or surgical tubing
- They quite often need to be oiled so that they are able to run smoothly

LINEAR SLIDES IN FTC ROBOTICS



CASCADING VS CONTINUOUS LIFT



LINEAR ACTUATOR

- Two rails that are powered by a screw that allows for great amount of gear reduction and immense torque
- Unlike linear slides, the linear actuator is slower and can be controlled more finely
- Most often used to lift the whole robot off the floor

SERVO OR MOTOR?

- For linear slides and linear actuators, what would you use, a motor or a servo
    - Servos are slow and have somewhat great torque; also know angle to the degree
    - Motors are fast and can have great torque

SERVO OR MOTOR?

- Motor would be the best choice
  - For linear slides, you are going from collapsed to extended so speed is necessary to get the fastest extension time
    - Motors tend to be faster than servos
  - For the linear actuator, you would need speed because the screw is reducing the speed so much that if aservo was used, it would take a long time to fully extend
    - Servos are already slow enough as they are so using one in this case would make it so that the time to extend is not justified
- However, For extremely light applications, servos are helpful because they require much less voltage to run

DESIGN YOUR OWN MECHANISM

- Imagine you are designing a robot to stack large lego bricks. What mechanisms would you use to lift up the block? If the block's mass is 20 grams then what mechanism would you use? If it was 2000 grams then what would you use? Discuss in groups and brainstorm a design for how to grip the lego block. You will be presenting at the end of class.

GENERAL STEP	FTC
DEFINE THE PROBLEM	Yearly challenge: design a robot to move lego and spherical elements from one corner of a playing field to the other corner • In a meeting, list all of the requirements of the challenge

GENERAL STEP	FTC
GENERATE CONCEPTS	• Each team member - sketch exact mechanism idea • Hold meeting to decide upon initial mechanism versions

GENERAL STEP

DEVELOP THE SOLUTION (INTO A CAD DESIGN)

FTC

- ~~CAD mechanism~~
  - ~~Software: Autodesk Inventor, Autodesk Fusion360, Onshape, SOLIDWORKS~~
- Sketch mechanism ideas with annotations
- When you get feedback in the EVALUATE THE SOLUTION step, come back to this step and create new design sketches with the improvements

GENERAL STEP	FTC
BUILD DESIGN	• Build mechanism

GENERAL STEP	FTC
EVALUATE THE SOLUTION	• ~~Determine all problems in person and redesign CAD then rebuild and keep iterating~~ • Discuss the design with everyone in the main session, get feedback

GENERAL STEP	FTC
PRESENT THE FINAL SOLUTION	• Present the product in a slideshow page

SESSION ENDED

SEE YOU ON THURSDAY @ 5 PM!

ROBOTICS COURSE

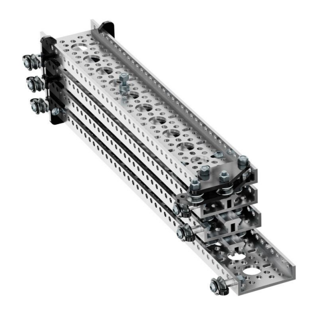
Week 2, Day 2

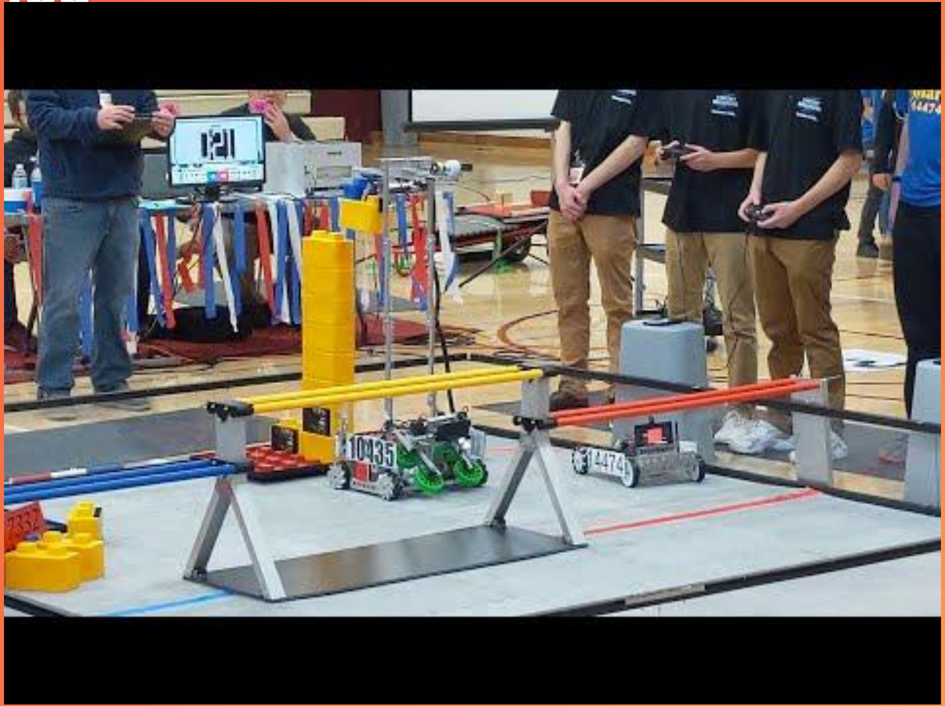
REVIEW OF LAST CLASS

WHAT ARE LINEAR SLIDES?

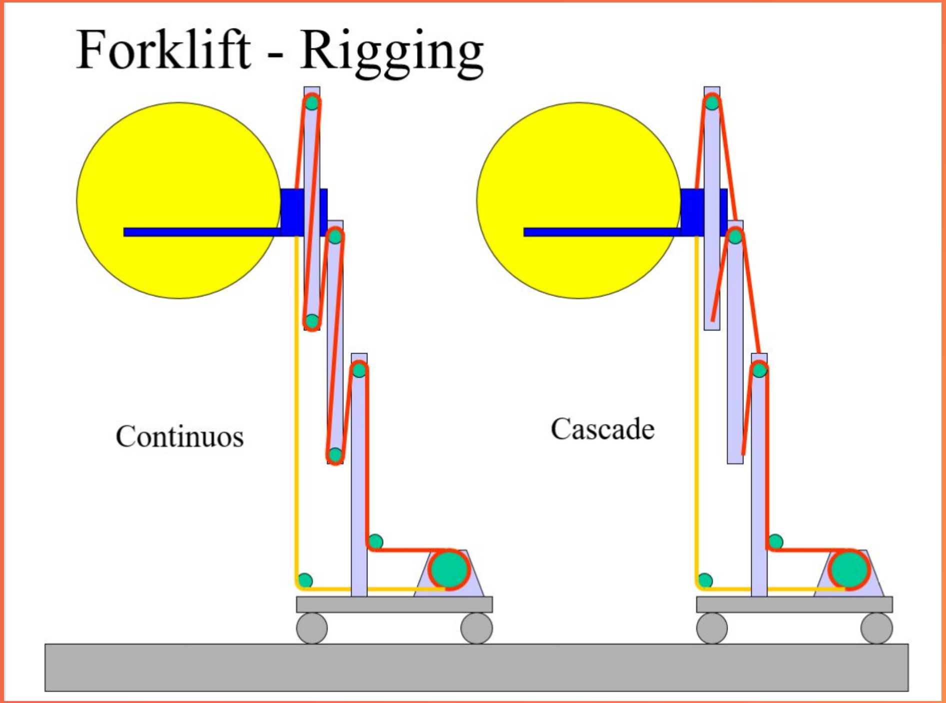
- Linear slides are two rails joined together that collapse and extend based on the tension of a rope/string pulling on it
- They can retract back into a small form factor with the use of elasticity from something like rubber bands or surgical tubing
- They quite often need to be oiled so that they are able to run smoothly

LINEAR SLIDES IN FTC ROBOTICS





CASCADING VS CONTINUOUS LIFT



LINEAR ACTUATOR

- Two rails that are powered by a screw that allows for great amount of gear reduction and immense torque
- Very low speed, very high torque
- Most often used to lift the whole robot off the floor

SERVO OR MOTOR?

- For linear slides and linear actuators, what would you use, a motor or a servo
    - Servos are slow and have somewhat great torque; also know angle to the degree
    - Motors are fast and can have great torque

SERVO OR MOTOR?

- Motor would be the best choice
  - For linear slides, you are going from collapsed to extended so speed is necessary to get the fastest extension time
    - Motors tend to be faster than servos
  - For the linear actuator, you would need speed because the screw is reducing the speed so much that if aservo was used, it would take a long time to fully extend
    - Servos are already slow enough as they are so using one in this case would make it so that the time to extend is not justified
- However, For extremely light applications, servos are helpful because they require much less voltage to run

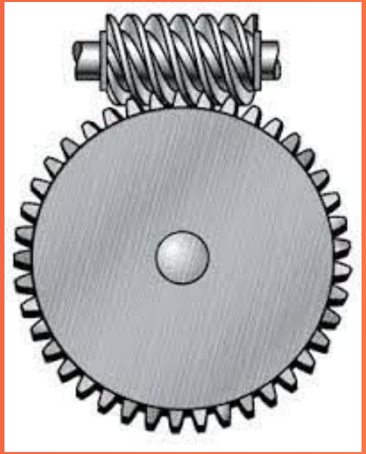
Rotational Motion

ROTATIONAL MOTION TRANSFER DESCRIPTION

- Motion transfer that occurs when one rotating body causes another body to rotate as well
- Can you think of any rotational motion transfer in our daily life?

ROTATIONAL MOTION TRANSFER IMPORTANCE

- Allows flexibility in a design
- Motors or engines can be in any orientation or position and can still function using rotational motion transfer methods



TYPES OF ROTATIONAL MOTION TRANSFER

- Belt
  - Has teeth that interlock with that of a pulley
  - Often has infused carbon fiber or fiberglass strands that increase the strength of the rubber base
    - Usually do not expand much because of high tensile strength
  - Usually used to rotate from point A to point B but one can use many more pulleys for a single belt
  - Since belts are a fixed length, it requires much more thought to get the length of the belt just right
  - Are often more prone to slippage but can be run in any orientation

TYPES OF ROTATIONAL MOTION TRANSFER

- Chain
  - Has holes that interlock with the teeth of the sprocket
  - Made of steel or other tough metals
    - Often expand due to the quality of the metal
  - Usually used to rotate from point A to point B but one can use many more sprockets for a single chain
  - Can break the chain using a special tool so that the length can be adjusted
    - Makes it so that there can be variable lengths
  - Are unable to run reliably sideways because chain has higher chance of slipping and falling off

TYPES OF ROTATIONAL MOTION TRANSFER

- Rotary Wheel
  - Requires the direct contact between two or more wheels
    - Relies on friction to get other body spinning
      - Is unable to handle much load because friction forces are not that great in magnitude
  - Simpler but less effective than a gear
  - Usually not used in robotics because it has very little torque that it can exert but it is still an important type of rotational motion transfer

TYPES OF ROTATIONAL MOTION TRANSFER

- Gears
  - Often requires multiple gears in order to span large distances
  - Is one of the most reliable due to no slipping between the gears because the mesh is tight
  - Often the most common way to reverse the direction of an axle
    - Turning right but having another axle turn left
  - Can also change the orientation completely unlike chain and belts

WHAT IS LOST WITH MORE ROTATIONAL MOTION TRANSFER?

ENERGY!

- When there is a lot of rotational motion transfer, much of the energy is lost to friction and turned into heat
  - Belts - energy is lost between the teeth of the belt and the pulley
  - Chain - energy is lost between the teeth of the sprocket and the chain
  - Gears - energy is lost between the teeth of the two different gears

SENSOR

COLOR SENSOR

- Emits white light, reads returned light wavelength

TACTILE SWITCH SENSOR

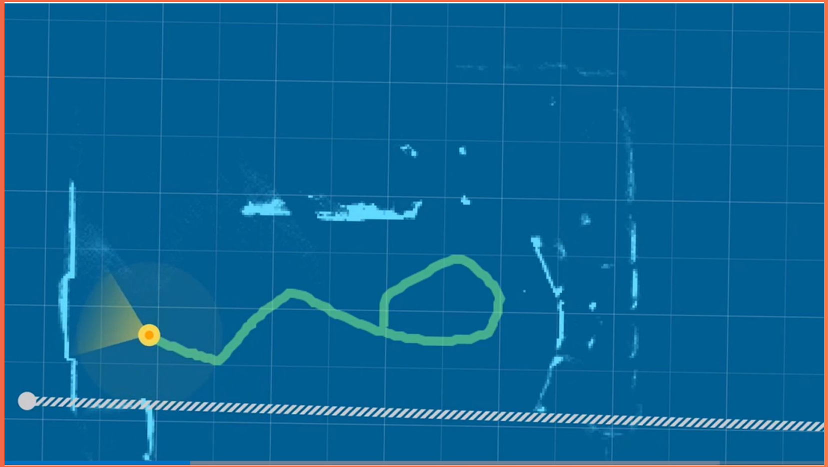
- Receives digital input (2 possible inputs - (pressed, not pressed)
  - Pressed = True
  - Not Pressed = False

DISTANCE SENSOR

- Either light or sound emitted
  Known: speed (v), time (t)
  We can determine: distance
  using d = vr
- When 2 are used together, can determine robot position in relation to field walls
- FAULT - IF A GAME ELEMENT COMES IN THE WAY, LOCALIZATION WILL BE INCORRECT

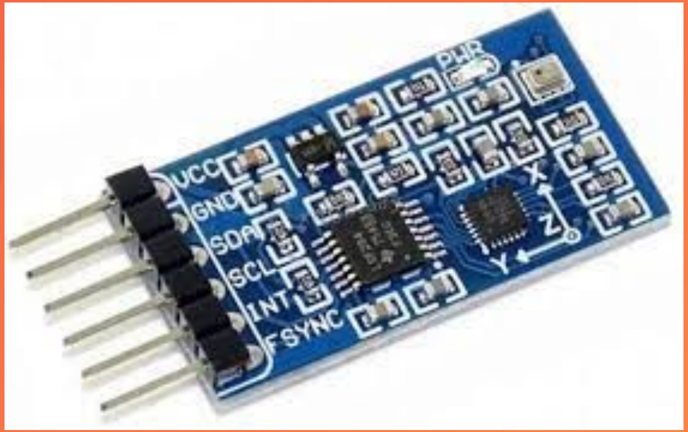
CAMERA - INTEL T265

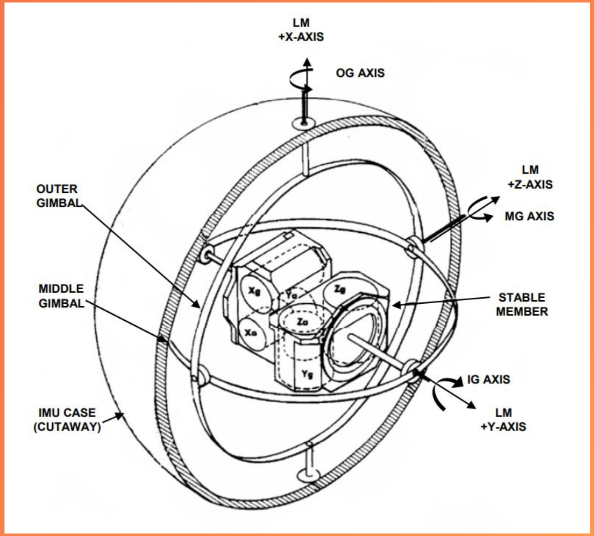
- Captures images, contains distance sensor



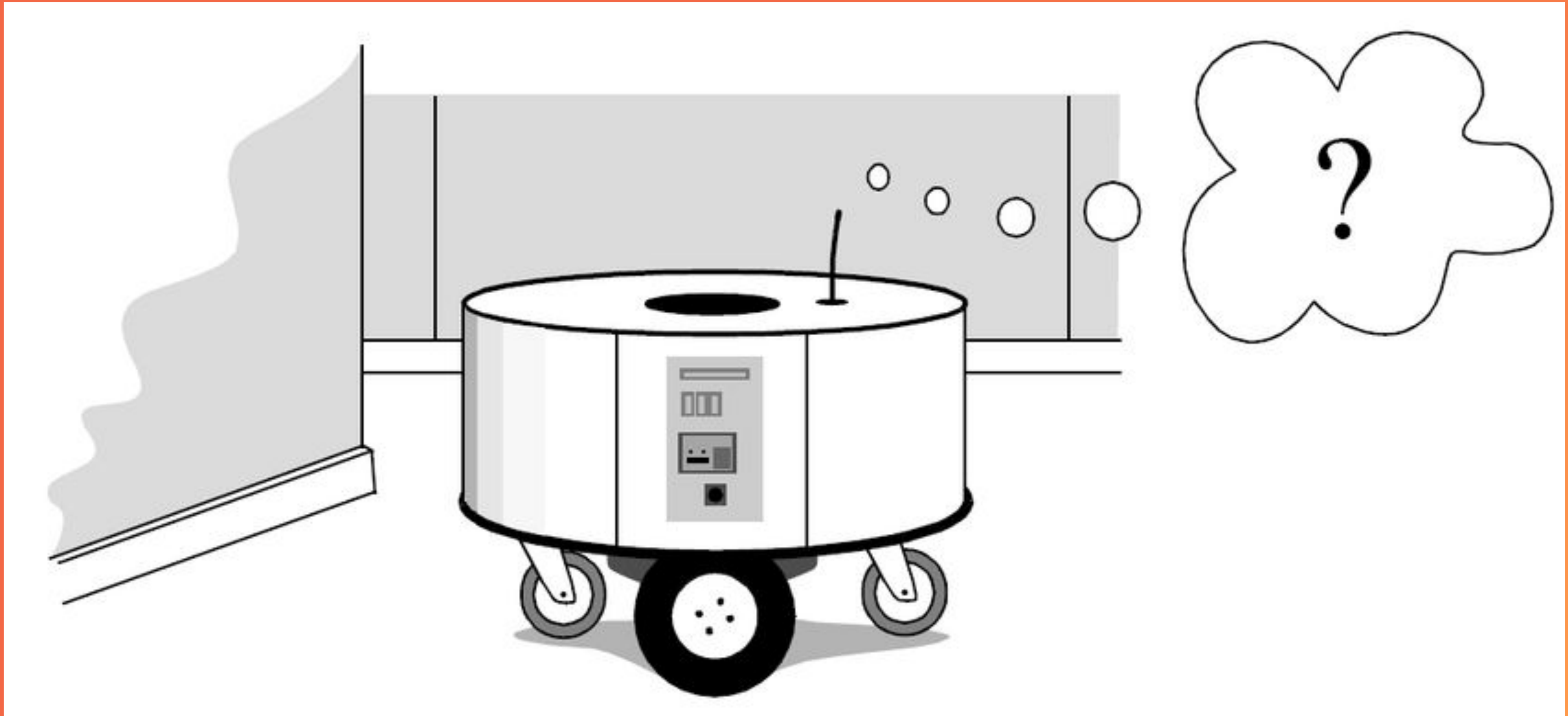
INERTIAL MEASUREMENT UNIT (IMU)

- Constant orientation - will work regardless of surrounding changes
- Robot position compared to IMU position to determine current angle



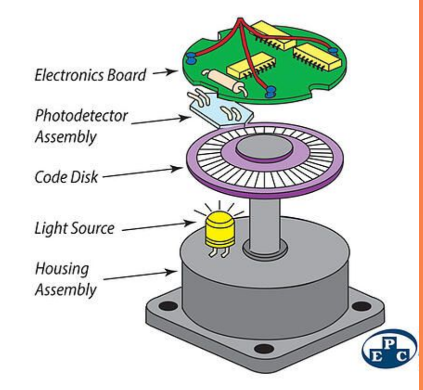


HOW CAN WE TELL WHERE A ROBOT IS ON A FIELD?



