FTC ENGINEERING COURSE

Hansei Technology

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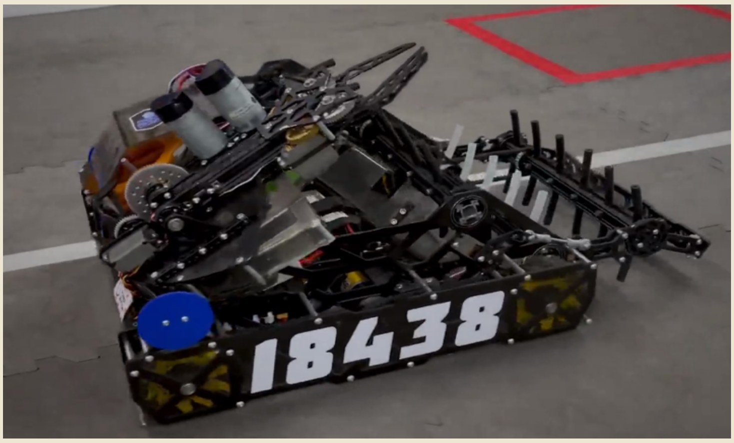
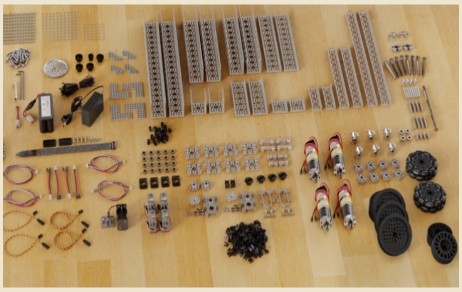
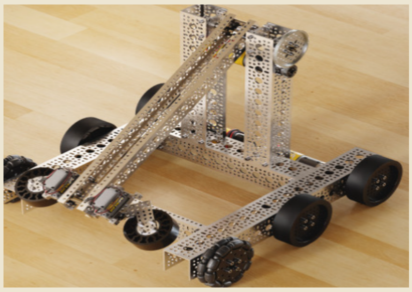
CHAPTER 1: Introduction

Every year, in FTC you are faced with a new theme for that season. You might need to build a robot that throws discs, grabs cones or even builds a tower. Depending on what your robot needs to do, you will choose different systems to put on your bot.



CHAPTER 2:
What is a screw?
What is a nut?

Whatever your bot needs to do, all robots have something in common which you need to assemble them, **screws** and **nuts**. Without them, your robot would be just a pile of parts.

 +  = 

A screw is a type of fastener typically made of metal and characterised by a helical ridge, called a male thread (external thread).

A nut is a type of fastener with a threaded hole. Nuts are almost always used in conjunction with a mating screw to fasten multiple parts together.

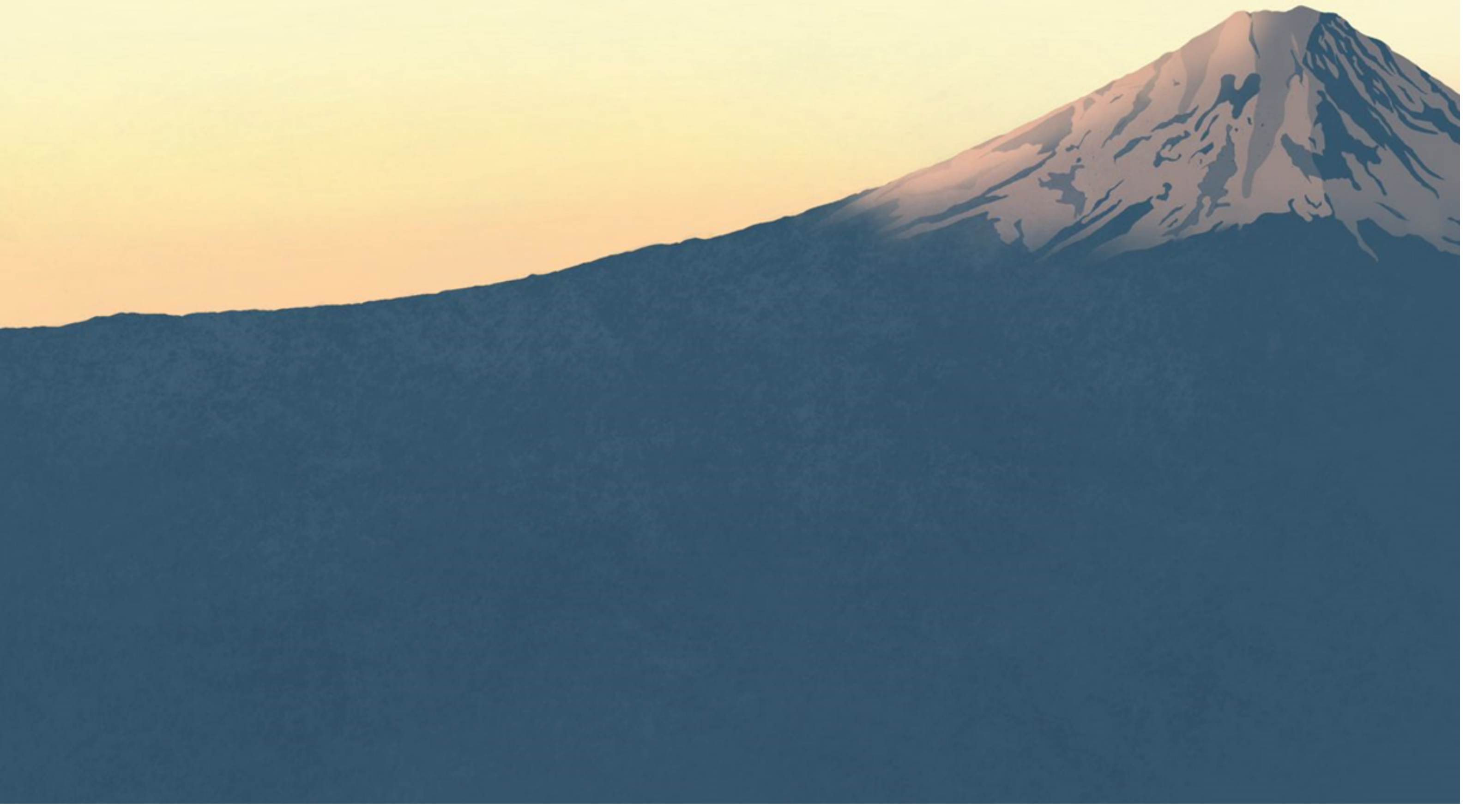
In most cases, you need some **tools** to fasten the parts together besides the screws and nuts. For example, in FTC the most commonly used tools for building robots are **hex keys**, **wrenches** and **nut drivers**.

cheie hexagonală cheie fixă chei tubulare

99% of times, if you rotate your hex key clockwise you will tighten the screw and if you rotate it counterclockwise, you will unscrew it. I am saying 99% of times because there exist some screws with reversed thread, but I am pretty sure you will not need them in FTC.

In this competition, the most used screws are the *M3 hex cap* from **REV Robotics** and the *M4 socket head screws* from **goBILDA**. You can use whatever screws you want, but you will find it easier to use these sizes of screws due to the fact that most manufacturers drill the holes in the hardware to fit the M3 and M4 threads.

CHAPTER 3:
FTC Parts



What do I need to build a robot, you might ask? Well, the most important parts you need are the structure parts. You need some kind of channel or an extrusion, then you fasten it to another, then to another and so on. How do you connect them? It's easy, with screws and nuts.

I. STRUCTURE

1. goBILDA

- **Channel**

Channel is a foundational building component. Its design allows for various mounting options, and its large center holes allow for the seating of bearings and the passing-through of rotating components.

- **goRAIL & Open goRAIL**

Extrusion-based building provides unlimited mounting positions. goRAIL has T-slot style grooves down the sides for slide-and-fasten style building.

- **Shafting & Tubing**

The shafting and tubing comes in many shapes and sizes. Some have a primary use as an axle, while others have built-in features giving them versatility to also be used as a structural element.

- **Beams**

Beams are on the compact side of the structural elements with a simple to use 8mm linear pattern. They can be used as a stand-alone to create a chassis from scratch, or as a supporting component to bring together the details of a larger scale build.

- **Mounts**

These are cornerstone pieces to the major framework of your project. Mounts allow you to create solid junctions, add support, and open up mounting possibilities.

- **Clamping Mounts**

These mounts give you the ability to adjust the axial and radial positions of mating components. The clamping mechanism allows for a solid, non-marring connection between parts.

- **Grid Plates**

Grid Plates contain 4mm holes on a simple 8mm grid so that you have plenty of mounting options while staying on pattern.

- **Pattern Plates**

Pattern plates have the goBILDA pattern down the length of the plate. Use them to add support as a bracket to attach something to, or as a trim panel to get just the right look for your build.

- **Brackets**

These are supporting pieces intended for fastening to larger structural elements to add support, and create connections and angles that might not otherwise be possible.

- **Baseplates**

- **Pattern Adaptors**

If your inventory of robot parts includes more than just goBILDA®, these adaptors will allow you to mix and match with ease.

- **Pattern Spacers**

These spacers have many uses beyond spacing two pieces apart. They can be used as a bearing mount for 14mm OD flanged ball bearings. The 1mm recess around the bore allows a flanged bearing to sit flush with the top of the pattern spacer. The OD of the pattern spacer is compatible with 32mm pillow blocks, and clamping mounts.

- **Standoffs & Spacers**

Standoffs and spacers can provide clearance, adjust the distance between parallel parts, add structural integrity, add a threaded hole for mounting other components, or mount a bearing in a rotating assembly.

- **Threaded Plates**

Threaded plates have multiple holes that align with common attachment points within the build system. Using a plate with multiple threaded holes allows you to take screws in and out without having to hold a nut from turning.

- **Hinges**

Hinges are a clean and simple way to create motion with a single degree of freedom.

2. REV

- **U Channel**

The U Channel has a square profile.. It can be used in locations where additional torsion strength is required. On the sides of the channel is the Extended Motion Pattern which uses M3 hardware for attaching brackets, extrusion, and channel together. Locations for mounting bearings, shafts, motors, and servos are available every 16mm. Slots on the top of the channel accept standard M3 hex-head bolts or nuts, rather than expensive t-nuts. The top of the channel also has the Motion Pattern with M3 holes on a 16mm diameter circle pattern repeating down the channel.

- **C Channel**

The C Channel has a rectangular profile. It can be used in locations where additional torsional strength is required. The 45mm wide side of the channel features the Extended Motion Pattern which uses M3 hardware for attaching brackets, extrusion, and channel together. Locations for mounting bearings, shafts, motors, and servos are available every 16mm. Slots on the 15mm sections of the channel accept standard M3 hex-head bolts or nuts, rather than expensive t-nuts.

- **Brackets**

Using these brackets allows for easy construction of robot frames, mechanisms, and structure.

- **Extrusion**

A square extrusion with slots designed to fit standard M3 hardware rather than expensive t-nuts.

- **4 Pack Extrusion**

It comes in a square extrusion. The slots are designed to fit standard M3 hardware rather than expensive t-nuts. Use the extrusion when more strength is needed for an application.

- **MAX Pattern Plates**

MAX Pattern Plates are compatible with the REV ION System and feature a bore surrounded by #10 clearance holes on a 0.5in grid. The plates are available in various lengths, with the pattern repeating every 2in.

- **Extrusion with 45° ends**

For smaller applications it is this square extrusion. The slots are designed to fit standard M3 hardware rather than expensive t-nuts. The extrusion has ends cut neatly at a 45 degree angle. Great for diagonal bracing without extra cutting.

- **Standoffs**

The standoffs provide spacing for mounting key items on your robot. These are tapped on each end for a #10-32 thread and have a 3/8in flat to flat dimension, similar to a #10-32 nut.

- **MAXHubs**

MAXHubs provide a way to transfer torque to a MAXSpline bore from shafts of various shapes and sizes. Other hub variants allow for other bores or mount holes to populate within an existing MAXSpline.

3. TETRIX

- **MAX Flat Bar**

These structural pieces are made of heavy-duty aluminium. Can be cut to custom lengths using a metal-cutting blade.

- **Channels**

Made of heavy-duty aluminium, these channels are the structural base for a building system. Available in five lengths to provide flexible building options, the channels can be cut to custom lengths with a metal-cutting blade.

- **Inside Corner Brackets**

Those are two-sided brackets that fit the outside of the Channels and can be used to bookend a channel to secure it to another structural element.

- **Inside C Connectors**

This is a three-sided bracket that fits inside the Channels. This connector helps to create perpendicular joints when space is tight. It can be placed facing out of the end or the open side of a channel. It is very strong as it attaches to two sides of the structural element.

- **Flats**

Flats create added versatility, whether you're making a flat surface or creating a scoop or other angled piece. Using those you can create rails, braces, brackets, gussets, and other custom pieces with ease.

- **Adjustable Angle Flat Brackets**

Structural elements can be connected at varying angles with these slotted flat brackets.

- **Flat Round Spacers**

Ideal for maintaining proper distance between two elements attached on either side of a structural part.

- **L Brackets**

These brackets enable the connection of structural elements at 90-degree angles.

- **Flat Building Plates**

The plates are made of heavy-duty aluminium and can be cut to custom lengths using a metal-cutting blade.

- **Angles**

They are made of heavy-duty aluminium featuring a 3 mm thickness, these angle bars with holes are great for reinforcement and creating builds with high structural integrity.

- **Flat Brackets**

Perfect for connecting structural elements or for creating a servo leverage arm.

- **Angle adjustment brackets**

These slotted corner brackets allow the structural elements to be connected at varying angles to modify and customise builds.

II. ELECTRONICS

The electricity is used in all domains to power diverse things such as motors, bulbs or even our phones and computers. Electronics is a scientific and engineering discipline that studies and applies the principles of physics to design, create, and operate devices that manipulate electrons and other electrically charged particles.

In FTC we need this to power our robots. Without an electric circuit, the robot can not move.

Below are the used electronics:

1. BATTERIES

To give electrical power to your robot you need to store it because you can not plug your robot in a different source during a competition.

Legal batteries in FTC:

- TETRIX® NiMh Battery
- Matrix 12V NiMh Battery
- 12v Slim Battery

2. Control Hub &Expansion Hub

At first, your robot will not know what to do so you have to write its code. That code will be uploaded in the Control Hub which is like the brain of your creation.

Running the Android operating system gives the Control Hub the flexibility to control both basic and advanced robots while also being field-updatable as new features are developed.

The REV Robotics Expansion Hub is a hardware controller which can communicate with any computer, including Android tablets/phones and the REV Robotics Control Hub. The Expansion Hub is loaded with hardware interface options to enable driving motors and servos, interfacing with sensors, and communicating with other devices via several protocol options.

Documentation:

- Managing a Control Hub
- Connecting the Expansion Hub to the Control Hub
- Control Hub User Manual
- Getting started with Control Hub
- REV Robotics Expansion Hub Getting Started Guide
- Software Resources

3. MOTORS

A direct current (DC) motor converts electrical energy into mechanical energy. It takes electrical power from your robot in the form of direct current and transforms it into mechanical rotation. DC motors are used to power the wheels of a drivetrain and various mechanisms such as sliders, arms, and turrets.

These motors typically have two sets of wires: one provides power to the motor (often referred to as the 'bullet'), while the other is an encoder used for locating the robot on the field.

Examples of legal motors include:

- TETRIX 12V TorqueNADO DC Motor
- AndyMark NeveRest series DC Motors
- REV Robotics Core Hex DC Motor
- Yellow Jacket Planetary Gear Motors

The RPM (rotations per minute) of a motor describes both its torque and speed. Motors with lower RPM values tend to be more powerful, while those with higher RPM values offer greater speed.

Please exercise caution when selecting the size of screws for mounting a motor on a structural part, as using screws that are too long can potentially damage the motor's gearbox.

4. SERVOS

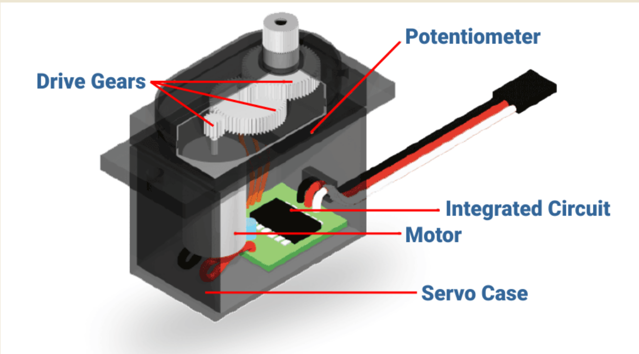
Servos are electronic devices and rotary or linear actuators that rotate and precisely push parts. They are primarily used for angular or linear positioning, specific velocity, and acceleration.
In FTC, servos are utilised for intakes, outputs, and various systems.

Examples of legal servos include:

- Smart Robot Servo REV
- goBILDA Speed, Super Speed, Torque
- Axon Robotics MAX+, MINI+

Servos require a servo programmer to easily switch between the default mode and continuous rotation mode. In the *default mode*, the servo can rotate a maximum of 280-360 degrees, depending on the vendor, and provides positioning feedback. This mode is excellent for applications requiring precise and repeatable movements. In *continuous rotation mode*, the servo operates like a gear motor coupled to a speed controller. The input remains a normal servo signal (PWM), but the signal determines the speed and direction of the servo, rather than the position. This mode is excellent for driving wheels, winches, cams, and collection devices.

Exception: Axon Robotics servos require a special servo programmer to program them using a computer.



They have three different wires:

- Power (red)
- Ground (black or brown)
- Signal (yellow or white

5. SENSORS

Sensors in FTC are mostly used during the autonomous period to provide immediate **feedback** for consistency or in the TeleOp to make **automations** to gain more speed.