1) Encoder

- Parts
  - Light source
  - Disk with dark lines (ticks)
  - Photodetector
  - Circuit board
  - Wire (to connect motor to control hub; placed in this port)
- As motor rotates, lines pass in front of light source; subsequent dimming is detected by the photodetector and counted as a "tick"
- Ticks to unit distance ratio is added as a constant in robot code; can code motor to move *x* inches forward and the motors will turn (*x* * ticksPerUnitDistance) ticks

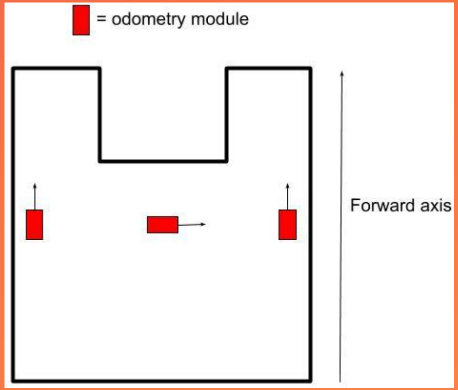


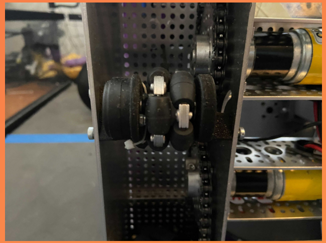
ENCODER (DIS)ADVANTAGES

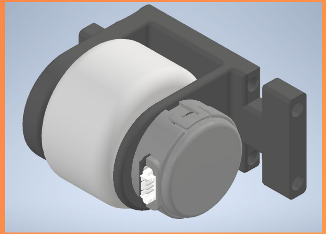
Disadvantages	• As it is, encoders can only be used for accurate motion; cannot be used to determine position
Advantages	• Comes built into common motors, such as goBilda Yellow Jacket motors and VEX Falcon 500 motors • Can be used in applications other than driving; e.g., this year can be used in outtake flywheel speed control • Acceleration control w/ PID tuning is much more consistent than that of REV Control Hub

2) ODOMETER

- Parts
  - Encoder
  - Casing
  - Omni wheel
- 3 odometers are placed as shown in the diagram
- As robot moves, encoders capture movement and send to Control Hub; software combines readings to determine displacement from starting position & current location (returned as a coordinate)
- Field is converted to a coordinate system
  - Starting point is origin
  - Any target position is specified as a coordinate (unit is inch)







ODOMETER (DIS)ADVANTAGES

Disadvantages	• PID tuning is very time consuming (took our team around 4 days) • Some delicate parts need to be handled very carefully (especially the clear disk with the ticks), otherwise you will get inconsistent readings
Advantages	• Returns exact location on the field -- very useful in challenges like Ultimate Goal • Roadrunner (written by team Acme Robotics) gives all robot motion functions (strafe, spline, etc.) -- no need to write code from scratch • Many teams have released odometry modules for any team to use

3) DISTANCE SENSOR

- Parts
  - Emitter
  - Receiver
- A beam of a light or a wave of sound is emitted at and bounced off object, time till return is recorded; using D = (RT) / 2 one can determine the distance to the object
- Can be used in conjunction with either odometers or encoders

DISTANCE SENSOR (DIS)ADVANTAGES

Disadvantages	• Can only be used when other reference objects (obstacles) are available -- not self-sufficient
Advantages	• Does not require any tuning time • Quite inexpensive • Adaptable; can be used to navigate around unpredictable obstacles

SUMMARY

Encoder: Allows precise speed, acceleration, and distance control

Odometer: Allows position reading/control and converts field into intuitive coordinate grid

Distance Sensor: Returns distance to an objects, used in conjunction with either odometers or encoders

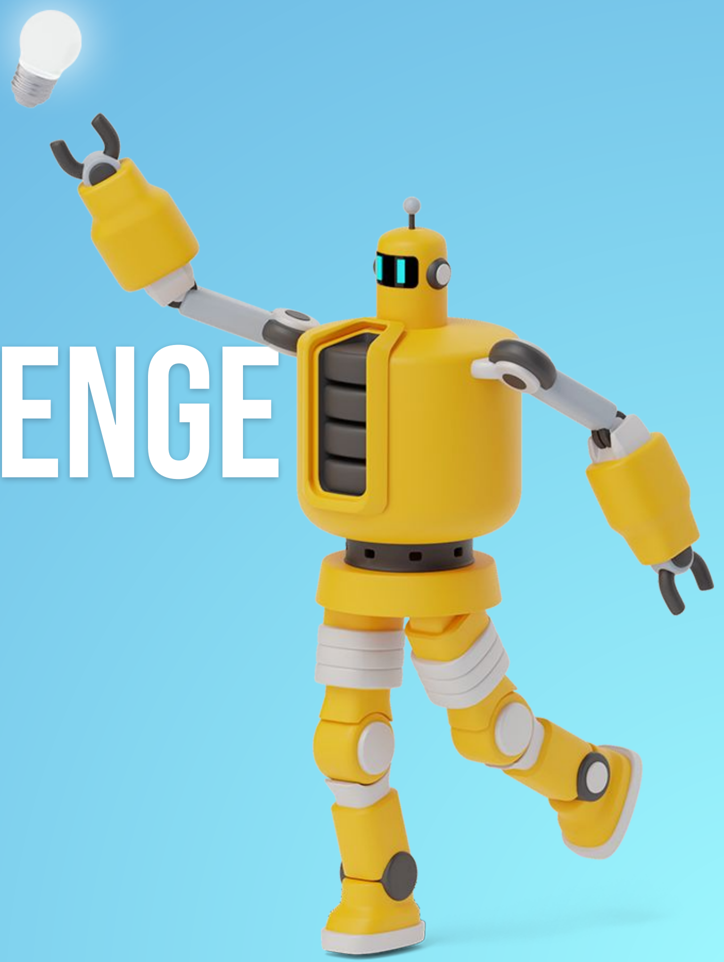
It is up to your team to decide the nature of the challenge and which form of navigation is the most applicable.

CHALLENGE TIME!

There are three objects in front of you spaced 6 inches apart. Two of the objects are white balls 3 inches in diameter and a yellow cube that is 12 inches in height. If you were to use a sensor to determine which of the objects was the cube, what would you use. Also design a mechanism to intake the balls and launch them in a 12 inch hoop.

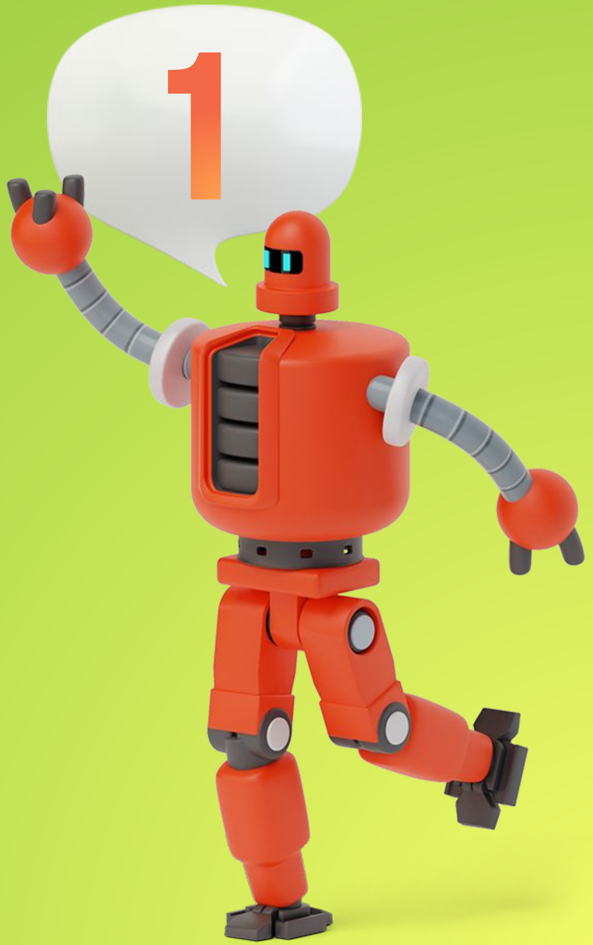
SKYSTONE CHALLENGE

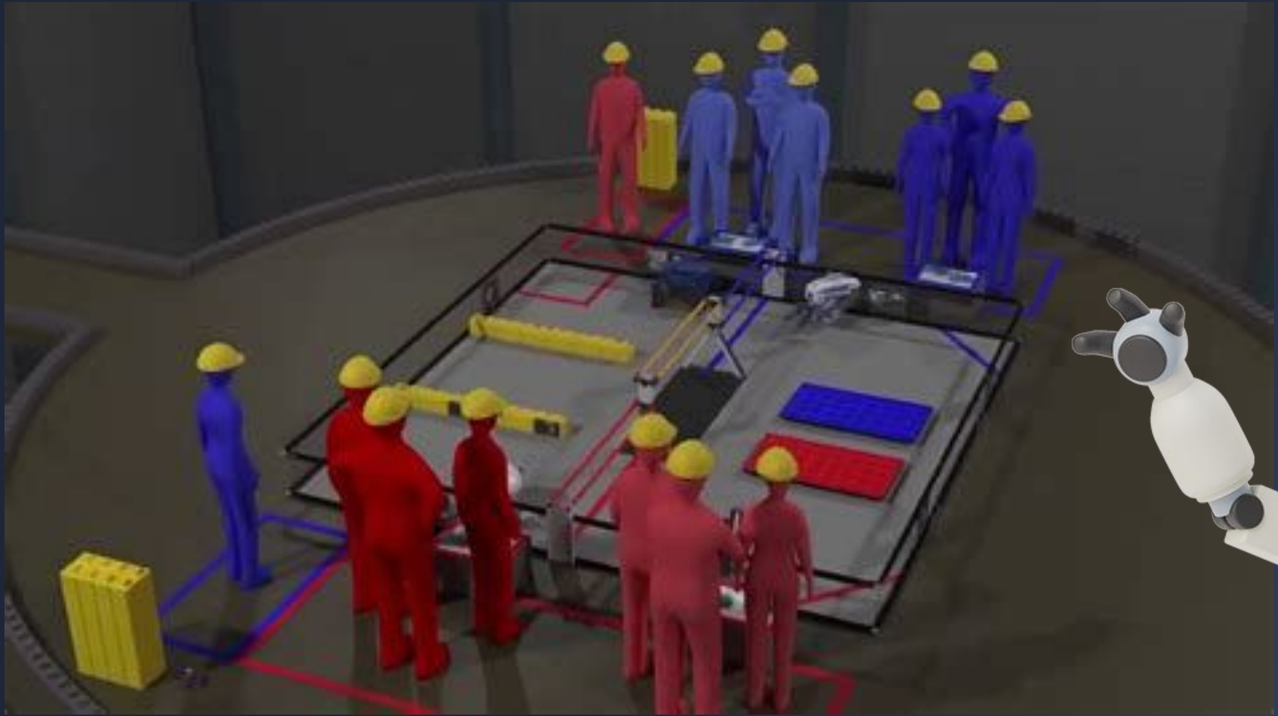
(2019 - 2020)

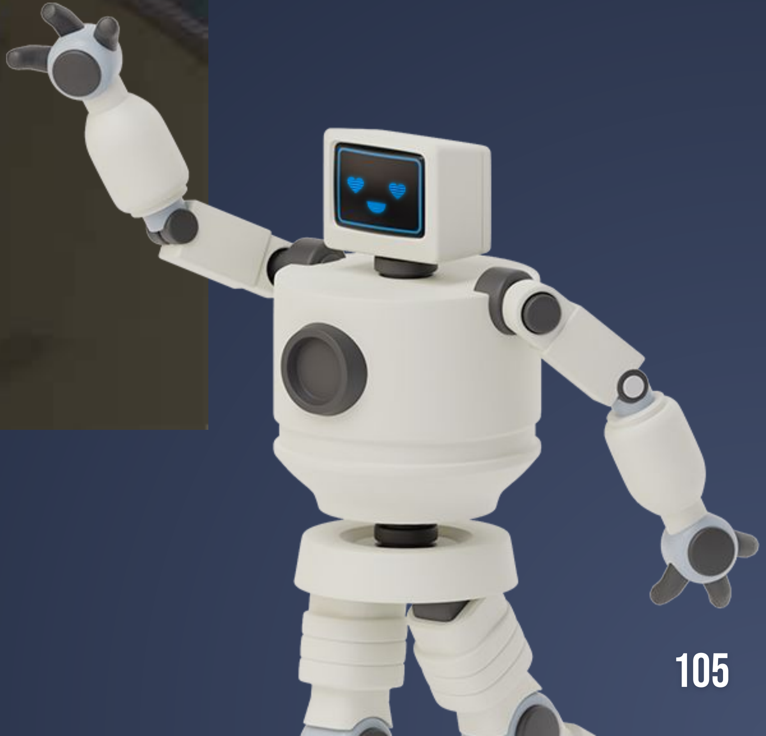


PREVIEW THE CHALLENGE

Understand the challenge and the ways to earn points.



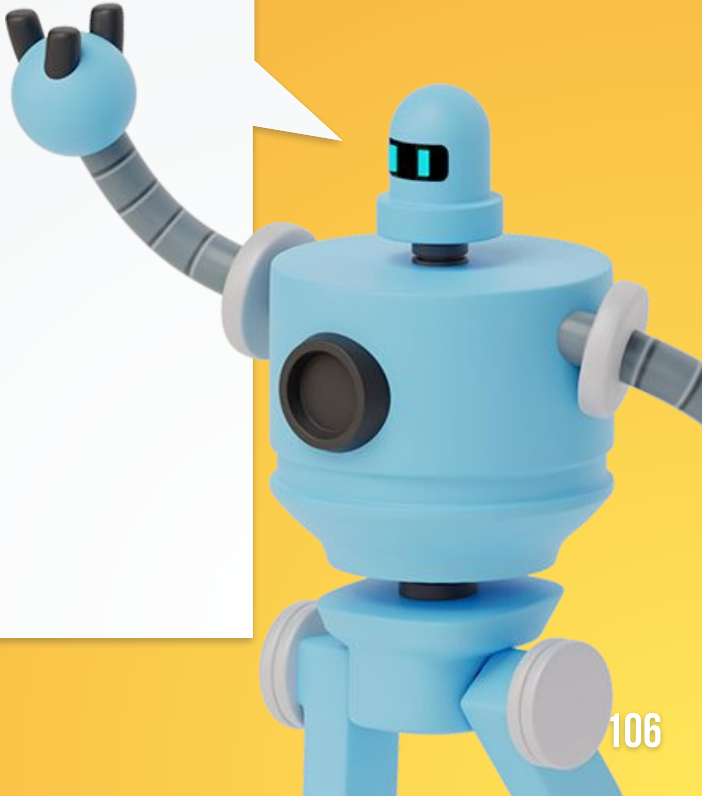




Skystone Challenge

Overall Objective:

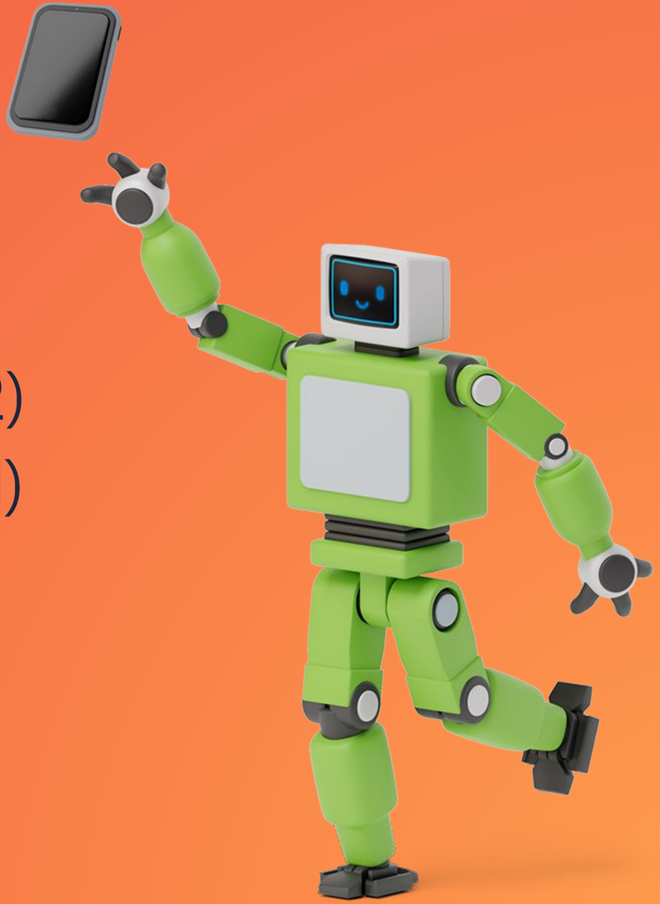
"To stack the stones (yellow blocks) onto alliance specific foundations"



POINT BREAKUP

Autonomous:

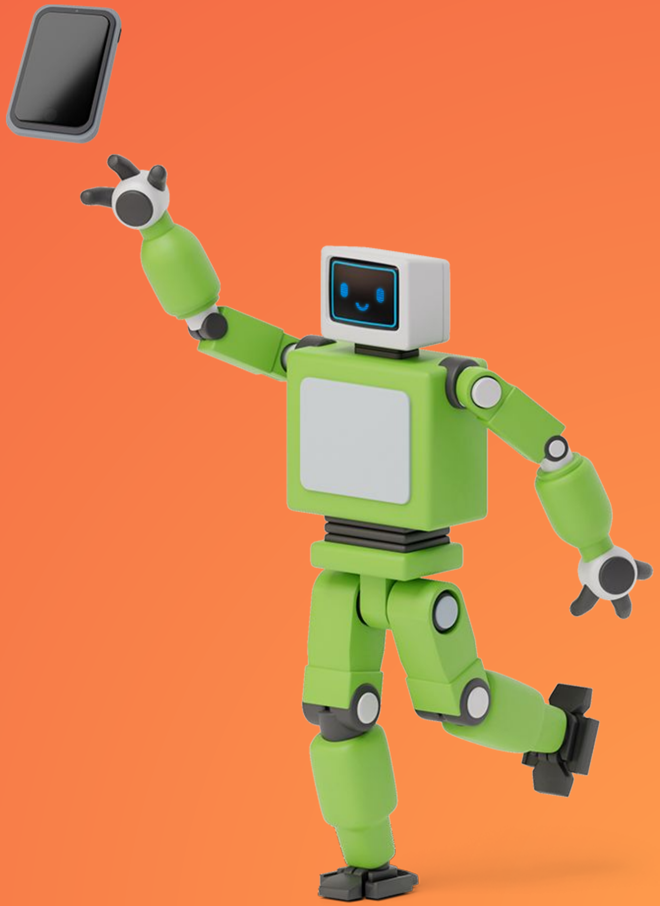
- Reposition foundation (10)
- Stone delivered to building zone (2)
- Skystone delivered (first or second) (10)
- Parked over midfield tape (5)
- Stone in foundation (10)



POINT BREAKUP

Teleop:

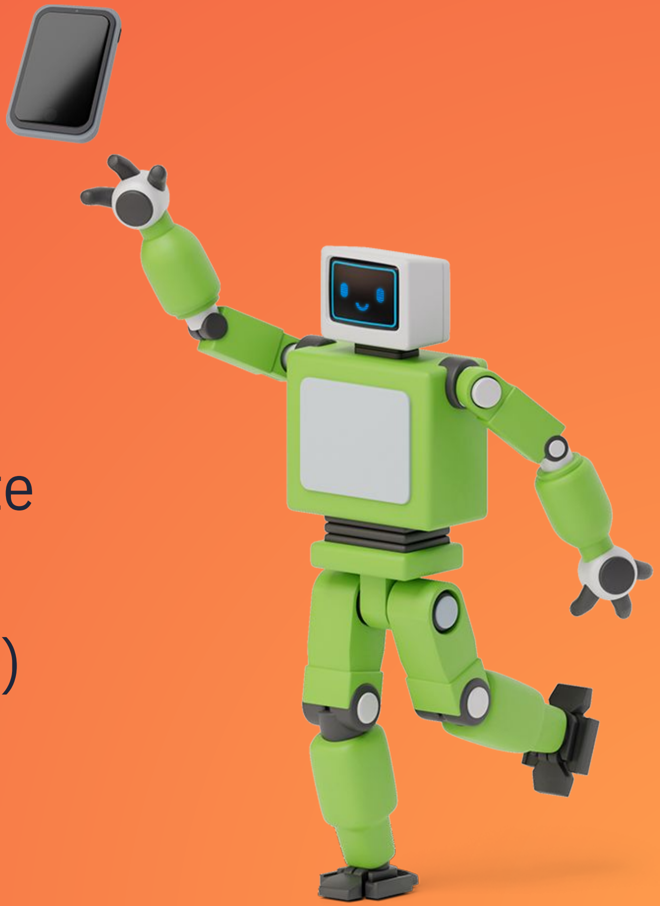
- Stone delivered through alliance bridge (1)
- Stone placed on foundation (1)



POINT BREAKUP

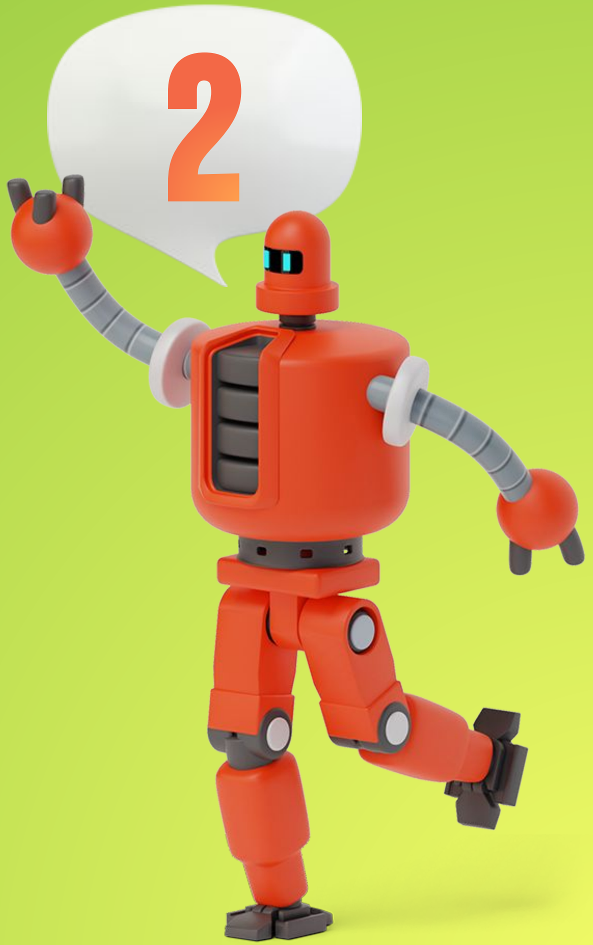
Endgame:

- Capstone on skyscraper (5 + 1 per stone level)
- Move foundation out of building site (15)
- Parked in building site (5 per robot)



BRAINSTORMING

Begin separating tasks into mechanisms and brainstorming specific designs for each one.



MECHANISMS AND PRIORITIZING

Most important tasks

- Score blocks by placing on the foundation
- Place capstone on top
- Move foundation
- Recognize skystone

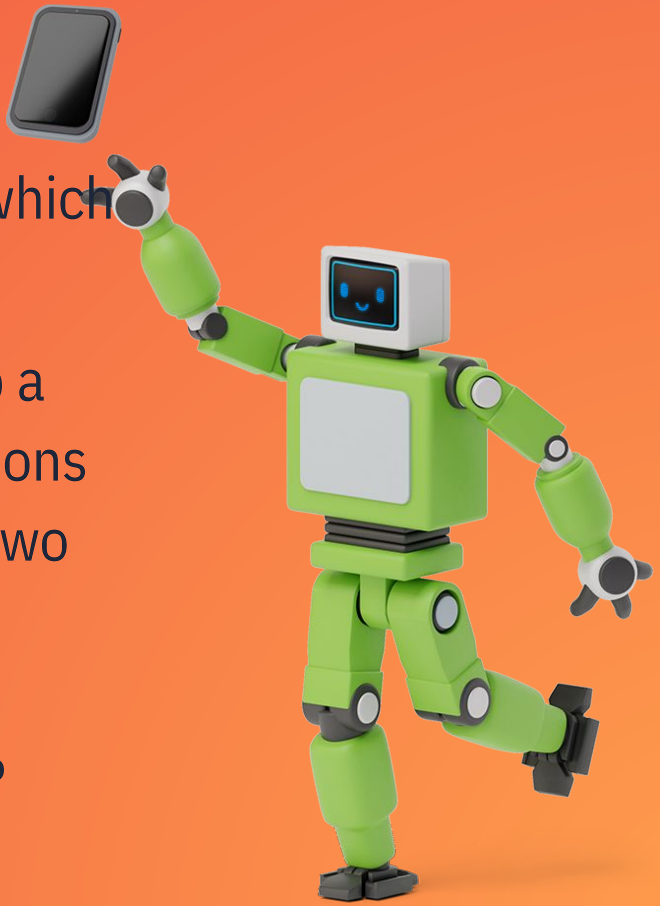
Mechanisms

- Intake stones
- Outtake and stack stones
- Outtake the capstone
- Hook mechanism
- Sensors needed + autonomous stacking

INTAKE

Pick up the block and place in a position which it can be stacked with

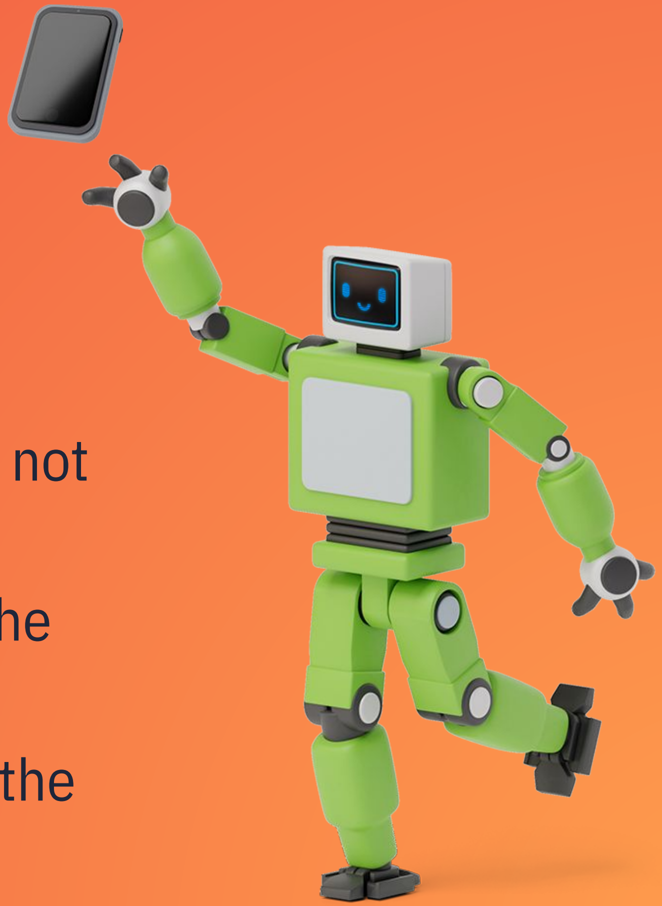
- Consider the different ways to pick up a block, including the different orientations
  - Vertically, horizontally, using the two prongs, scooping, etc.
- Consider using wheels or clamps
- How will the intake release the block?
- Will the intake be fast enough?



OUTTAKE

Receive the block and stack it upward.

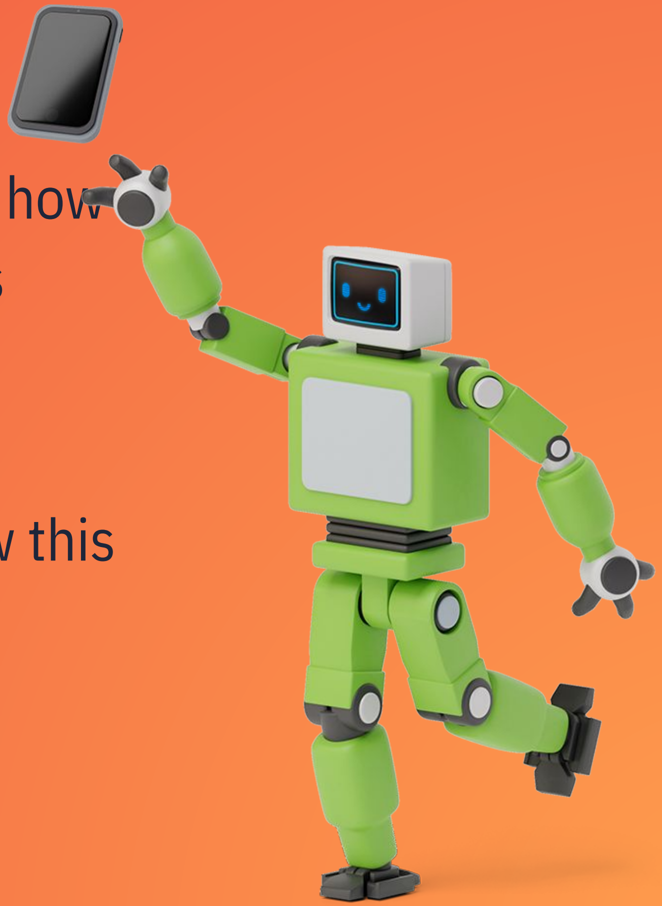
- Similar to the intake, consider the different ways to pick up a block.
- How can you make sure the stack will not tip over?
- How will the outtake be raised up to the height needed?
- What type of power is required to life the outtake to that height?



OUTTAKE THE CAPSTONE

Determine the shape of the capstone and how the outtake should be built to outtake this capstone.

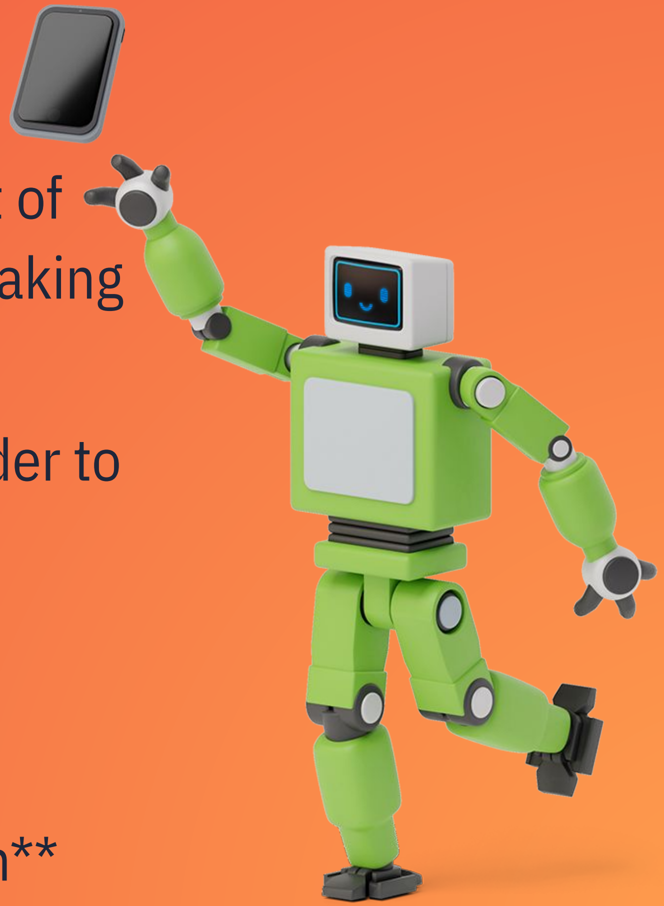
- Will the two outtakes be combined?
  - What capstone shape would allow this to occur?
- How tall can the capstone be placed?



HOOK MECHANISM

Must move the foundation completely out of the build zone. Must be stable/without shaking the foundation

- Where must the hook be placed in order to stably move the foundation?
- How can the hook move stably?
- How will the hook be deployed and released?
- **Consider the 18 inch size restriction**



SENSORS

Must recognize a skystone during autonomous and move it without moving the other blocks.

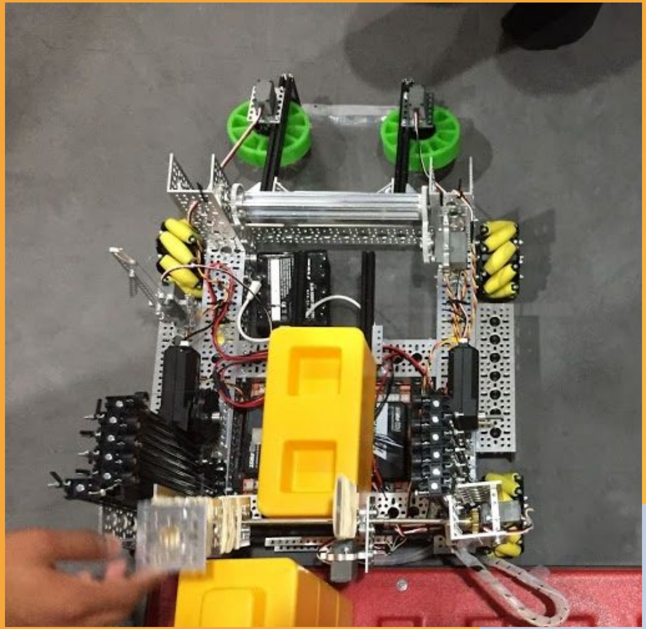
- What is the difference between a skystone and regular stone?
- What sensor can determine this difference?
- Can any other mechanism be reused to move the block?