The most used sensors are:

1. **Color sensor**

A color sensor is able to measure the color of an object. Most of them require the object in question to be relatively close to the sensor.

2. Distance sensor

- Ultrasonic

An Ultrasonic Distance Sensor is able to measure the distance between an object and the sensor. It does this by sending out a sound wave and measuring the time it takes for the wave to travel to the object and back. Using this and the speed of sound the distance can be calculated.

- Optical

An Optical Time of Flight (ToF) Sensor is able to measure the distance between an object and the sensor. It does this by sending out a light beam and measuring the time it takes for the beam to travel to the object and back. Using this time and the known speed of light, the distance can be calculated. Be aware that the way the object interacts with light can change the accuracy of distance measurement.

3. Touch sensor

A touch sensor detects the activation of a button. It can be used as a limit switch, a way to limit the range of motion of a mechanism.

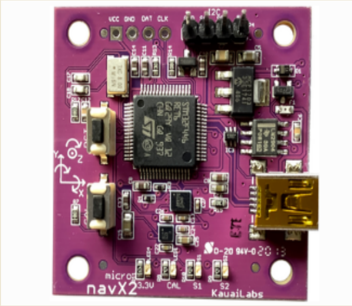
4. Magnetic limit switch

A Magnetic Limit Switch is used to detect the presence of a magnet in near proximity. It is used to limit the range of movement of a mechanism that would cause damage if it went beyond the limit. This is done by placing a magnet on said mechanism which would cause the Limit Switch to activate.

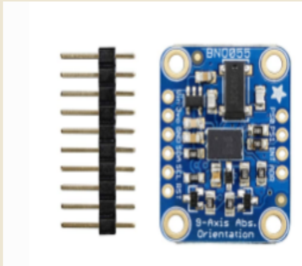
5. Range sensor

The Modern Robotics Range Sensor measures distances from 1 cm to 255 cm. It combines an ultrasonic sensor to detect objects from approximately 5 cm to 255 cm and an optical sensor to detect objects closer than 5 cm.

6. IMU



An Interial Measurement Unit (IMU) is a combination of a Gyroscope, Accelerometer, and Magnetometer. A Gyroscope is a device that reports the angular orientation of an object in 3 dimensions. An Accelerometer is a device that reports the acceleration of an object in 3 dimensions. Acceleration can be thought of as the rate of change of speed at any given instant. A Magnetometer is a device that measures the strength of magnetic fields in 3 axes. This can be used as a compass to gain the orientation of a robot relative to the poles of the Earth, an absolute measurement.



Documentation:

- IMU Basics
- Universal IMU Interface

7. Potentiometer

A potentiometer changes the output voltage based upon the degree to which the adjuster is turned. It is often used as a form of measuring the absolute orientation of an axle. The manner in which the output voltage changes is based on the Potentiometer that is used. Such a device is typically attached via the analog port of the REV Hub.

CAPITOLUL 4:
What do we need to build a robot?

1. STARTER KITS

a. goBILDA

The FTC goBILDA Starter kit contains a massive amount of individual pieces. For rookie teams this is a good offer because for the price of $599.99 with the FTC discount you get pieces from every category.

This kit goes well with the and the Strafer Chassis Kit and the Viper-Slide KIt Cable-Driven or the Belt-Driven. With those combined you can build an entire robot from scratch and have a decent performance. Even so, just the kits are not enough if you want remarkable performances.

The kit includes:

a) Motors and wiring
b) Servos and wiring
c) Servo Mounts
d) Battery and accessories
e) U-Channels
f) Brackets and mounts
g) Standoffs and spacers
h) Gears
i) Sprockets and chain
j) Wheels
k) Bearings
l) Shafting
m) Hubs, couplers and collars
n) Screws, nuts, washers, shims and tools

b. REV

FTC REV Starter Kit has over 1400 parts and was created based on feedback from teams. It provides robot design flexibility, focusing on giving teams a strong foundation to build on, as well as loads of additional components.

All of this is supported by extensive design examples and documentation.

Features:

a. C Channel aluminium structure
b. Configurable UltraPlanetary Gearboxes
c. Smart Robot Servos with new accessories
d. Grip Wheels
e. Chain Tool

Documentation:

- FTC Starter Kit Guide
- Channel Drivetrain Build Guide
- Starter Bot Resources
- Starter Bot Build Guide
- FREIGHT FRENZY Kickoff Concepts (2021-2022)

c. TETRIX

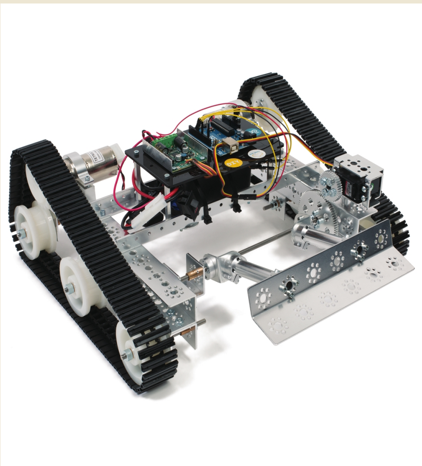
TETRIX® FIRST® Tech Challenge Competition Set contains a large array of building elements that enables teams to create rumble-ready robots year after year.

In addition to the kit, you will receive a pack of eight cables that enable you to connect the TETRIX MAX TorqueNADO® Motors and encoders to the FIRST Expansion Hub.

Resources: TETRIX Competition Set Product List

What you will get:
- 824 TETRIX MAX building elements
- Structural, motion, and hardware elements including a variety of wheels, gears, channels, flats, and connectors
- Four TorqueNADO motors with encoders, motor cables, FIRST expansion hub conversion cable pack, and four 180-degree standard-scale servo motors - Rechargeable battery pack and charger
- Assembly tools
- Sturdy storage bin, lid, and sorting tray

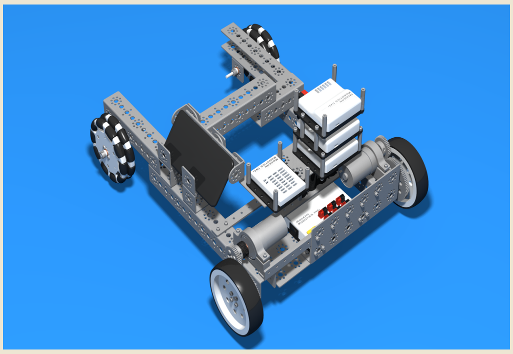
2. CHASSIS TYPES



Tank Drivetrain

A tank drivetrain primarily uses traction wheels and cannot strafe (move sideways). To change directions, this type of drivetrain relies on either turning the wheels on the left and right side in opposite directions or running one side faster than the other side.

Prioritize: traction and acceleration over maneuverability. The tank drivetrain has potential to traverse obstacles and play defense.



Pushbot (2 Wheel Drive)

This is a simple rookie drivetrain. It often has direct driven traction wheels with unpowered omni wheels. It has poor turning as the center of turning is at the back of the robot between the two powered wheels and it has poor acceleration due to only using 2 motors.

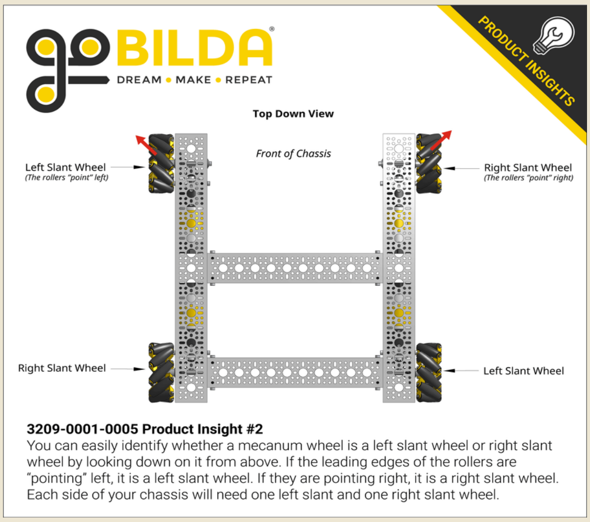
Advantages:
- Most simple drivetrain to build
- No need to power 4 wheels

Disadvantages:
- Slow
- Underpowered
- Lacks agility, maneuverability
- Poor acceleration
- Often direct driven which can cause problems

Mecanum drive

Mecanum drivetrains use 4 mecanum wheels which are powered independently by one motor. This configuration angles the velocity of each wheel, allowing the robot to strafe (move sideways).

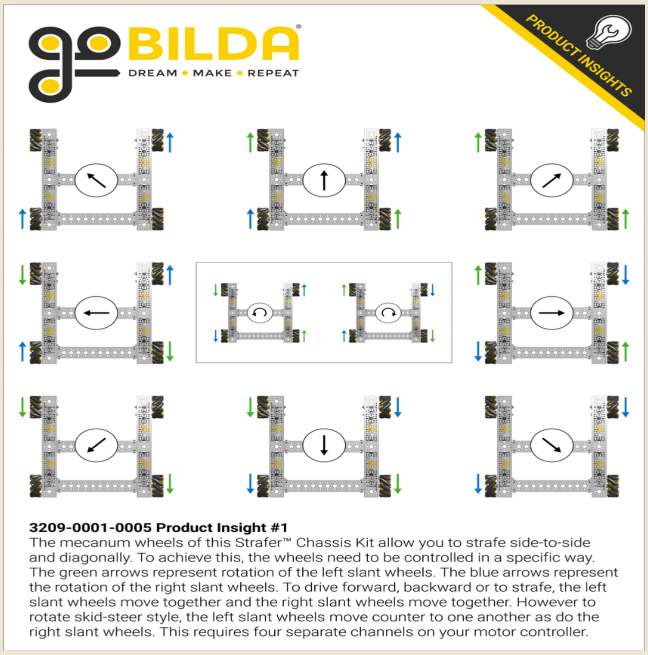
- A mecanum wheel consists of a series of rubber rollers rotated 45 degrees to either the left or right. Running those wheels on one diagonal in the opposite direction to those on the other diagonal causes sideways movement (strafe).
- It is important to note that in order to maximize the efficiency and stability of mecanum drives, when viewed from above, **the rollers of each wheel should point towards the center of the robot, forming an X shape**.



Due to the fact that mecanum wheels are more likely to slip because of the diagonal rollers, an optional addition to them is a separate odometry mechanism in order to track the robot's location during the autonomous period.

Advantages:
- Good maneuverability and agility
- Versatile

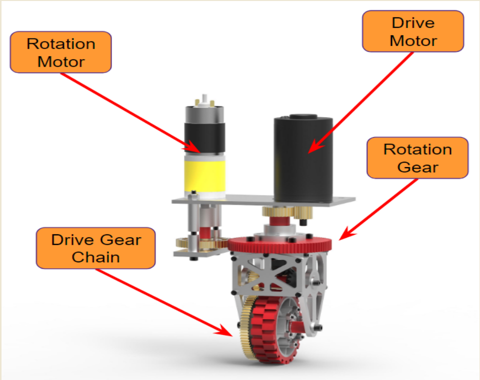
Disadvantages:
- Mecanum have lower traction than traction wheels
- Can be pushed around on defense
- The wheels **must** be powered independently



Swerve

Swerve is a form of drivetrain that uses "pods" which are able to rotate independently of each other. Since each pod can rotate, the drivetrain can move in any direction.

There are 2 types of swerves (coaxial and differential). The difference between them is how it rotates the pod and moves the wheel.



Coaxial

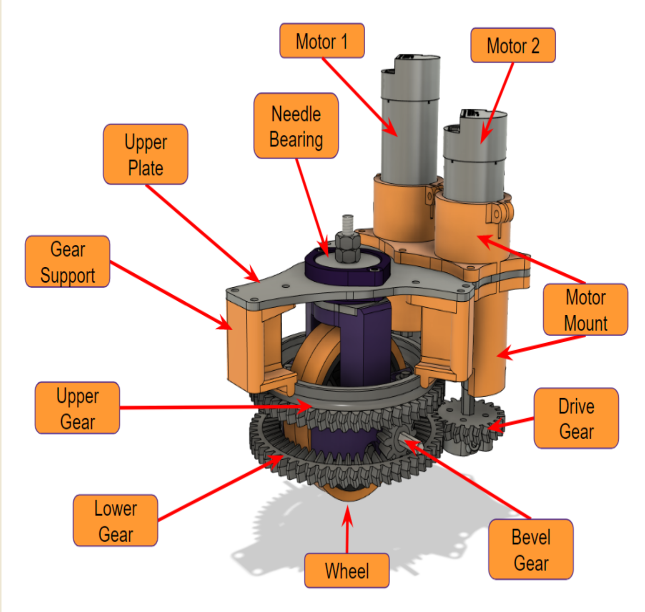
It works by having one motor rotate the pod and another one the wheel. However, the motor that rotates the pod doesn't have to be a DC motor, it can be a servo.

Advantages:
- Easier to understand
- Simple to program
- Can be used servos for rotation

Disadvantages:
- Less powerful
- It needs extra belts/chains/gears
- More vertical space needed

Diferențial

It has two sets of gears, an upper set and a lower set. In between, there is another gear connected directly to the wheel with an axle. When the upper and lower gears move in the same direction, the central gear stays put and the whole pod rotates. When the upper and lower gears move in opposite directions, the central gear also rotates, which in turn rotates the wheel. If the top and lower gear are moved at different speeds, the two actions can be combined.



Advantages:
- More strength
- Reliable
- Smaller vertical profile
- Do not have to use belts/chains

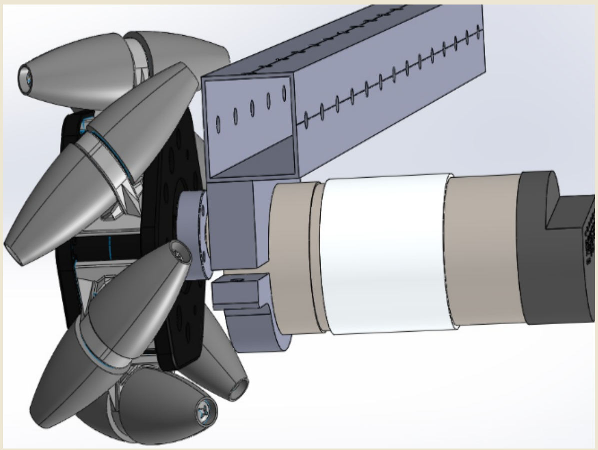
Disadvantages:
- Complex to build and to program
- Uses all 8 DC motors and encoders ports
- Uses more power
- Drains battery quickly

3. POWER TRANSMISSION

When building any mechanism you have to consider how it will be powered. There are 4 main forms of power transmission.

a. Direct Drive
b. Gears
c. Chain
d. Timing Belt

a. DIRECT DRIVE



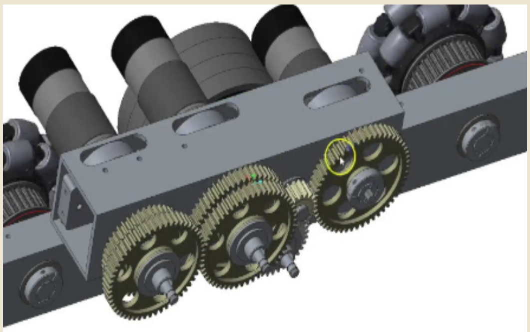
Direct drive consists in powering a mechanism directly from the motor axis. This way you put unnecessary load on the drive motor. This is because the shock loads can destroy gearboxes. Gearboxes are able to resist load along the axis of rotation for example when the wheel changes direction. However, in direct drive the gearbox shaft can be exposed to other shock loads outside of the normal axis for example when the wheel comes into contact with another robot.

b. GEARS

Gears are used in power transmission for 3 common applications:

- Changing the direction of power
- Changing the amount of torque
- Changing RPM

The most common material for gears is 7075 aluminium. Never mesh plastic and metal gears together. You can mesh different types of metal gears together, as long as they have the same diametral pitch.



When you are meshing gears, you have to be sure that the gears are not too loose nor too tight. If the gears are too loose, the teeth will easily wear out,decreasing its longevity. But if they are too tight, they will have too much friction and possibly grind or bind up. **The ideal way to mesh gears is to make sure the teeth interlock and just touch the base of the gear.**

Advantages:

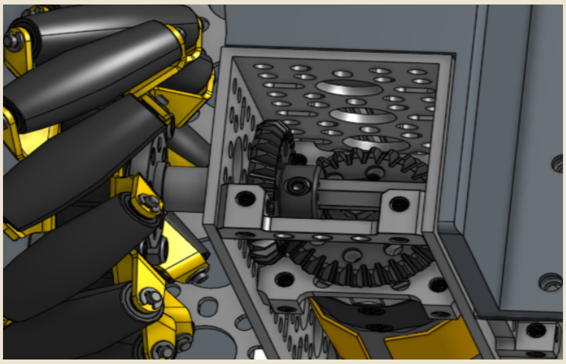
- Solid and proven power transmission method
- Simple to use
- Give big reduction in small areas
- No tensioning needed

Disadvantages:

- Some ratios are not easy to build
- Long distance transmission is impractical

- Meshing can be tricky
- Gears wear faster than sprockets

Bevel gears



Miter gears are bevel gears which have a 1:1 ratio between the drive gear and driven gear. They are used especially for drivetrains. Their steel construction and large tooth size make them perfect for high-torque applications.

Chain

When your shafts aren't right next to each other, chain and sprockets will help you transmit power securely between your shafts.