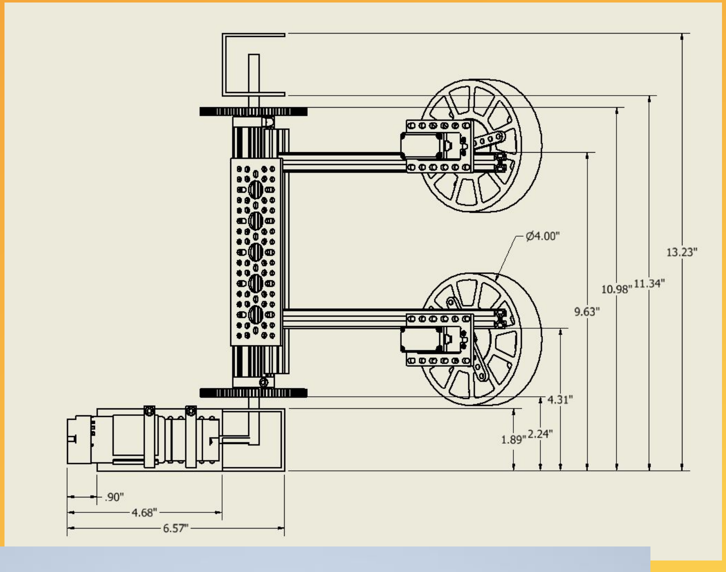
PREVIOUS SOLUTIONS

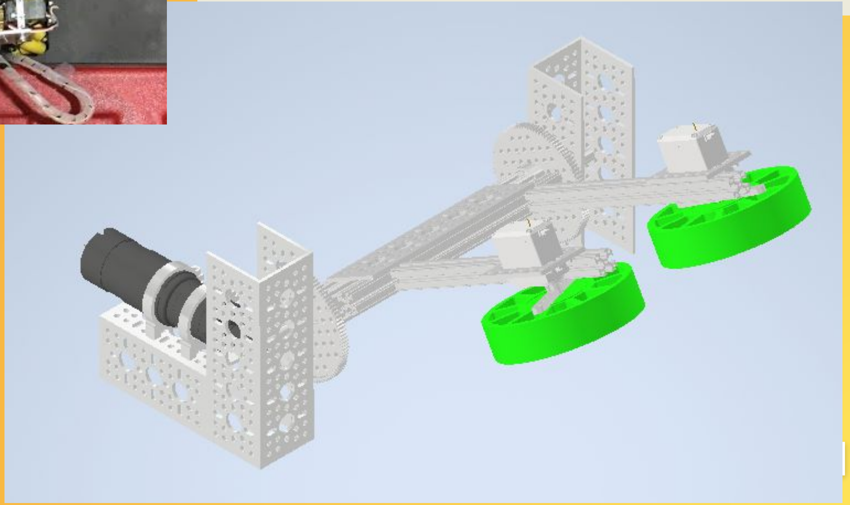
Analyze the advantages and disadvantages of Ink and Metal's designs for this challenge.

VIDEO DEMONSTRATION

INTAKE







INTAKE

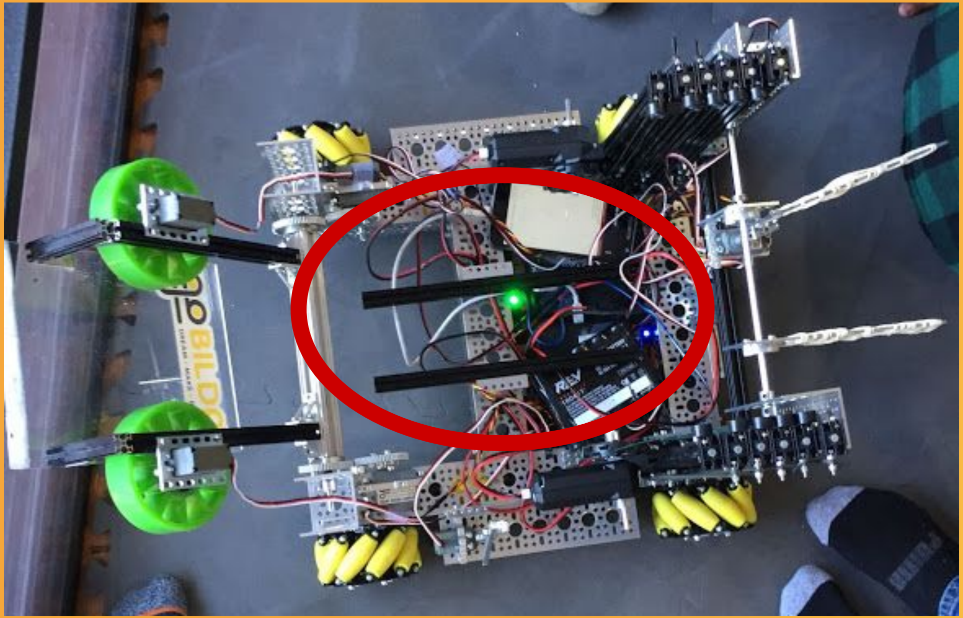
Advantages

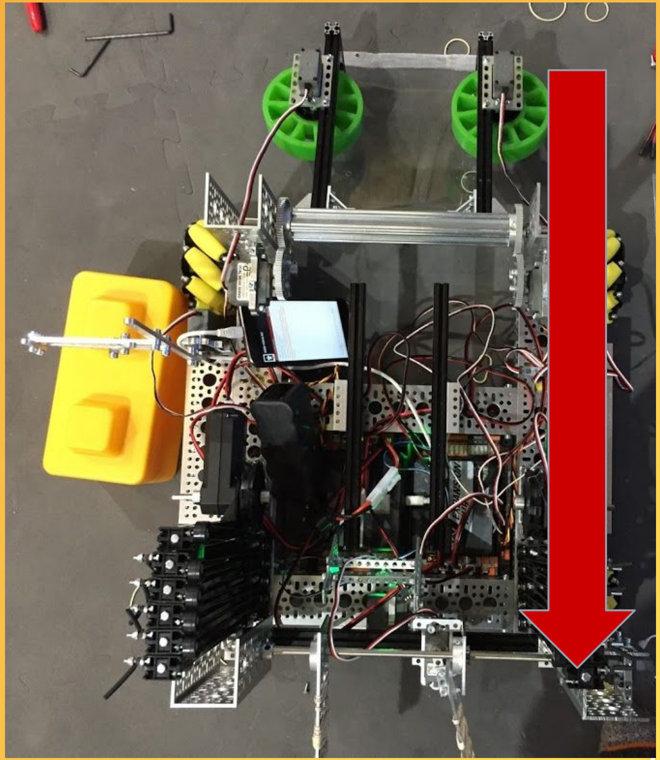
- Quick intake if everything worked

Disadvantages

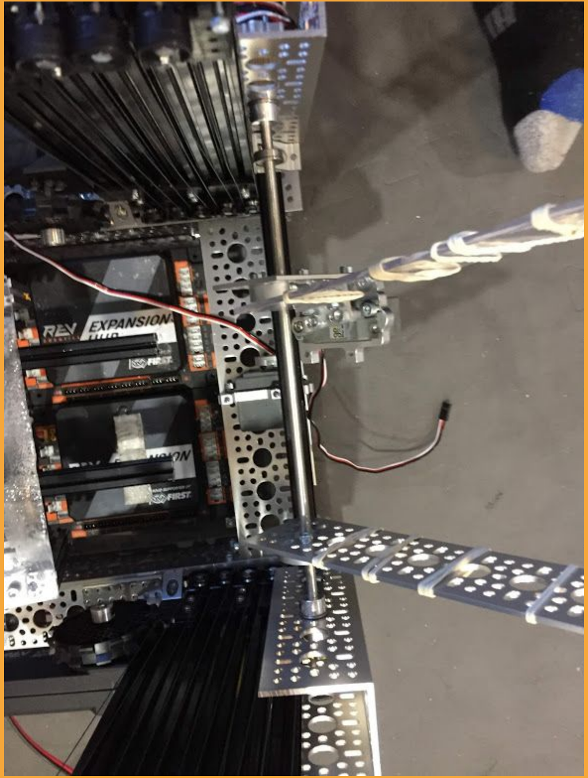
- Unreliable due to tension issues
- Didn’t always intake immediately due to the angle
- Didn’t always place it well into the transfer

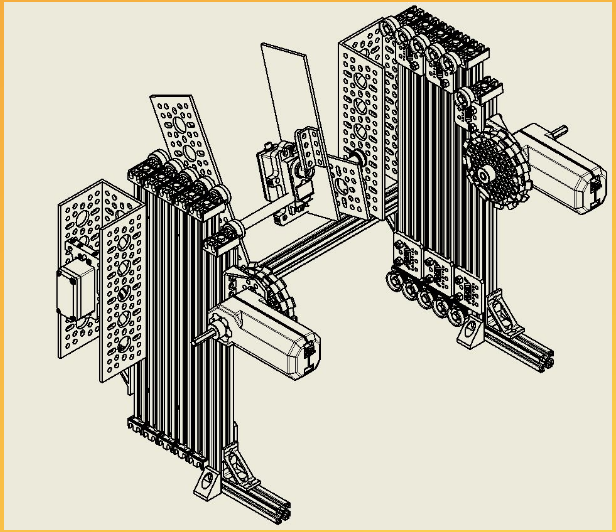
TRANSFER





OUTTAKE





OUTTAKE

Advantages

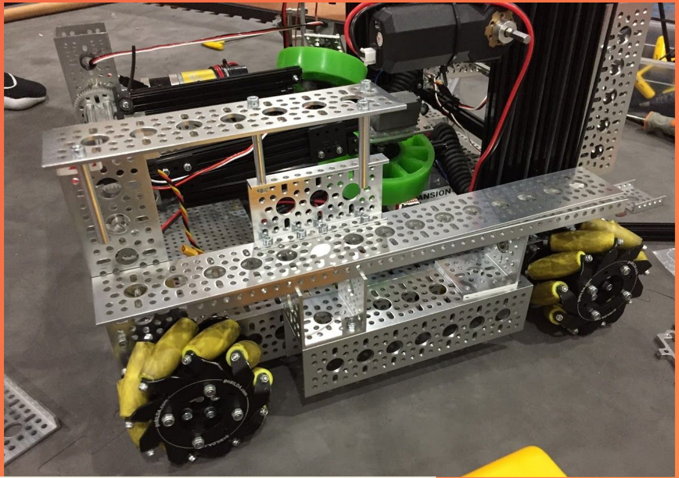
- More control in order to stack
- Mounted on linear slides to raise up to necessary heights

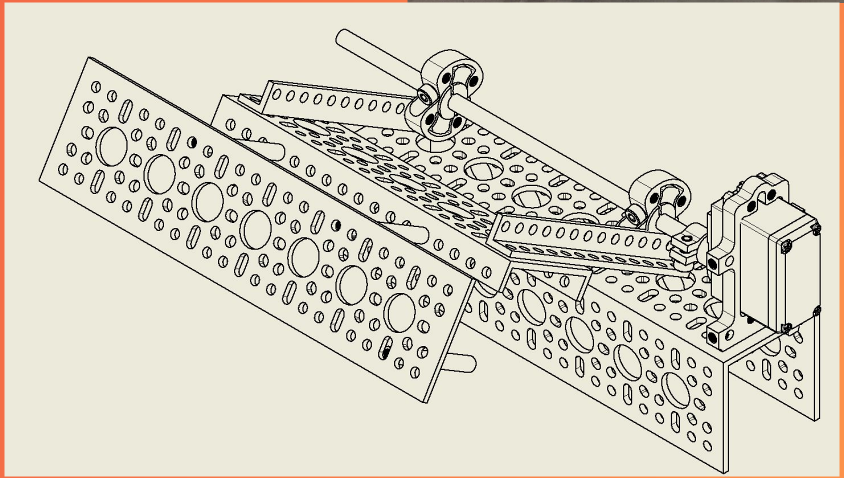
Disadvantages

- Block may slip due to lack of traction
- Required driver to align perfectly in order to stack

HOOK MECHANISM

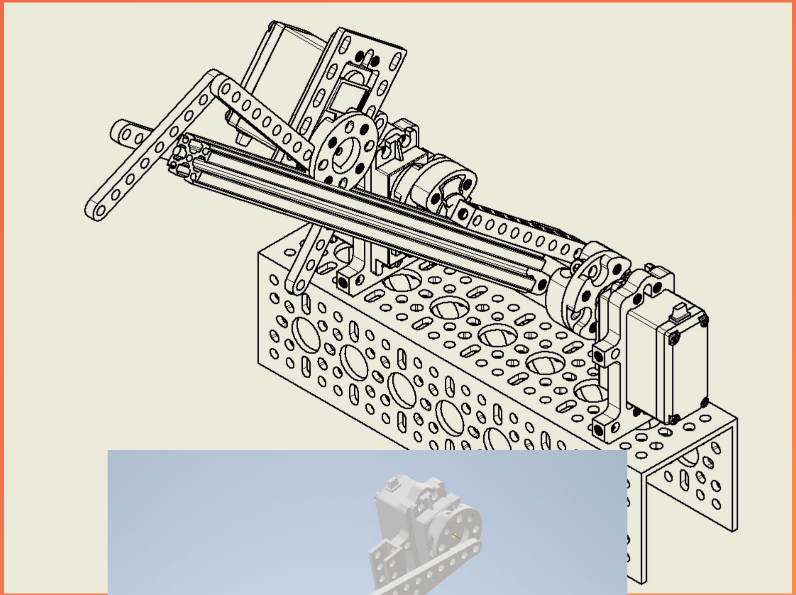
- Numerous iterations
- Needed more surface area to grip the foundation
- Used a flat plate to grip

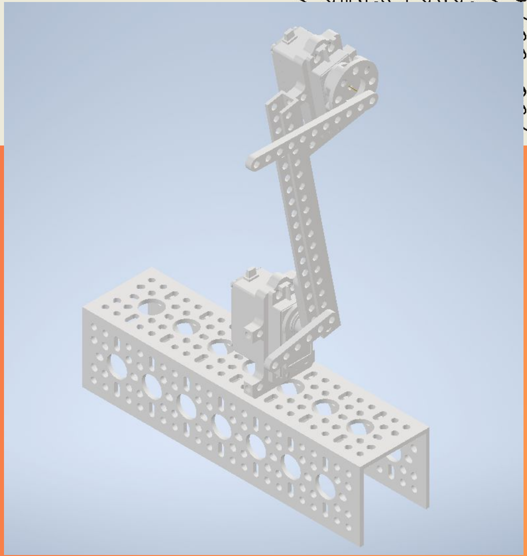




SENSORS AND SKYSTONES

- Used a color sensor
- Intake required skystone to be vertical, but in autonomous, must intake horizontally
- Did not need to stack the block





THANK YOU

Any questions?

CONTROLLING THE ROBOT

REVIEW

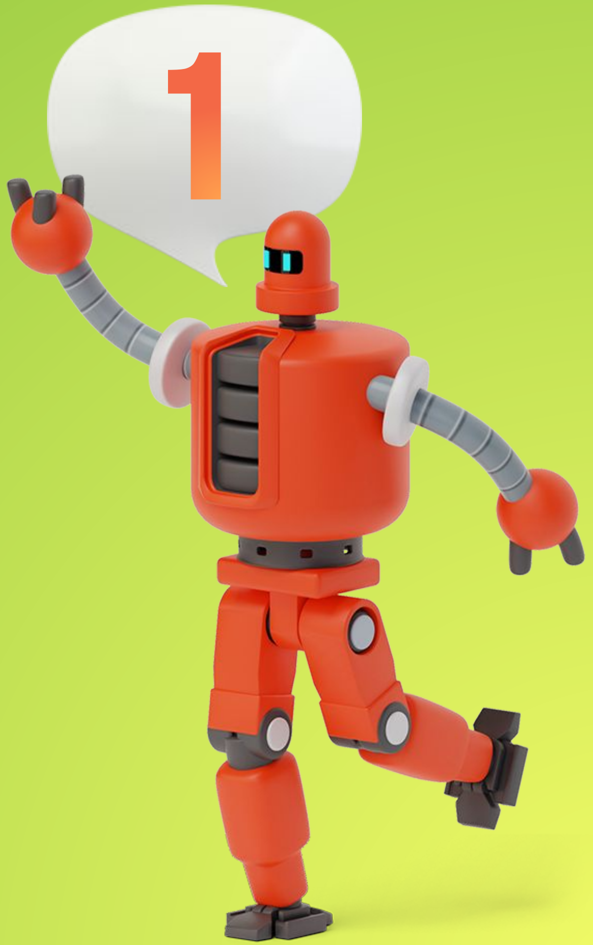
- Rotational motion.
    - We discussed different types of motions
- Sensors
    - Talked about the numerous sensors involved in robotics
        - Color Sensor
        - Intel RealSense Camera
        - Distance Sensor
        - Switch Sensor
- Activity
    - Designed how to locate a robot in the field and get exact coordinates.

AGENDA

- Control Award: What is it?
- Control award Submission Example
- Controlling the robot
- REV, Expansion, and Control Hubs: What they are used for
- Remote Control
- Quick Activity: Skystone/Ultimate Goal design practice

CONTROL AWARD

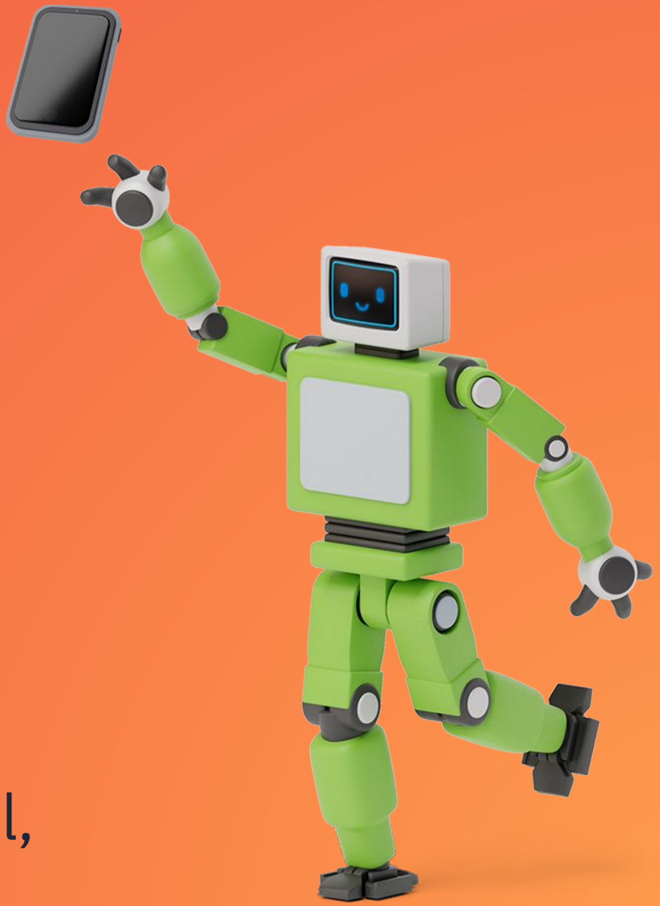
Learn how the robot is controlled through control award submissions.