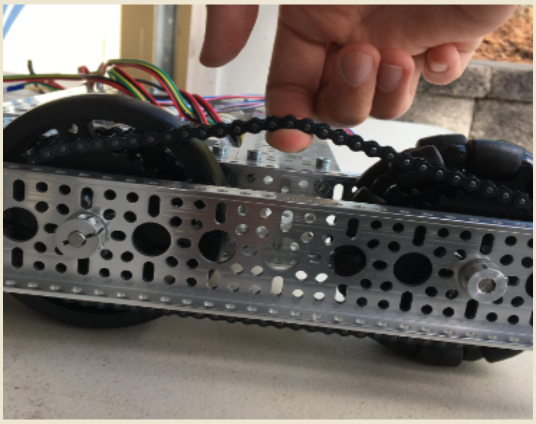
Chain wrap

Chain should, at the very least, have 90° of contact with the sprocket. The best practice is to have 180° or more of contact, as it is very unlikely to fall off with proper tensioning. Not tensioning or wrapping the chain properly can cause chain skipping, especially on drivetrains or arms.

You have to make sure you do not tension it too much or let the chain too loose. Letting it loose can result in the chain falling off the sprocket or chain skipping, where the chain can skip along the sprocket. Too much tensioning the chain often results in the motor burning out, or a loss of efficiency.

How to verify if you have done it correctly: if the chain moves slightly without significant resistance, chances are you've done it just right. If it's too tight, then the chain will barely move under a gentle press.

Advantages:
- Hard to break
- Can be any size you wish
- Pretty precise



Disadvantages:
- It stretches over time
- The smaller the sprocket, the faster the chain stretch
- Problematic chain wrap
- Sprockets are big

TIMING BELT

Timing belts use a series of small, wide teeth to engage a pulley with a number of matching grooves.

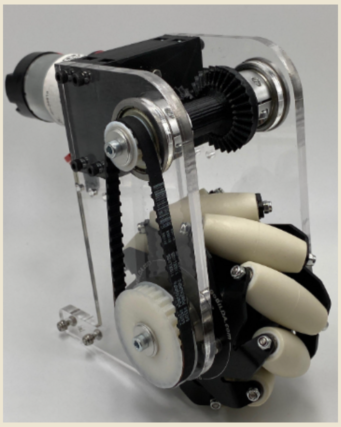
Even if timing belts have a similar objective as chains, their characteristics are different. Timing belts are lighter and more compact, but they lack the customizability of the chain - belts come in a closed loop of predetermined length.

Belt Wrap:

Belt should, at the very least, have 90° of contact with the pulley. The best practice is to have 180° or more of contact.

You have to make sure you do not tension it too much or let the belt too loose. Letting it loose can result in the belt falling off the pulley or belt skipping, where the belt can skip along the pulley. Too much tensioning the belt often results in the motor burning out, or a loss of efficiency.

How to verify if you have done it correctly: if the belt moves slightly without significant resistance, chances are you've done it just right. If it's too tight, then the belt will barely move under a gentle press.



Advantages:
- Pulleys can be made at home
- Belts are strong
- No slop when tensioned correctly
- Efficient and quiet

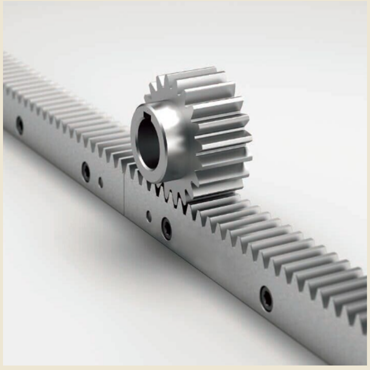
Disadvantages:
- Are not customizable
- Wider than chain
- Expensive

4. LINEAR MOTION

Linear motion is a movement in a straight line, opposite to the circular motion made by motors. .

Main mechanisms:
- Rack and Pinion & Worm Drive
- Linear Actuator
- Scissor Lifts
- Linear Slides

RACK AND PINION



A rack and pinion comprises a circular gear (the pinion) engaging a linear gear (the rack). Together, they convert rotational motion into linear motion. Rotating the pinion causes the rack to be driven in a line. Conversely, moving the rack linearly will cause the pinion to rotate.

Advantages:
- Easy way to extend upwards
- Power and linear motion
- Can be used for heavy load like hanging your robot

Disadvantages:
- Generally it is only used in one stage, because multiple mechanisms require other forms of powering it (belt, string, chain, etc.)
- It needs to be supported very well to sustain heavy load, or else the mesh will fail.

WORM DRIVE

A worm drive is a gear arrangement that uses a worm (a gear in the form of a screw) and a worm wheel (which is similar in appearance to a spur gear). The two elements are also called the worm screw and worm gear. Worm drives are a compact means of substantially decreasing speed and increasing torque.

LINEAR ACTUATOR

Linear Actuators work using a lead screw. This lead screw works with a metal bar that extends outwards, forming a screw to bolt relationship.

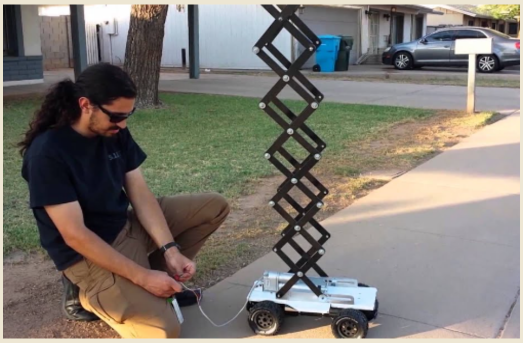
- **For examples: goBILDA Linear Actuator**

TECH TIP

Running any linear actuator past its endpoints will cause damage. Some actuators have built-in circuits which utilise limit switches and diodes to prevent overrun. To keep this kit FTC legal, it has no electronics. You need to utilise a motor with an encoder so that you can program endpoints for proper operation of the actuator kit.

SCISSOR LIFTS

They are operated by a rack and pinion or lead screw, which contract the scissor legs, causing upwards linear moving. One leg is stationary, while one scissor leg is attached to the motion mechanism (rack and pinion/lead screw).



Advantages:
- High torque
- Long distances
- Can be very fast

Disadvantages:
- Harder to build correctly

LINEAR SLIDES

There are 2 types of sliders: cable-driven and belt-driven. Although they work the same, you need different parts, for example for the belts you will need a Pitch hub mount timing belt pulley.

A timing belt adds simplicity and reliability to the drive system. For a cable-driven slider you need a spring to control the tension variances, but using belts you have access to quick rigging and excellent consistency from one cycle to the next. Whereas cable has the ability to move about freely when slack is introduced, a belt is limited by its width, and thus easier to tame.

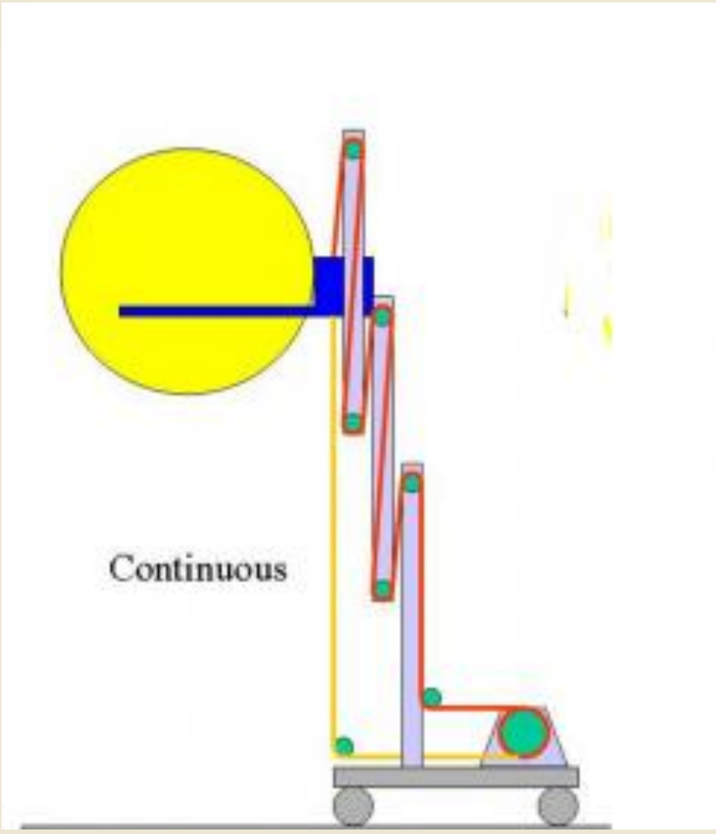
Linear slides work using a system of strings going stage to stage in a zigzag pattern. When the string is pulled, the stages will go up to compensate for the lost string.

The most used ones are:

- **Viper-Slide (Cable-Driven)**
- **Viper-Slide (Belt-Driven)**
- **MiSUMI Slides**
- **BTW Link Slides**
- **Long Robotics Slides**

Rigging is the way that string, belt, or chain is placed to extend and retract a linear extension. You can do this in 2 different ways: continuous and cascade.

1. CONTINUOUS RIGGING



Extension

You need a long extension string that comes from the spool mounted on a powered motor. After that you will set up the cable to the top of the base stage → bottom of the first stage → top of the first stage → bottom of the second stage and so on.

Retraction

The origin of the retraction string is a second spool on the same axis as the extension one, but coiled in the opposite direction. That cable is anchored on a spring to the top stage.

How it works you might ask....