CONTROL AWARD VIDEO

ELEMENTS OF THE CONTROL AWARD

- The control award requires that a team demonstrates autonomous operation, intelligent control with mechanical systems, and implementation of software, sensors, and mechanical control
- In our video, we highlight our autonomous programs, PID control, odometer usage, and more

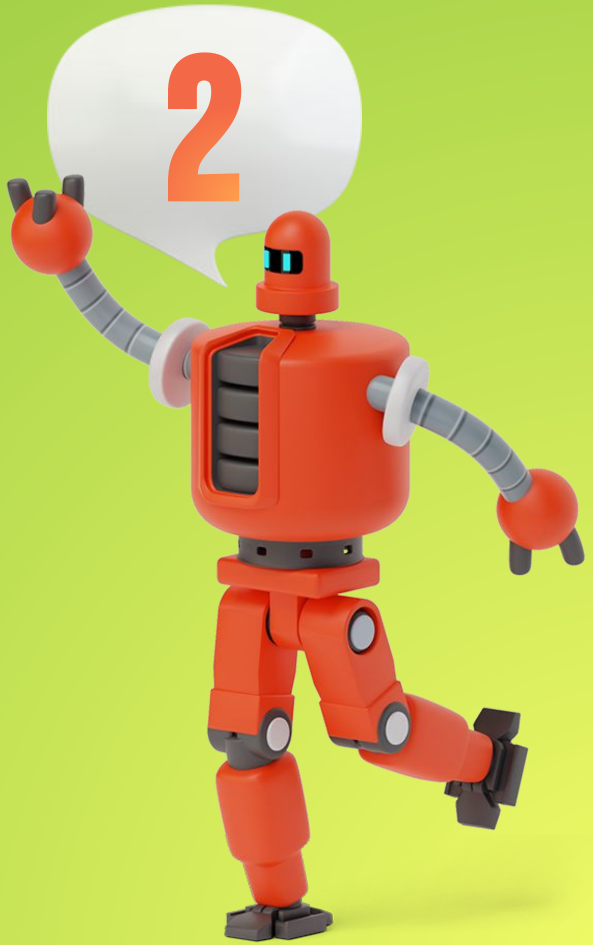


ANY QUESTIONS?

If you have any questions about the control award and its elements or about certain parts of the video, ask now!

CONTROLLING THE ROBOT

Understand how the robot is controlled and programmed through REV Hubs and Driver Stations.



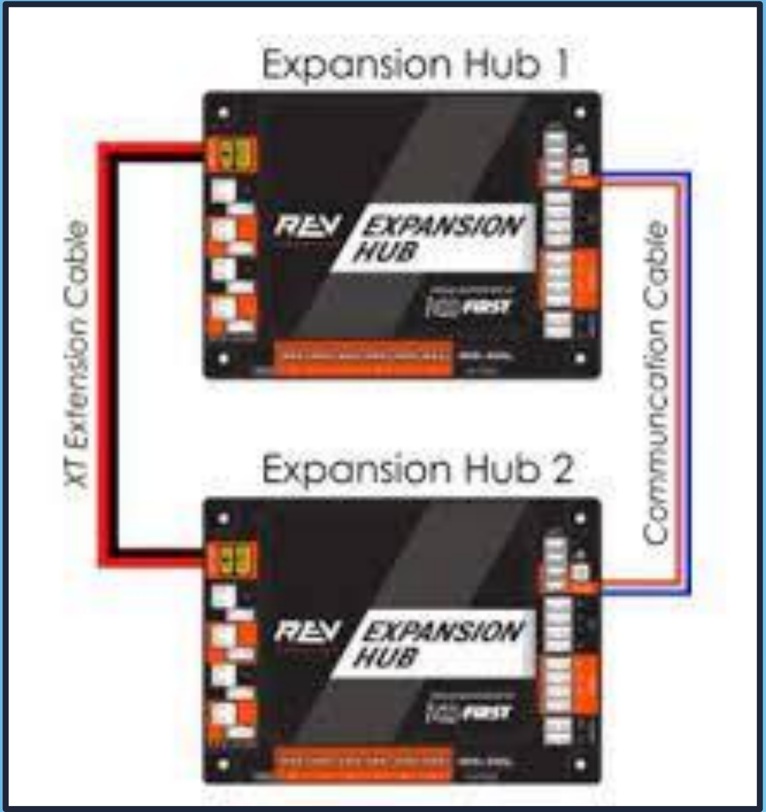
REV CONTROL HUB

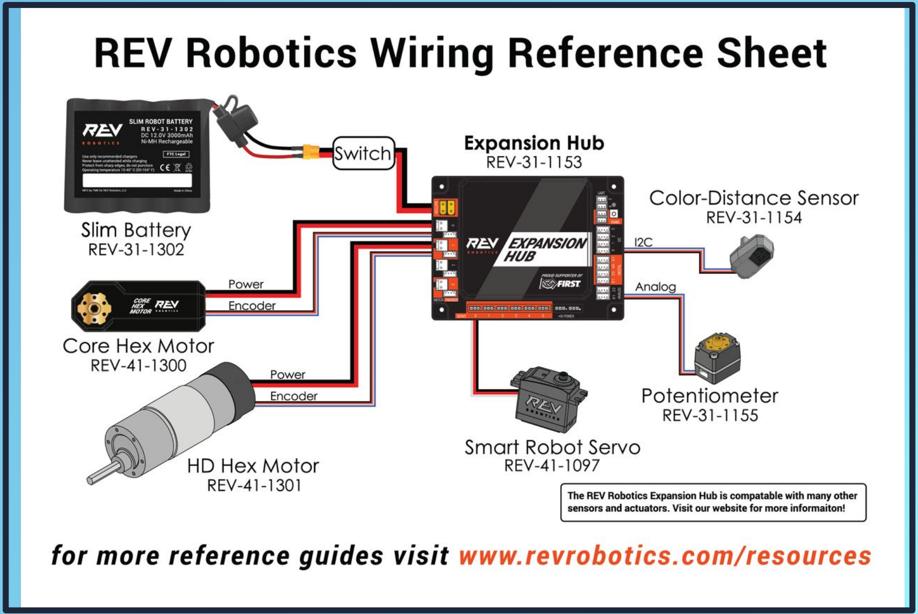
- Many for ports cables (e.g. USB)
- In-built robot controller (no need for driver station phone)
- Includes 4 DC motor + encoder ports, 6 servo motor ports, power, 4 analog, 8 digital, and 4 I2C ports for sensors, an in-built IMU for heading, 2 RS485 ports to connect to another expansion hub

REV EXPANSION HUB

- Comes with 4 DC motor + encoder ports, 6 servo motor ports, power, 4 analog, 8 digital, and 4 I2C ports for sensors, an in-built IMU for heading, 2 RS485 ports to connect with other expansion/control hubs
- Must connect to a phone (as driver station) if not used with control hub
    - If used with control hub, used to expand motor and sensor ports

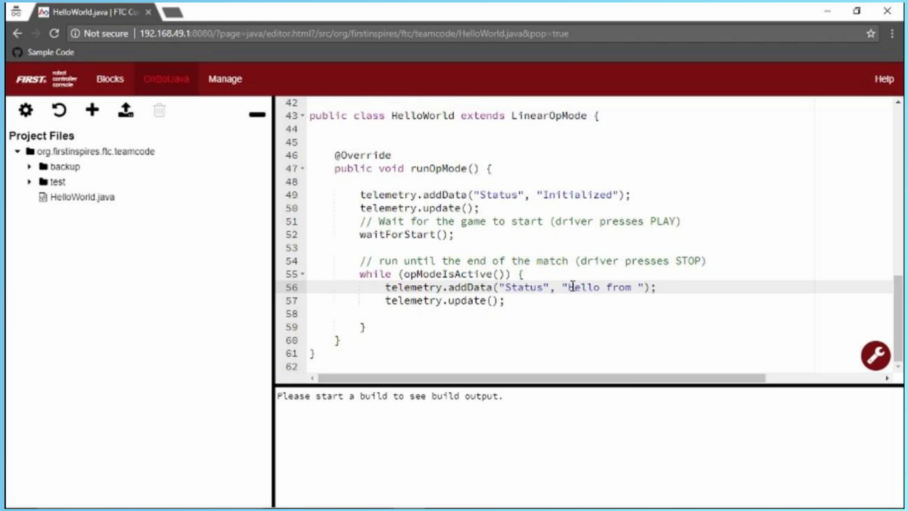
EXPANSION HUBS





REV HUBS

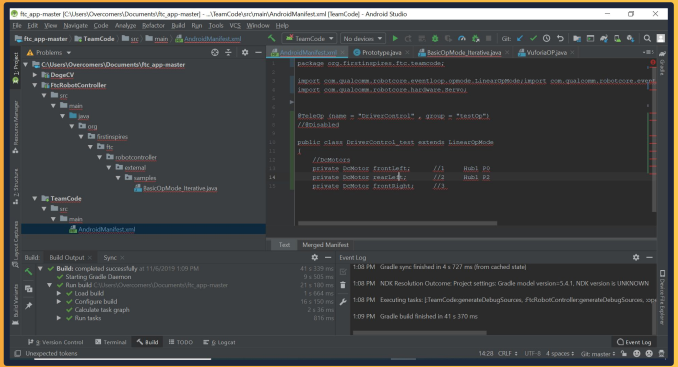
- Both are used to control the robot
  - Use Java programming language with the FTC programing library



REV CONTROL AND EXPANSION HUB EXPLANATION

ANDROID STUDIO

- Downloadable IDE (code editor) to write Java programs to control robot
  - Download project template with FTC library in it
  - Can download version with Roadrunner software as well
- Upload code to REV Control Hub or Driver Station Phone



ANDROID PHONE

- If you are using REV Control Hub
  - Use only 1 android phone to run code remotely
- If you are using REV Expansion Hub and Driver Station
  - Use 1 android phone for Driver Station
  - Use 1 android phone to run code remotely

REMOTE CONTROLLERS

- Use remote controllers plugged into android phone which runs code remotely
- Used to control robot during teleop with code
- Images show our functions for our controllers

SKYSTONE ROBOT DESIGN PRACTICE

- https://www.youtube.com/watch?v=D2-CRBoGpJQ
    - Above is the video for the SkyStone Season
- Design a robot that picks up and stacks large bricks. Additionally, design a mechanism to move the foundation to the correct position.
- Design a robot that you feel will score the most points in a match. Consider efficiency and speed.

ULTIMATE GOAL ROBOT DESIGN PRACTICE

- https://www.youtube.com/watch?v=zYS0--eeUCM
  - Above is the video for the Ultimate Goal Season
- Design a robot that takes in rings that are 5 inches in diameter and shoots them to a certain goal. Additionally, it should pick up the wobble goal and deposit in the correct zones.
- Design a robot that you feel will score the most points in a match. Consider efficiency and speed.

ANY QUESTIONS?

Please don’t hesitate to ask, we’d be more willing to covering some parts of the presentation again!

SENSORS & ROADRUNNER

REVIEW

- **Control Award**
  - We talked about the FIRST Control Award and what it entails, and showed an example submission for it
- **REV Hubs**
  - We showed the strengths and weaknesses of the different REV Hubs and how they can be used
  - Also talked about Android Studio and controller inputs
- **Activity**
  - Designed a robot based on the guidelines of the FTC Skystone challenge; that could stack blocks, move a foundation, and fit in an 18” cube.

AGENDA

- Sensors (Since we didn't finish this last week)
    - Distance
    - Color
    - Potentiometer
    - Touch
    - Limit Switches
- Introduction to Roadrunner (Odometry software)
- If time permits, setup OnShape accounts for CAD (Computer Aided Design) that we will use next week

1

SENSORS IN FTC

Learn how sensors are used, and what kinds of sensors are used.

DISTANCE SENSOR

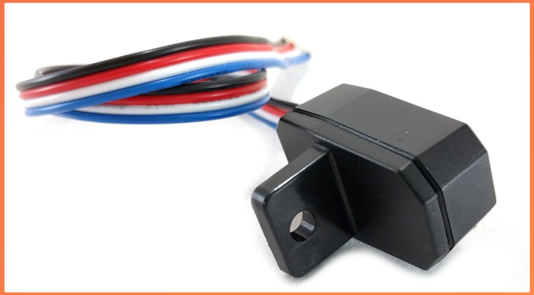
- Distance sensors output a signal (laser, infrared LED, ultrasonic) and read how it changed on its return
- The REV 2m Distance Sensor uses laser-ranging to measure distances up to 2 meters within millimeter resolution

Applications:

- Distance sensors are used to identify objects directly in front of it
- They are perfect to stop at a certain distance from a wall or object at a close range
  - Can be slightly inaccurate

COLOR SENSOR

- Uses a built-in IR Proximity Sensor and white LED for active target lighting
  - The sensor detects the light reflected back from the detection object with a receiver
  - Based on the light intensity, the color can be determined

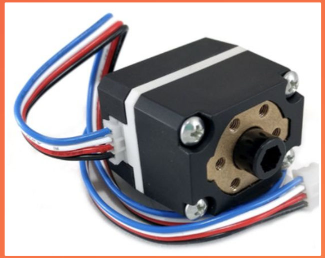


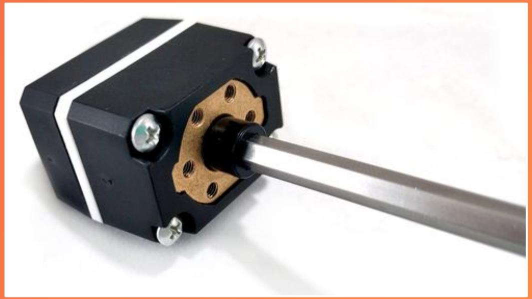
Applications:

- Robots can move across a field upon seeing a certain color
  - E.g. following a tape on a field
- Robots can also use it to detect an object of a certain color and verify it is that color

POTENTIOMETER

- The REV Potentiometer is an analog sensor with a 270 degree range of motion
  - Works by converting the angular position of a shaft into an analog voltage signal
  - Detects how much rotational motion occurred in a mechanism



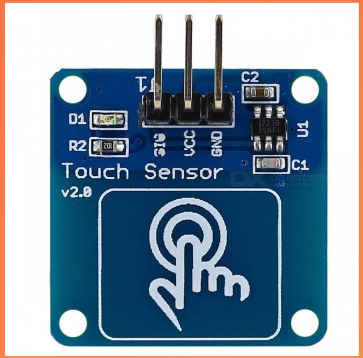


Applications:

- Potentiometers can be used to limit how much an axle rotates
  - If you have a robot arm, you can rotate it until it rotates 90 degrees, and make sure it stops at that point.
- This is more accurate than if you did it, for example, by time.
- Can be used as voltage dividers and audio control as well.

TOUCH SENSOR

- Digital sensor (binary output)
- When button is not pressed, LED is unlit and has high voltage
- When button is pressed, LED will light and has low voltage



Applications:

- Best used for user input and can be used as a limit switch
  - Humans can use it to start the robot.
- Can be used to limit how much a mechanical arm rotates down
  - If arm touches switch, it can send a signal to cease rotation.
- Can sense whether robot hits something

LIMIT SWITCH

- Digital sensor that has a three-sided digital hall effect switch
  - There are triggers on the top and two on the side
  - Any can be reported to be triggered
- REV Magnetic Limit Switch detects magnetic fields.
- Essentially, a more triggerable touch switch.

Applications:

- Similar to the touch sensor applications
- Used for controlling machinery as a part of a control system
  - E.g. limits robot arm from going past it
- Can be used to count objects that touch it

REV "BLINKIN" LED DRIVER

- Compact LED driver module that controls 12V RGB LED and 5V LED strips
- Combines internal LED drivers, a 5V power source, and a pre-programmed controller
- You can use PWM pulse to control color patterns
- Not really a sensor, but should be noted

Applications:

- Useful to show different stages/steps of the robot
  - In FTC challenge, use lights around robot to display which stage robot is in (autonomous, teleop, endgame)
- Can be used to test robot
  - Show different colors for different actions

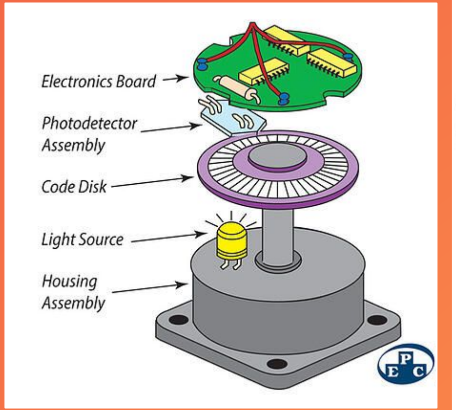
2

MOVEMENT SENSORS IN FTC

Learn about sensors which are used to guide the robot through navigation.

ENCODERS

- Has a light source, disc with dark lines (ticks), photodetector, circuit board, and wire
- As a motor rotates, lines pass in front of a light source and the photodetector counts “ticks”
- Can use encoders to power motor until amount of ticks or inches is achieved

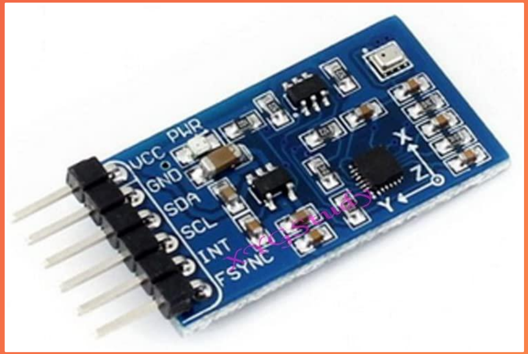


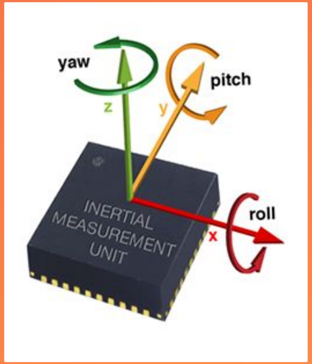
Applications:

- Used to limit how far your robot moves
  - E.g. stop after moving 10 inches
- Used to measure how long you travel
  - E.g. drive forward for 10 seconds, see how many inches/ticks the encoder counts
- Not too accurate however, as only measures after full rotations.

IMUS (INERTIAL MEASUREMENT UNIT)

- Detects linear acceleration using accelerometers and gyroscopes (for rotation)
  - Essentially, it keeps track of the angle of the robot
  - Sometimes includes magnetometers for angle reference



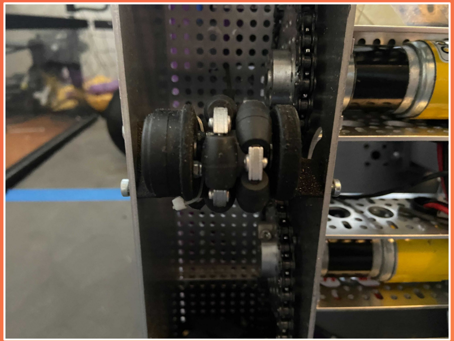


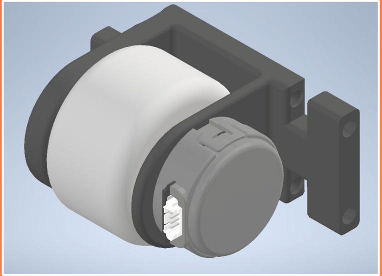
Applications:

- IMUs can keep track of the angle of your robot on a field
- This is very helpful as you can turn your robot until it is near a certain heading (e.g. turn until robot turned 90 degrees)
- IMUs are also commonly used with odometers and encoders for field navigation and knowing where your robot is on the field.

ODOMETERS

- Has an encoder, casing, and omni wheel
- Encoders capture movement and readings determine displacement from starting position and current location
- Creates a coordinate plane
- Using 3 allows for finding horizontal location, vertical location, and heading.



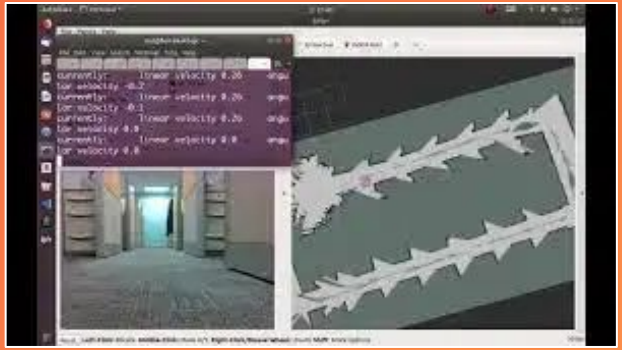


Applications:

- Useful for robot navigation
  - More accurate than encoders, use to make robot move and rotate to certain coordinate position on the field
  - Can measure distance like encoders
  - Can also measure heading

SLAM (INTEL REALSENSE T265)

- SLAM - simultaneous localization and mapping
- Process of creating a virtual map that robot uses to navigate an environment
- Has V-SLAM technology (Visual Inertial Odometry SLAM algorithms), fisheye camera lenses, an IMU, and USB ports

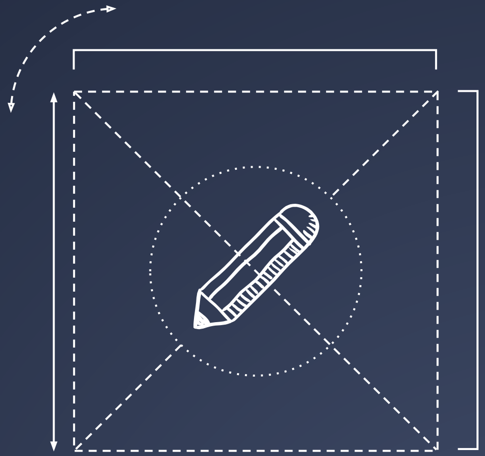


Applications:

- Mainly used in autonomous navigation
    - E.g. automated car piloting, automatic robot navigation on a field
- FTC teams used SLAM to autonomously pick up objects, e.g. rings that fell on the floor by generating pathing to pick them up.

ANY QUESTIONS?

control award and its
the video, ask now!



3

ROADRUNNER ODOMETRY SYSTEM

Learn how Roadrunner Odometry works, and what it is.

ODOMETERS AND ROADRUNNER

Most robots use 3 odometers to find the horizontal and vertical location on the field and the robot's heading

- The Control Hub determines the coordinate of the current location

Odometers convert the field into a coordinate grid, which they then use to return the current location of the robot on the field.

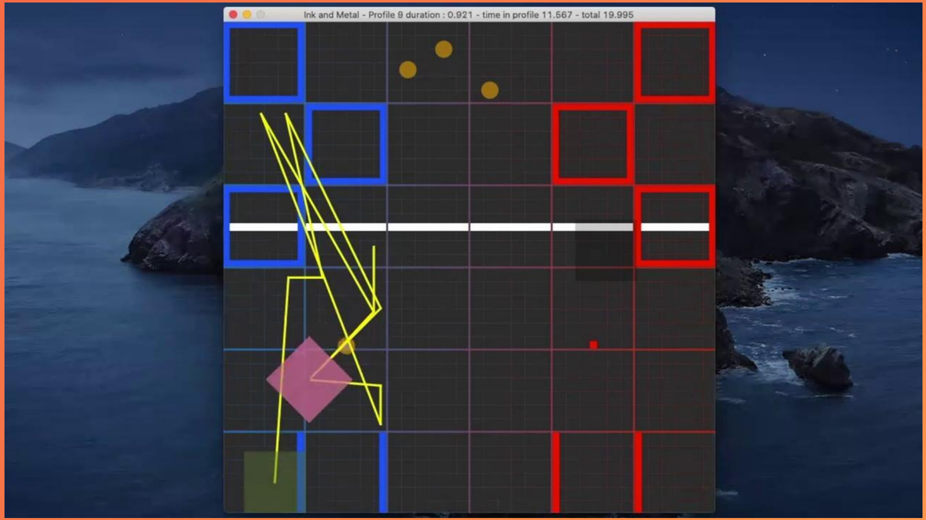
Road Runner is a motion planning library primarily used for the FTC robotics competition, which allows for automatic movement path generation for robots.

Road Runner works by using odometers

- After setting up the Road Runner library with the FTC SDK, you can use your odometers to create these autogen paths to specified locations

ROAD RUNNER IN ACTION

Physical Robot



Virtual Robot

UNDERSTANDING LOCALIZATION & POSITIONING

Localization is the ability for your robot to know where it is at any point in time

- This is generally done using odometry
- However, other methods like VSLAM (T265 camera) can be used

Odometry is used to feed information into respective kinematic equations which creates an approximate (x, y, heading) location of the robot on the field.

There are two types of locations

- A Vector2d is a simple (x, y) coordinate
  - Vector2d myVector = new Vector2d(10, -5);
- A Pose2d includes (x, y) and a heading
  - Pose2d myPose = new Pose2d(10, -5, Math.toRadians(90));

OPEN LOOP VS CLOSED LOOP CONTROL

Open Loop - estimates voltage needed to power a motor

- This is not too accurate and does not adjust for real world problems that reduce motor speed (physical tolerances)

Closed Loop - uses feedback from the motor to adjust the voltage

- If the motor is given some voltage but it is too slow, more voltage will be given
- This is done through a PID (proportional integral derivative) controller and the use of a motor encoder

So, ideally you should use Closed Loop Control, but Open Loop is easier to set up.

4

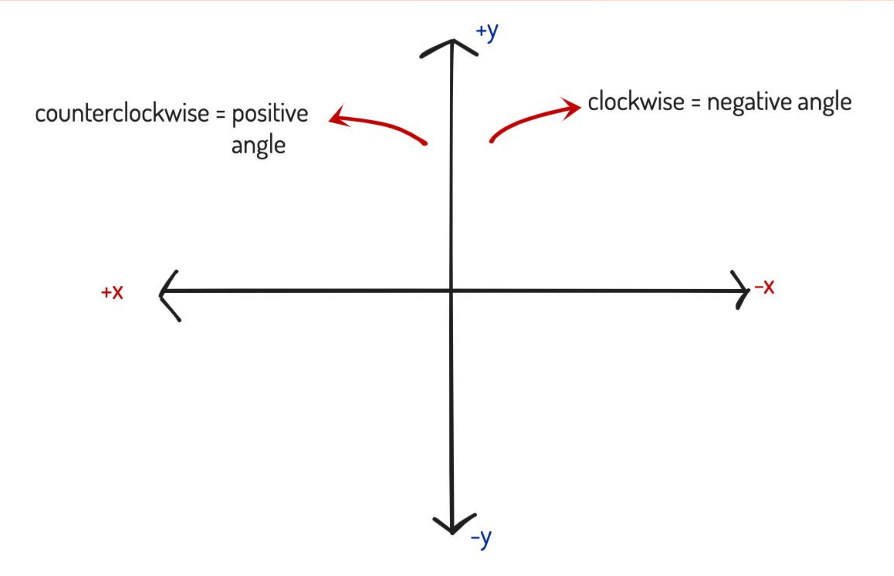
ROADRUNNER VIRTUAL ROBOT

Understanding and using the virtual robot with Road Runner.

ABOUT THE VIRTUAL ROBOT

Road Runner comes with the ability to write paths for a virtual robot- it is written in the programming language Kotlin, which can interoperate with Java.

Coordinate system in real and virtual robot



USING ROADRUNNER

- First, install Intellij (A free IDE to use)
- Next, download the RRPath Visualizer project from GitHub
- Then, open the project with Intellij
- You may have to set the project SDK

CREATING TRAJECTORIES IN RRPATH VISUALIZER

- There are several types of trajectories you can use, for example: lineTo(), lineToLinearHeading(), splineToConstantHeading(), etc.
- Each trajectory is unique and has different parameters that you must provide it (e.g. Pose2d or Vector2d)

CREATING TRAJECTORIES (CONT.)

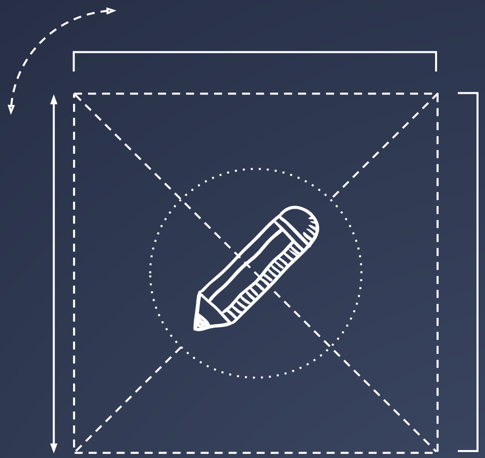
To make trajectory, you must use the following steps

1. Create Trajectory List
   - val list = ArrayList<Trajectory>()
2. Create the Builder
   - val builder1 = TrajectoryBuilder(startPose, startPose.heading, combinedConstraints)
3. Reset the Builder with the Last Position
   - builder1 = TrajectoryBuilder(Pose2d(10, 15, (90.0).toRadians), (90.0).toRadians, combinedConstraints)
4. Make the Trajectory
   - builder1.lineToConstantHeading(Vector2d(30, 40))
5. Add the Trajectory to the List
   - list.add(builder1.build())
6. Return the List
   - return list

ANY QUESTIONS?

control award and its

f the video, ask now!



Access This link: https://www.onshape.com/en/education/#form-container

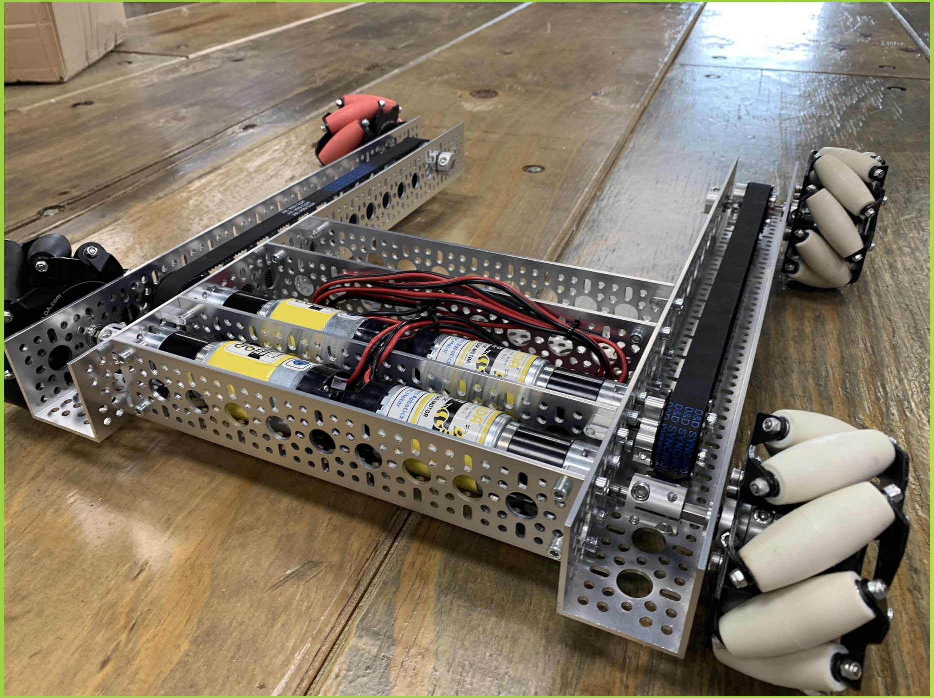
THANKS FOR COMING!
ANY QUESTIONS?

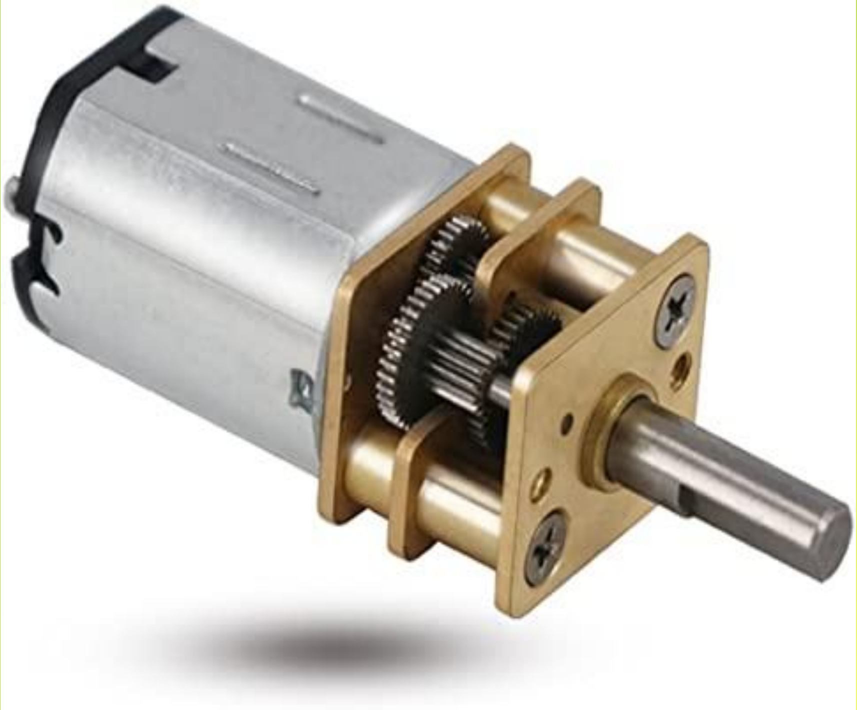
MOTORS!

DC MOTORS

Brands in FTC: goBILDA, REV, & AndyMark

APPLICATIONS



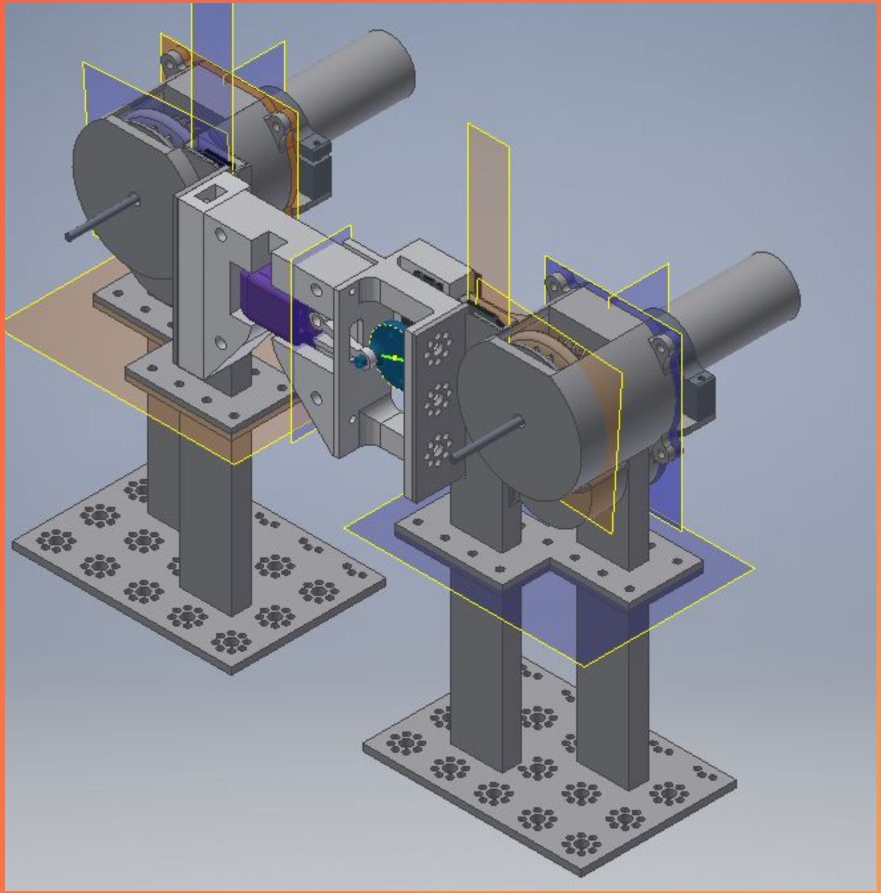


SERVOS

SERVOS VS DC'S

Differences

- Torque
- RPM
- Size
- Cost
- Power Expenditure



HOW DO THE DIFFERENCES DEFINE THE USAGE?