Rotating the motor in one direction causes the string to become shorter (the extension spring is coiling on the spool) and because of this, the distance between the top of one stage and the bottom of the next stage decreases. This way the system extends. Once the last stage hits the limit, the next one extends and the pattern repeats until every stage is fully extended.

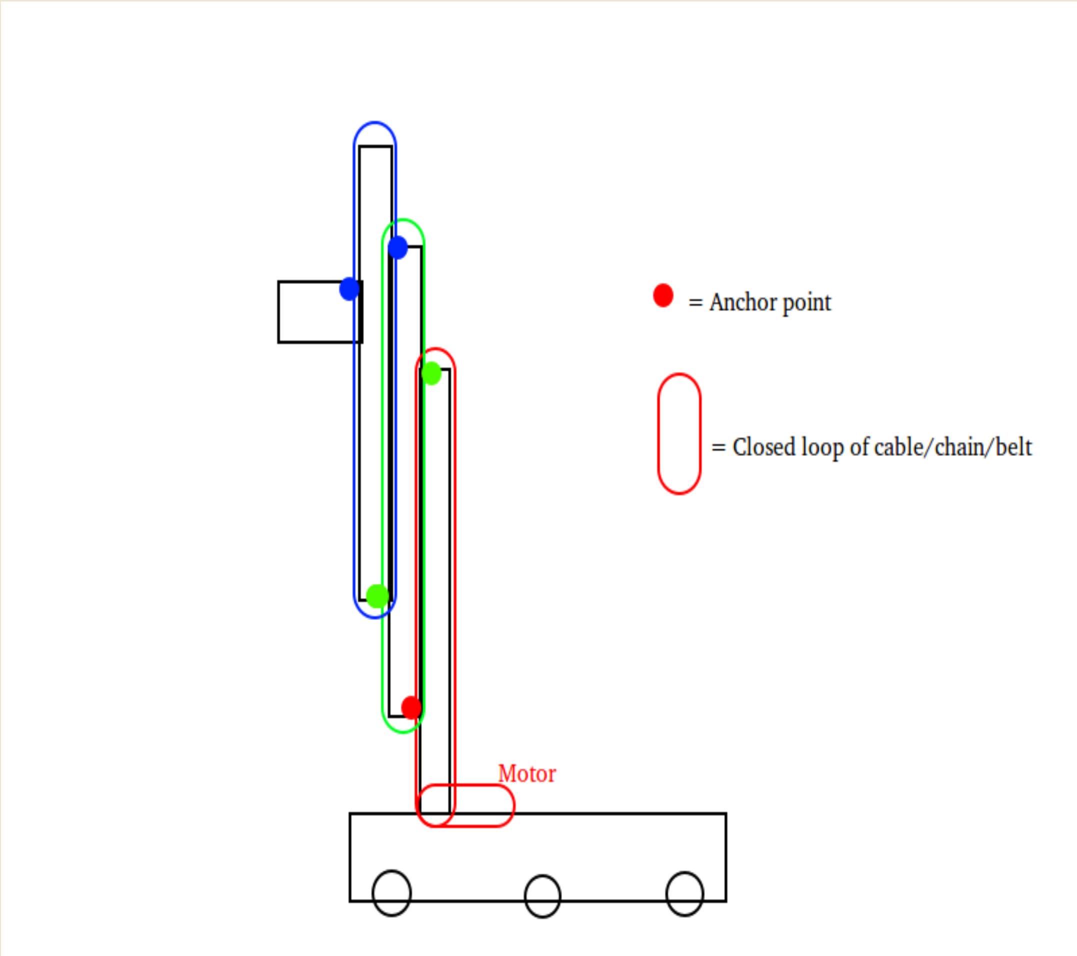
Rotating the motor in the opposite direction, the retraction string is coiled on the spool. This causes the pooling of the top stage to the starting position until the whole system is fully retracted.

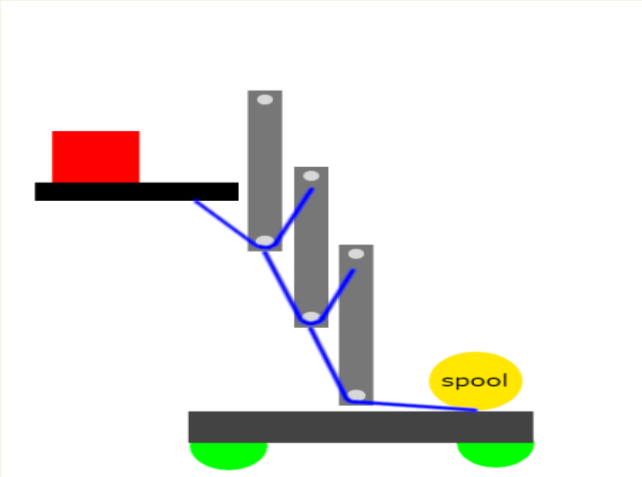
- The extension spool and the retraction spool should be the same diameter
- You need to make sure that you are pulling the string straight because misalignment can lead to the string coming off of your pulley
- Continuous spools can be powered by a system with a relatively low gear ratio

2. Cascade Rigging

Extension

You will need a different string for each element of your slider. The first cable comes from the spool mounted on a powered motor and goes up to the first element through a V Groove Ball Bearing then to the base of the next stage fixed with a not. The pattern repeats until the whole slider is done.





Retraction
For the cascade rigging the retraction is not necessary. It entails simply rigging another set of cascade string that can retract the system when engaged.

If cascade retraction is being used with continuous extension, the two spools cannot be the same diameter.
N- number of stages→ the diameter of the continuous extension spool must be *N* times bigger than the cascade retraction spool.

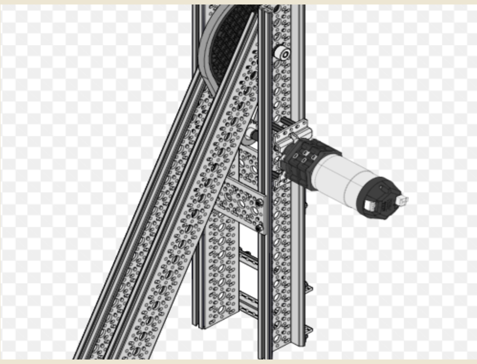
5. ARMS

Arms are a way to achieve extension, but unlike linear extension they require lots of torque. When building arms, the torque should be transferred via gear, chain or belt.

There are 2 types of arms in FTC**: single arms** and **multi-axis arms.**

Advantages:
- The single bar ones are simple to build
- Useful in low-load applications

Disadvantages:
- Require a big amount of torque
- Single arms are often not enough, they cannot provide the extension needed for most of the games

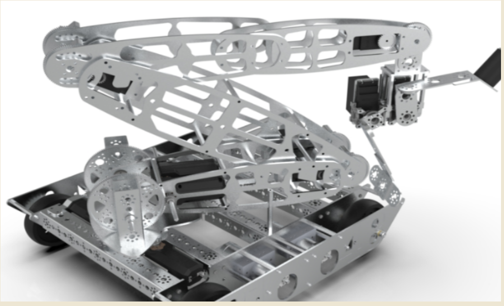


Single arms

A single arm refers to an arm on one axis of rotation. The extension is often not enough so, some teams build a single arm with an added linear extension mechanism to reach the desired extension length.

Multi-axis arms

A multi-axis arm is an arm which has multiple points of rotation.



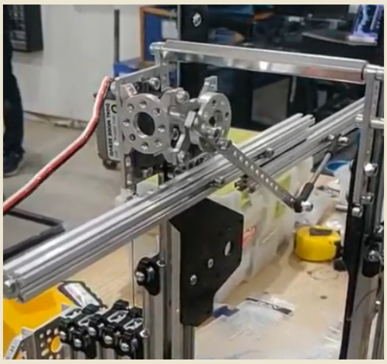
Highly discouraged for inexperienced FTC teams due to the difficulty of building as well as the need for machine tools.

6. LINKAGES

Linkages are used to convert rotational motion to linear motion. They are made of solid links or bars connected to 2 or more links using sliding joints, ball-and-socket joints, hinges etc.