Situation #1

Small space, just moving arm that is lightweight

Situation #2

Very heavy load, and large space

Situation #3 (Tricky one)

Motor used in chassis

REAL SITUATION: OUR ROBOT

Wobble goal rotator— why were servos used?

Key things to note:

- Medium Load (High torque needed)
- Small amount of space

THANKS FOR COMING!

ANY QUESTIONS?

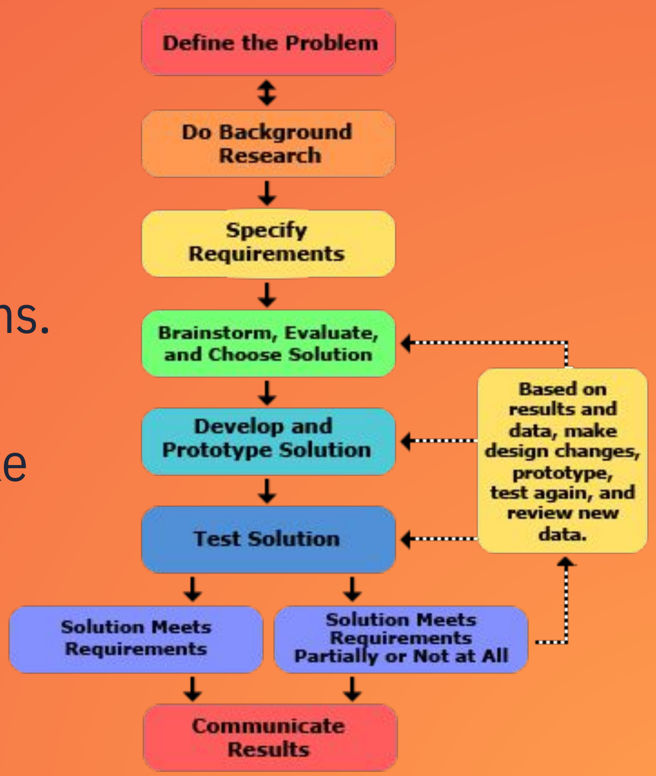
ROBOTICS REVIEW

1

ROBOTICS FUNDAMENTALS

HOW ARE ROBOTS MADE?

- While there are many kinds of robots,most are made using the **design process.**
- The **design process** is a series of steps that a person can take to turn their ideas into real items.
- By using the design process, engineers and builders across the world can develop things like robots.



2

THE FIRST ROBOTICS INITIATIVE

WHAT IS FIRST?

First is a robotics organization that hosts competitions and events in order to draw attention to the robotics as a whole.

THE FIRST TECH CHALLENGE

What is it?

FTC is a challenge that FIRST gives out to FTC teams every year. They're unique, and require teams to construct complex robots to complete.

These challenges can range to anything from shooting balls to stacking bricks.

Building Constraints

Robots are not just restricted in terms of rules, they're also restricted in their very designs. The most basic constraint is that they must fit within an 18"x18"x18" cube, along with many other restrictions.

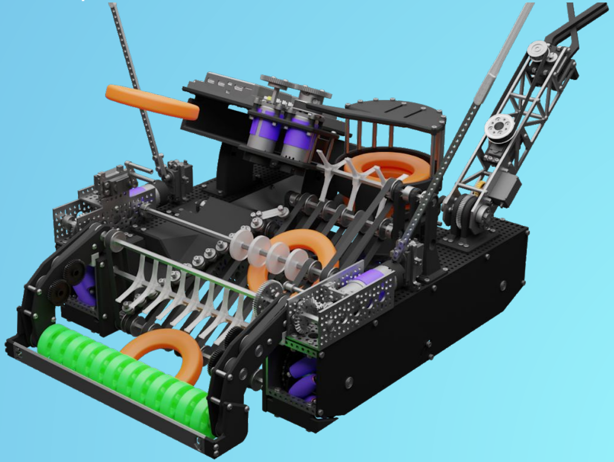
Teams must work within these restrictions to come up with the best robot possible.

Rules

These competitions usually operate in a tournament-based system, where robots compete against each other for points until one (or two) are left.

Points can be scored in numerous ways, but it all depends on the challenge, and how teams build their robots to maximize point gain.

After competitions, awards are given out to teams, and can depend on everything from how the robot looks to how interesting its design was. These awards advance teams to future competitions.

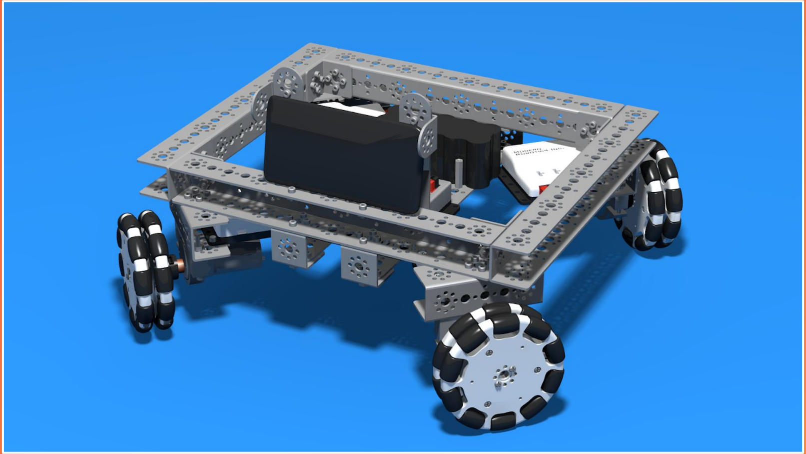


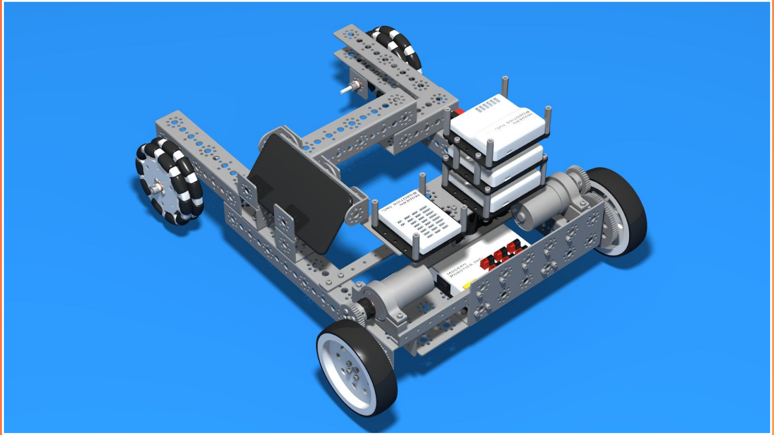
3

CHASSIS

Chassis

A frame of some sort that usually holds the body + motor of a vehicle





Build Systems

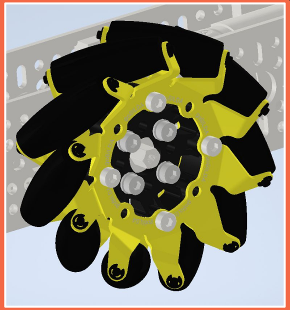
Companies partnered with FIRST

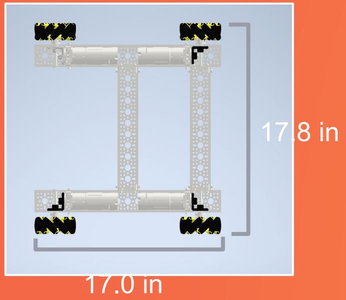
- Gobilda
- Andymark
- REV Robotics
- And many more!

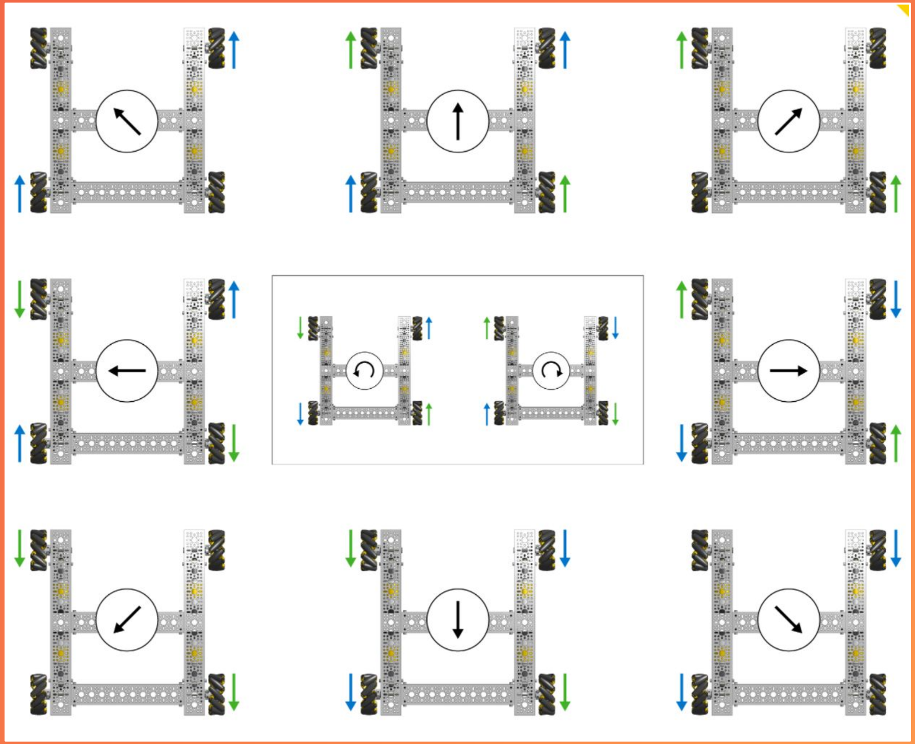
Using these company's build systems, you can construct your robot.

GoBilda Strafer Chassis

- Uses mecanum wheels that allow for diagonal movement
- 17 x 17.8 in
- Requires GoBilda Yellow Jacket motors that are fitted within the channels
- Uses a 1:1 gear ratio







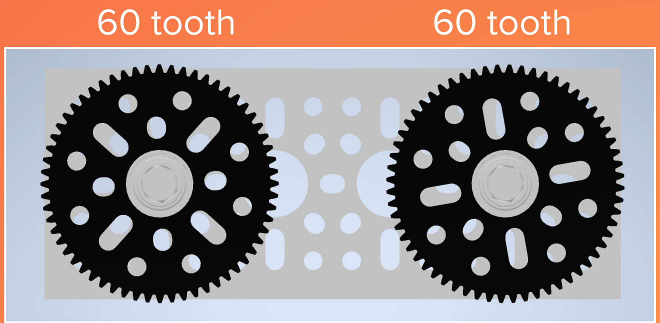
GoBilda Strafer Chassis

Advantages

- Lightweight
- Motors are conveniently hidden and out of the way
- Can easily move in all directions
- Space to build intake, outtake, and other mechanisms

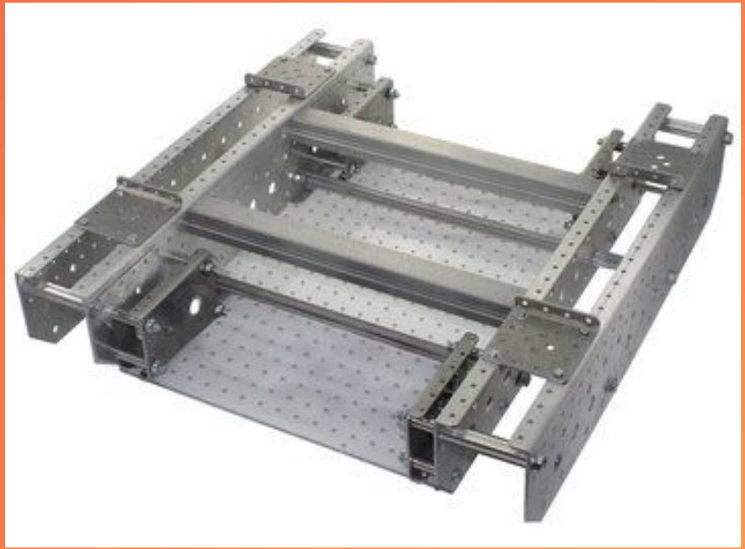
Disadvantages

- Using a 1:1 gear ratio can prevent increased speed
- Wheels are exposed on the sides
- Beam in the back may obstruct building of certain mechanisms such as intake and outtake


60 tooth
60 tooth

AndyMark Tile Runner Chassis

- Uses mecanum drive
- Includes side and bottom plates
- Uses AndyMark parts with different hole pattern on the bottom



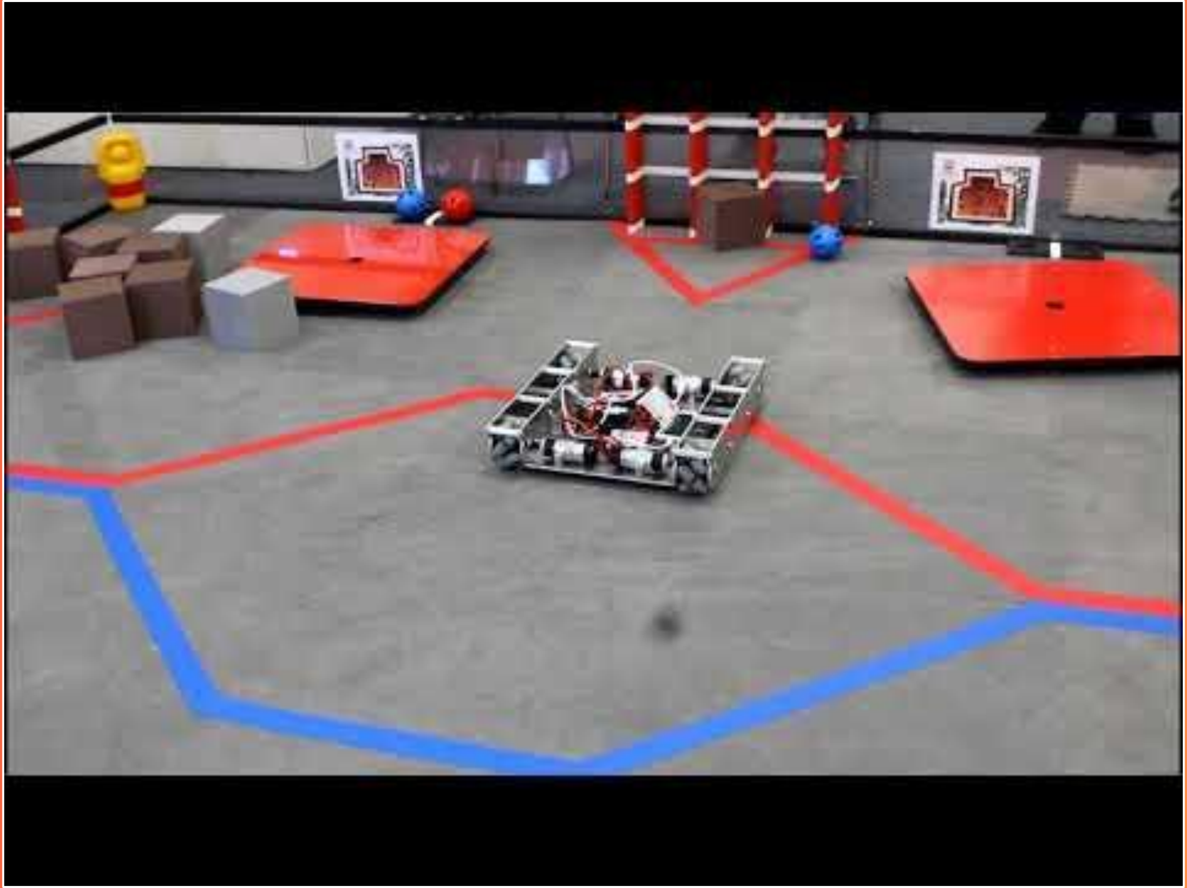
AndyMark Tile Runner

Advantages

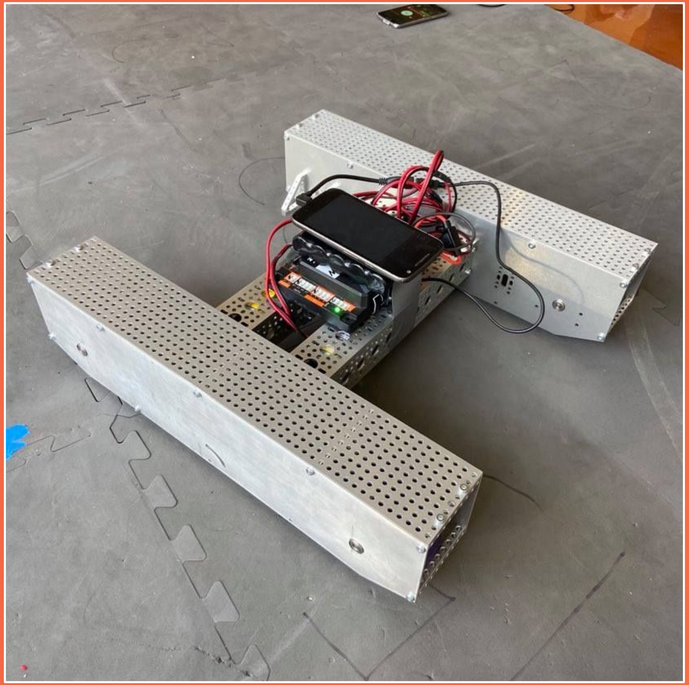
- Durable due to plating along the sides
- Can build on top of the side plates using the hole pattern
- Easy mounting on the bottom due to base plate

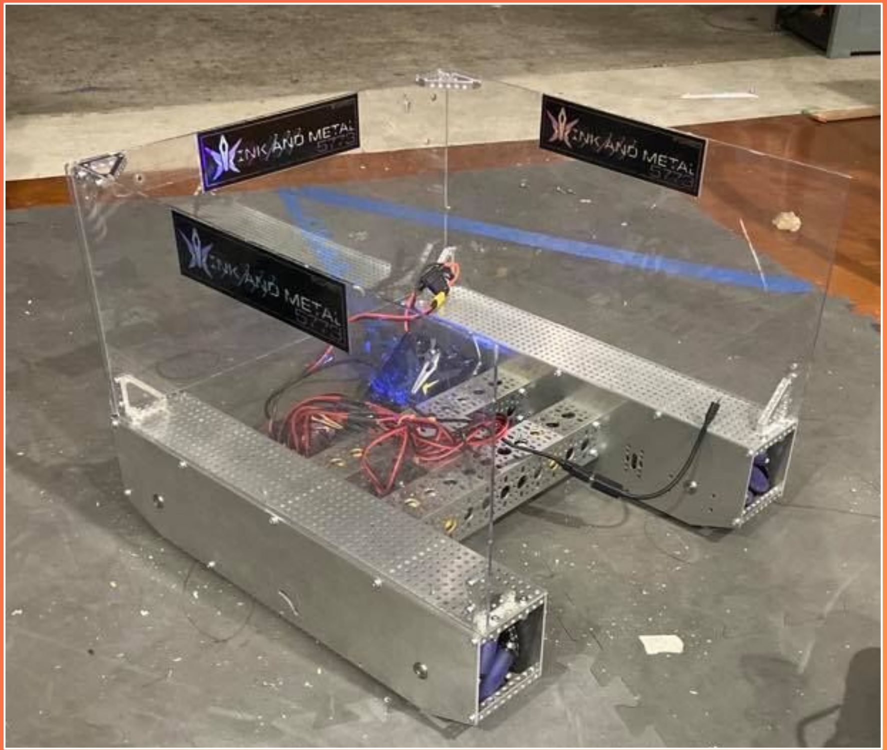
Disadvantages

- Much heavier
- Based on parts used, hole pattern may require adapters
- Less space overall due to placement of beams and side plates



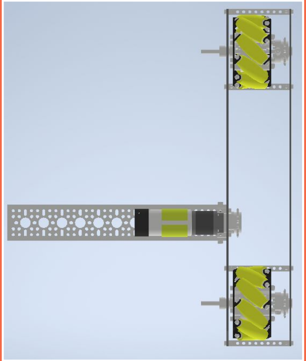
Ink and Metal Custom Chassis

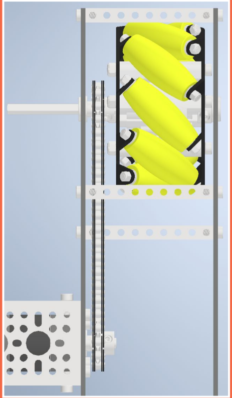


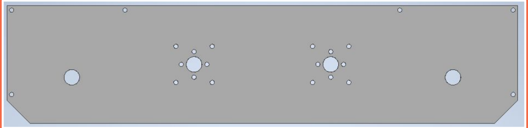


Ink and Metal Custom Chassis

- Connects using a 1:1 chain and sprocket ratio
- Motors are tucked into the middle beams







Advantages

- Motors are out of the way allowing more space for mechanisms
- Mechanisms can be mounted on top of the grid plates
- Lightweight, but durable chassis

Disadvantages

- Costly, High Risk-High Reward
- Can have unpredictable issues, such as slight drift

4

CONTROL AWARD

ELEMENTS OF THE CONTROL AWARD

Award Criteria

The control award requires that a team demonstrates autonomous operation, intelligent control with mechanical systems, and implementation of software, sensors, and mechanical

Video Example

In the video we will show, we highlight our autonomous programs, PID control, odometer usage, and more.

CONTROL AWARD VIDEO EXAMPLE

5

CONTROLLING THE ROBOT

REV CONTROL HUB

- Inputs for ports cables (e.g. USB)
- In-built robot controller (no need for driver station phone)
- Includes 4 DC motor + encoder ports, 6 servo motor ports, power, 4 analog, 8 digital, and 4 I2C ports for sensors, an in-built IMU for heading, 2 RS485 ports to connect to another expansion hub

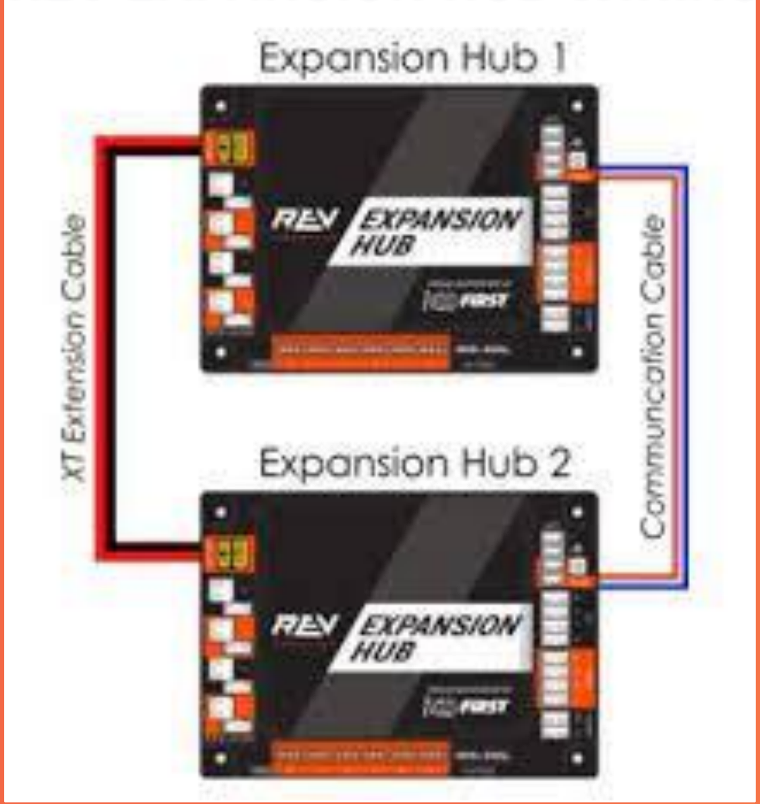
REV Control Hubs act as the brains of the robot- they take input through sensors, control motors and power, and decide how to robot operates. Additionally, their non-requirement of phones gives them far greater versatility.

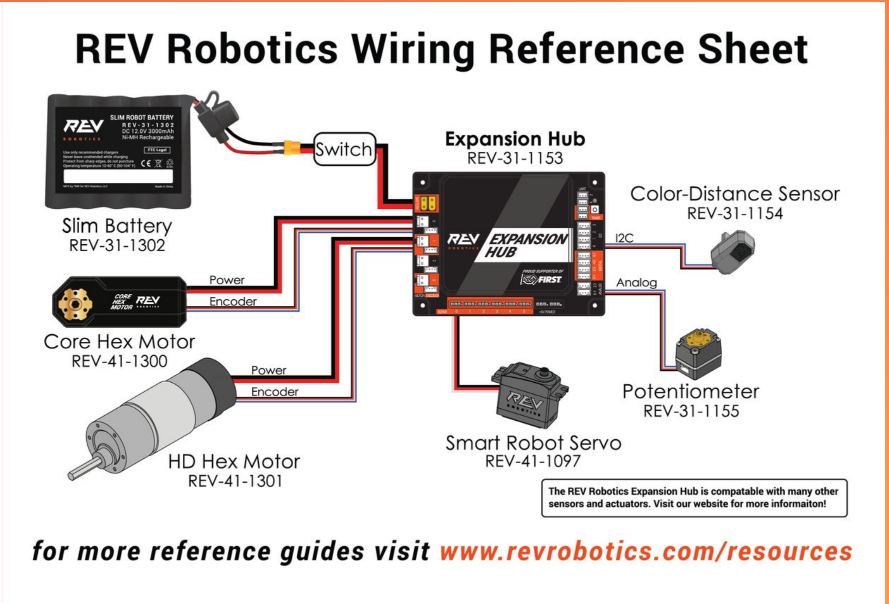
REV EXPANSION HUB

- Has the same functionality as Control Hub from the last slide, however this one requires a phone connection if not used with a control hub.
- They act as extra ports for additional sensors, motors, and other mechanisms.

REV Expansion Hubs are essential addons to control hubs to improve the range of functions performed. Using Expansion hubs gives users the ability to connect more motors, sensors, and general electronics.

REV EXPANSION HUB WIRING EXAMPLE





6

SENSORS

Learn how sensors are used, and what kinds of sensors are used.

DISTANCE SENSOR

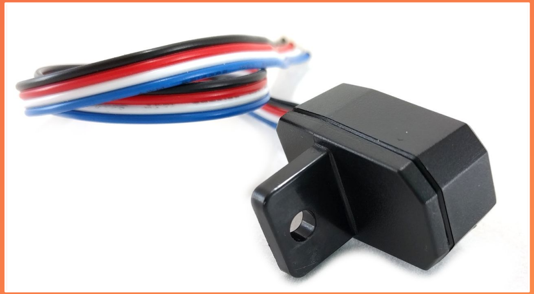
- Distance sensors output a signal (laser, infrared LED, ultrasonic) and read how it changed on its return
- The REV 2m Distance Sensor uses laser-ranging to measure distances up to 2 meters within millimeter resolution

Applications:

- Distance sensors are used to identify objects directly in front of it
- They are perfect to stop at a certain distance from a wall or object at a close range
  - Can be slightly inaccurate

COLOR SENSOR

- Uses a built-in IR Proximity Sensor and white LED for active target lighting
  - The sensor detects the light reflected back from the detection object with a receiver
  - Based on the light intensity, the color can be determined

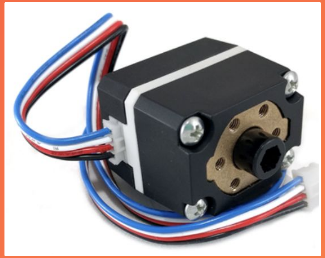


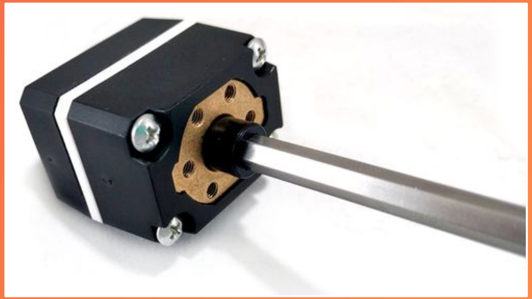
Applications:

- Robots can move across a field upon seeing a certain color
  - E.g. following a tape on a field
- Robots can also use it to detect an object of a certain color and verify it is that color

POTENTIOMETER

- The REV Potentiometer is an analog sensor with a 270 degree range of motion
  - Works by converting the angular position of a shaft into an analog voltage signal
  - Detects how much rotational motion occurred in a mechanism



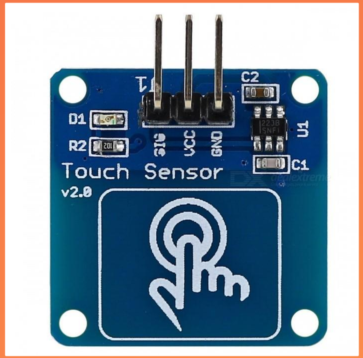


Applications:

- Potentiometers can be used to limit how much an axle rotates
  - If you have a robot arm, you can rotate it until it rotates 90 degrees, and make sure it stops at that point.
- This is more accurate than if you did it, for example, by time.
- Can be used as voltage dividers and audio control as well.

TOUCH SENSOR

- Digital sensor (binary output)
- When button is not pressed, LED is unlit and has high voltage
- When button is pressed, LED will light and has low voltage



Applications:

- Best used for user input and can be used as a limit switch
  - Humans can use it to start the robot.
- Can be used to limit how much a mechanical arm rotates down
  - If arm touches switch, it can send a signal to cease rotation.
- Can sense whether robot hits something

LIMIT SWITCH

- Digital sensor that has a three-sided digital hall effect switch
  - There are triggers on the top and two on the side
  - Any can be reported to be triggered
- REV Magnetic Limit Switch detects magnetic fields.
- Essentially, a more triggerable touch switch.

Applications:

- Similar to the touch sensor applications
- Used for controlling machinery as a part of a control system
  - E.g. limits robot arm from going past it
- Can be used to count objects that touch it

REV "BLINKIN" LED DRIVER

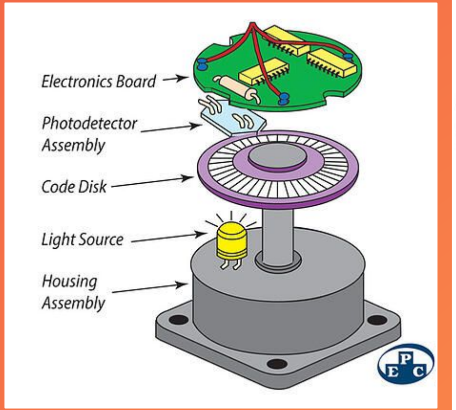
- Compact LED driver module that controls 12V RGB LED and 5V LED strips
- Combines internal LED drivers, a 5V power source, and a pre-programmed controller
- You can use PWM pulse to control color patterns
- Not really a sensor, but should be noted

Applications:

- Useful to show different stages/steps of the robot
  - In FTC challenge, use lights around robot to display which stage robot is in (autonomous, teleop, endgame)
- Can be used to test robot
  - Show different colors for different actions

ENCODERS

- Has a light source, disc with dark lines (ticks), photodetector, circuit board, and wire
- As a motor rotates, lines pass in front of a light source and the photodetector counts “ticks”
- Can use encoders to power motor until amount of ticks or inches is achieved

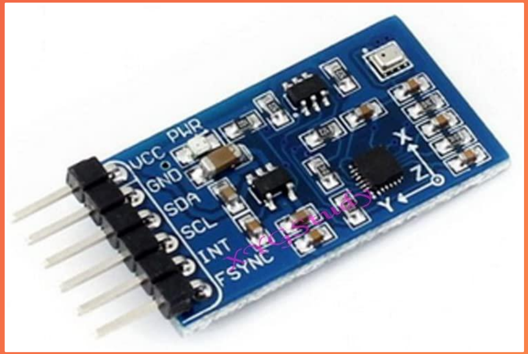


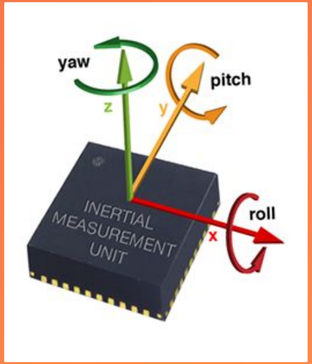
Applications:

- Used to limit how far your robot moves
  - E.g. stop after moving 10 inches
- Used to measure how long you travel
  - E.g. drive forward for 10 seconds, see how many inches/ticks the encoder counts
- Not too accurate however, as only measures after full rotations.

IMUS (INERTIAL MEASUREMENT UNIT)

- Detects linear acceleration using accelerometers and gyroscopes (for rotation)
  - Essentially, it keeps track of the angle of the robot
  - Sometimes includes magnetometers for angle reference



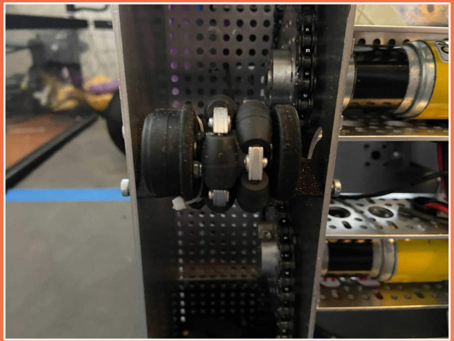


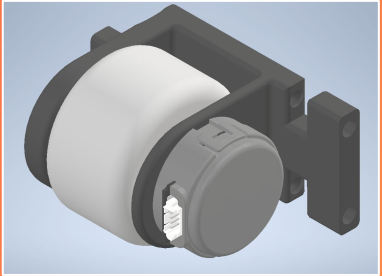
Applications:

- IMUs can keep track of the angle of your robot on a field
- This is very helpful as you can turn your robot until it is near a certain heading (e.g. turn until robot turned 90 degrees)
- IMUs are also commonly used with odometers and encoders for field navigation and knowing where your robot is on the field.

ODOMETERS

- Has an encoder, casing, and omni wheel
- Encoders capture movement and readings determine displacement from starting position and current location
- Creates a coordinate plane
- Using 3 allows for finding horizontal location, vertical location, and heading.



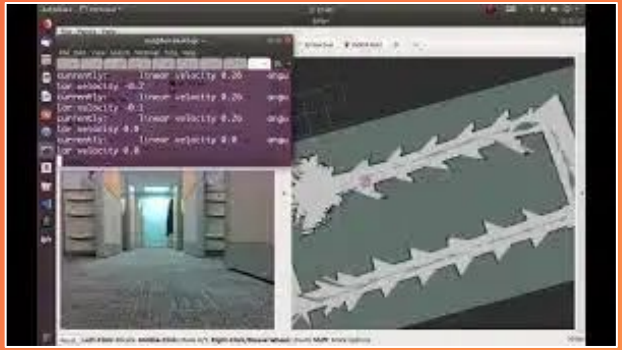


Applications:

- Useful for robot navigation
  - More accurate than encoders, use to make robot move and rotate to certain coordinate position on the field
  - Can measure distance like encoders
  - Can also measure heading

SLAM (INTEL REALSENSE T265)

- SLAM - simultaneous localization and mapping
- Process of creating a virtual map that robot uses to navigate an environment
- Has V-SLAM technology (Visual Inertial Odometry SLAM algorithms), fisheye camera lenses, an IMU, and USB ports



Applications:

- Mainly used in autonomous navigation
  - E.g. automated car piloting, automatic robot navigation on a field
- FTC teams used SLAM to autonomously pick up objects, e.g. rings that fell on the floor by generating pathing to pick them up.