Linkages types:
- Linkages slides
- Four Bar
- Virtual Four Bar
- Double-Reverse Four Bar

LINKAGES SLIDES



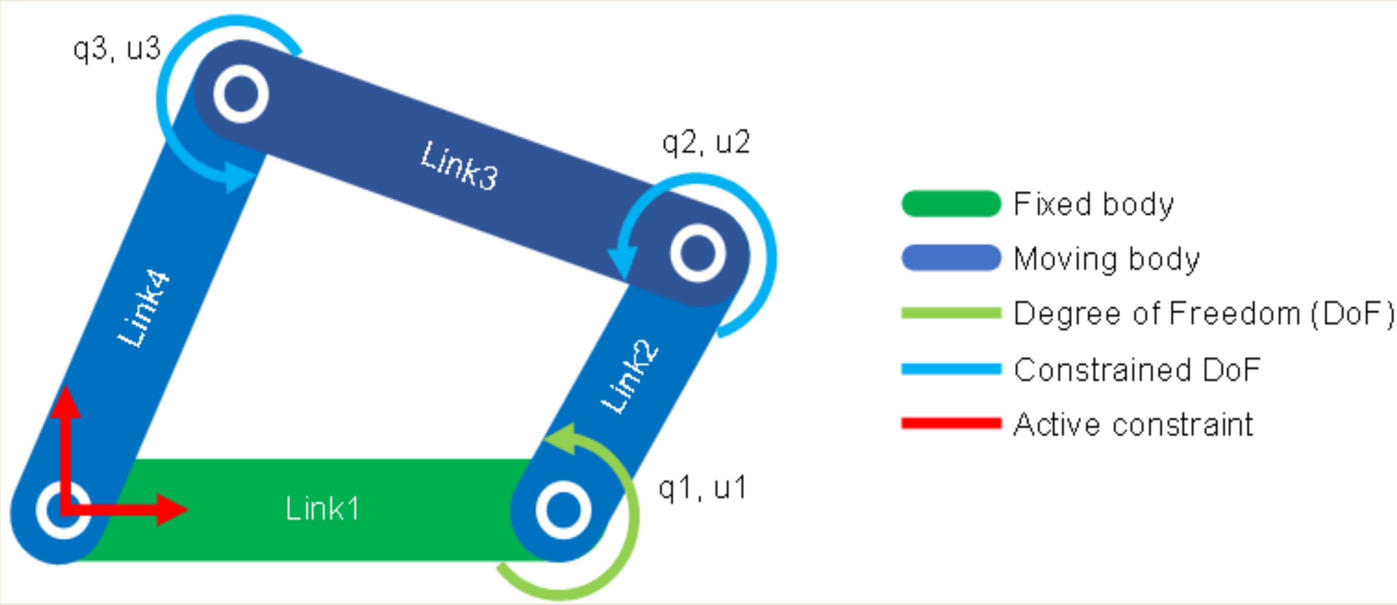
7236 Recharged Green

- Used to drive a linear extension
- Allows compact method of converting the rotational motion into linear motion

FOUR BAR

This is the simplest closed-chain movable linkage. It consists of four bodies, called bars or links, connected in a loop by four joints.Those are configured so the links move in parallel planes.

This is not widely used in FTC due to the space requirements and it travels less than 90 degrees in each direction.

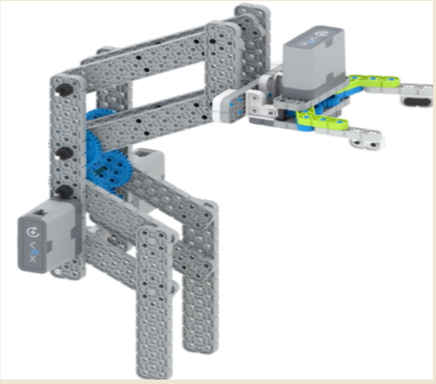


VIRTUAL FOUR BAR

A virtual four bar uses chains/belts to create an effect similar to a four bar, where the end link/bar is kept at a fixed angle to the ground.

This is more used in FTC and it travels more than 180 degrees, takes up less space, no additional bars are needed.

DOUBLE-REVERSE FOUR BAR



It is an extension of the four bar linkage because at the end of the four bar is mounted another one. This requires large space, but is a compact method of making large amounts of linear extension.

When building and using this, you have to make sure that each side of the mechanism is driven equally because asymmetric lifting can cause issues.

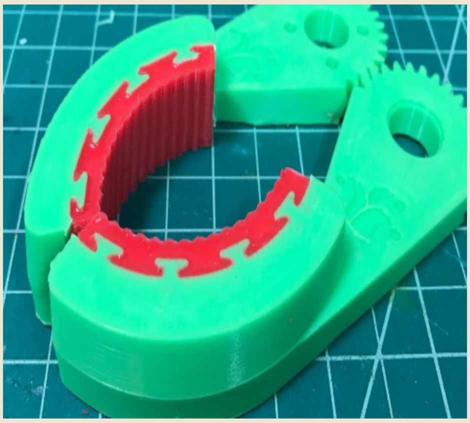
7. INTAKE TYPES

An intake is the name of a mechanism which collects elements. In FTC there are many types of intakes because the game elements are different each year.

Types of intakes:
- Claw
- Roller and Wheel Intake
- Tubing Intake

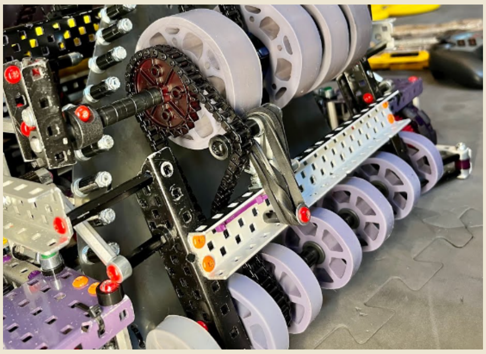
CLAW

The claw is the most common vertical intake. It can be used in various situations and you can not fail with it only if the game element is huge.



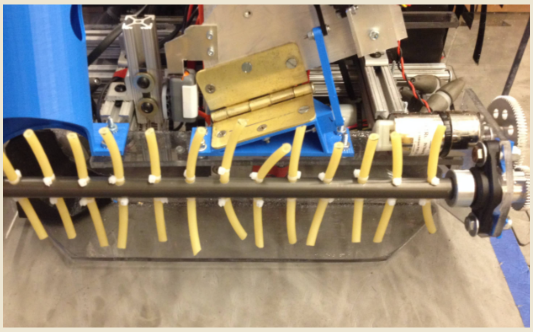
A claw is made of 2 arms with gears at the end. The arms come together on opposite sides of an object in order to gasp it. You can power your claw using 1 servo or 2. If you are using one, then the servo will be attached directly just to one of the gears of the claw. If you are using 2 then you can power both of the arms.

ROLLER AND WHEEL INTAKES



These intakes work by having a hard or pliable object rotate along an axis. For this it can be used different types of wheels (compliant, solid traction, foam wheels) in order to propel the game element to the storage or directly to your out take.

TUBING INTAKE



They usually use some sort of pliable tubing which is rotated very fast (high RPM) to intake game elements. Tubing intake is especially efficient when picking up small objects.

Advantages:
- Able to collect multiple elements
- More efficient than wheel intake
- Specialised in small and odd shaped objects

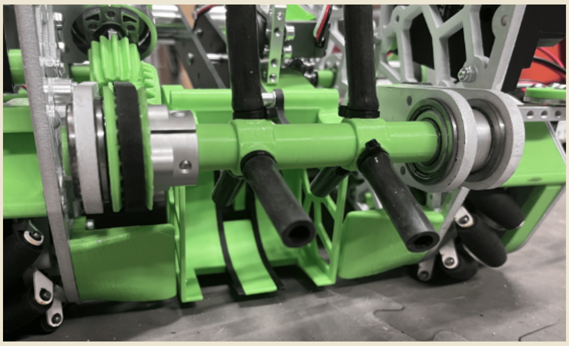
Disadvantages:
- Requires high RPM
- Less controllable
- Hard to pick up large elements

8. TRANSFERS

Transfer means moving or passing an object from one place. In FTC, it often refers to the mechanism between the intake and the outtake system.

Types of transfers:
- Direct Transfer
- Flip-Up Transfer
- Grate Transfer
- Conveyor Transfer

DIRECT TRANSFER



A direct transfer is the mechanism in which the items are moved to. It is placed behind whatever is picking up the game elements. It usually consists in an arm or a bucket to collect the items as soon as they enter the intake.

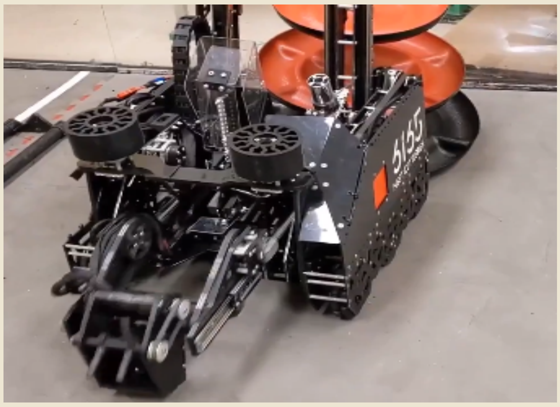
Advantages:
- Least mechanical complexity

- Does not take up much space
- Fast

Disadvantages:
- Does not move the element internally

FLIP UP TRANSFER

This is a form of transfer where the mechanism which is holding the game element is rotated around a pivot point to align to the other mechanism that collects. This is used to gain vertical height as well as some horizontal distance.



Advantages:
- Does not take up much space
- More flexibility (it allows the intake to stick outside the robot and start rotated up to fit inside the 18 inch size)

Disadvantages:
- Limited horizontal and vertical movement
- It need proper alignment
- Slow

GRATE TRANSFER

This transfer consists of 2 forks offset from each other which are used as both transfer and scoring mechanism. The forks can pass by each other without intersecting. This allows the game element to go from being supported by one set of forks to the other.

6929 Data Force

Advantages:
- It is not complex
- Fast
- Integrates well with linear mechanisms

Disadvantages:
- Complex design
- Careful alignment needed
- Limited in range of motion

CONVEYOR TRANSFER

A conveyor system is a mechanical handling equipment that moves materials from one location to another. It uses components to linearly move the game elements internally.

Conveyors can use rollers, belts, surgical tubing, rubber bands. They are usually either roller conveyors, where a series of rollers move the items, or continuous conveyors, where a continuous object moves the items. The hybrid ones combine those 2 types.

Advantages:

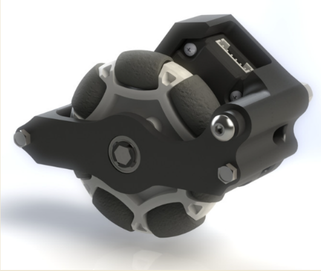
- Multiple game elements can be stored
- Moving across complex paths internally
- Continuously transferring

Disadvantages:

- Items can exit the conveyor
- Complexity

9. DEAD WHEELS

As you may already know, or should be aware, the first 30 seconds of every match represent the Autonomous Period during which your robot must move independently. The actions your robot will perform are programmed in the code, but it's essential to continuously track the precise position of your robot. To achieve this, you can utilise **encoders** on the DC motors that power your drivetrain, or for even greater precision on the field, you can employ **odometry** or **dead wheels**.



Dead wheels typically consist of 2 or 3 unpowered omni wheels mounted on a robot, with at least one of them oriented perpendicularly to the others. These wheels should be positioned along the circumference of a circle inscribed on the robot. To ensure optimal performance, dead wheels require a reliable **counterspring**, which can be created using a spring or surgical tubing. The use of countersprings makes odometry pods more precise than the encoders on your motors. For instance, if your robot becomes obstructed and you attempt to move forward, the motor's encoder may detect movement because the motor is trying to turn. However, dead wheels won't move unless your entire robot advances since they lack their own power source.

To implement this system, you will need 2 or 3 small omni wheels, 2 or 3 encoders**,** 2 or 3 3D-printed pods, and springs or surgical tubing for the countersprings. Once you have assembled these components, connect the encoder cables as needed.

10. TURRETS

In FTC, turrets are mechanisms that are able to do side-to-side rotation of another mechanism. This is useful for positioning an intake or scoring mechanism. For example you can mount your shooter on a turret for being able to score without moving the drivetrain.Turrets usually have a gear, sprocket, or pulley mounted used by the motors and servos to rotate.

Turrets are generally split in two categories: full turrets and mini turrets. The former are located at the base of the robot and move bigger mechanisms. They are usually powered by motors or multiple servos. The latter are usually located at the end of linear extensions or arms and only pivot an end effector, such as an outtake system. This type of turret is powered by one or two servos.

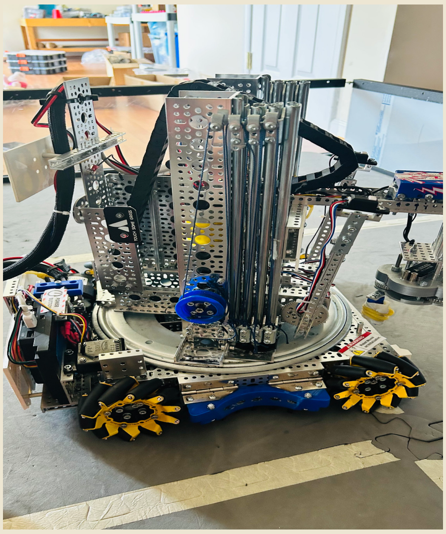
Type of turrets:

- Lazy Susan Turrets
- Bearing Stuck Turret
- Center-Bearing Turret
- Mini Turrets

These mechanisms are commonly located at the base of a robot and rotate slide, arm, or shooter assemblies mounted to them.

LAZY SUSAN TURRETS

Lazy susan turrets are based around a type of turntable called a lazy susan, which are available off the shelf.



Advantages:

- They come prebuilt
- Decent ones are relatively cheap

Disadvantages:

- They are prebuilt, meaning they're generally harder to customise than other options.
- Are not designed to handle lateral forces, for example the reaction force from a shooter could damage it

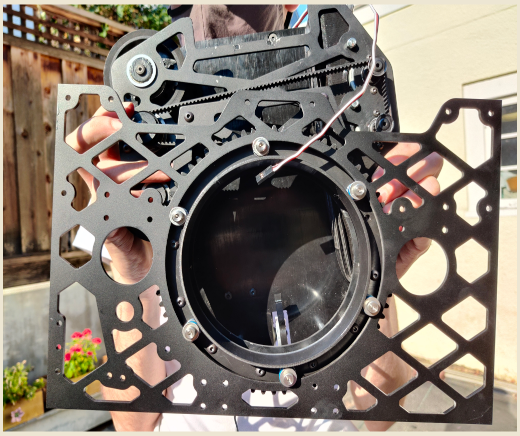
BEARING STUCK TURRET

These are stacks of bearings, usually there is a small bearing sandwiched between two large bearings on a screw shaft or standoff. A bearing stack turret has a disc tangent to the small bearing on many bearing stacks to rotate smoothly, while the bigger bearings constrain the disc vertically. Usually, the small bearing is a radial one, while the big ones may be thrust or radial.

As you can see in the photo below, there is a sample bearing stack, with a radial bearing sandwiched between 2 thrust bearings on a shoulder screw.

Advantages:
- Highly customizable

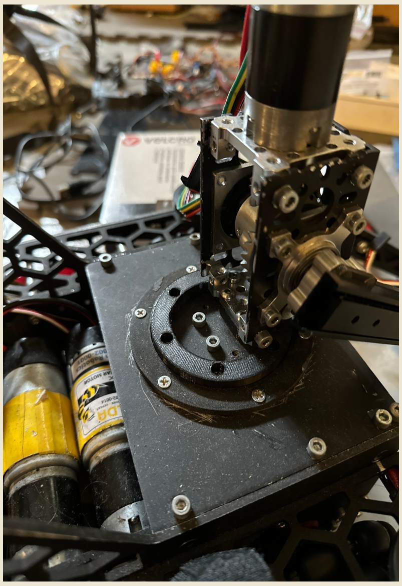
Disadvantages:
- Requires a lot of design work and precision manufacturing capabilities to build
- Many potential points of failure



18219 Primitive Data, Ultimate Goal, bearing stack turret

CENTER-BEARING TURRET

Center-bearing turrets are based on a bearing (or bearings) coaxial with the turret's axis of rotation.

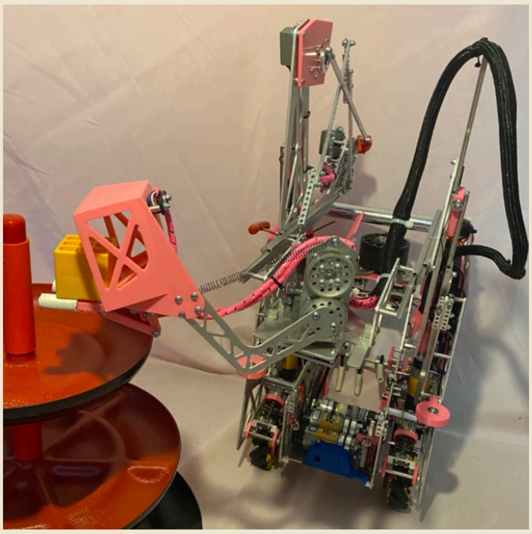


Advantages:
- Generally simpler than others, as they rotate similarly to any other mechanism on an axle
- Do not require complex or custom-manufactured components

Disadvantages:
- Significant problems because of thrust loads when using a radial bearing
- Hard to pass elements through the center due to a bearing being in the center, unless you buy large diameter bearings.

MINI TURRETS

Mini turrets pivot something small, typically an end effector, often at the end of a linear extension or arm. These are physically smaller and deal with smaller loads so are simpler than full turrets. Center-bearing technique is the most simple way to implement it.



Advantages:
- Accurate mechanism rotation, without drivetrain movement
- Much simpler than a full turret

Disadvantages
- Heavier
- More complex than no turret
- Provide fairly limited range compared to full turret

CHAPTER 5:
ORGANISE YOUR CABLES

Wiring is of paramount importance in FTC and can make the difference between winning or losing a match. More often than not, teams overlook the aspect of cable management and often deal with it in a very short amount of time before the competition is due to start. This is a bad practice and can lead to inconsistent and unreliable bots.

Here are some good practises when it comes to organising your cables:

1) When you have multiple cables in the same place, try to label them, else you may lose track of what cable should go in what port.

2) A wire connection means a possible point of failure. This means that for example where you connect a servo extension, tape up the connection with electrical tape, to make sure it doesn't come loose.

3) When plugging in motors or servos or any other hardware, pay attention to the port on the control/expansion hub.

4) Loose wires should be tied together using something like a ziptie and you should try to tie them down to a structural part, such as a u-channel.

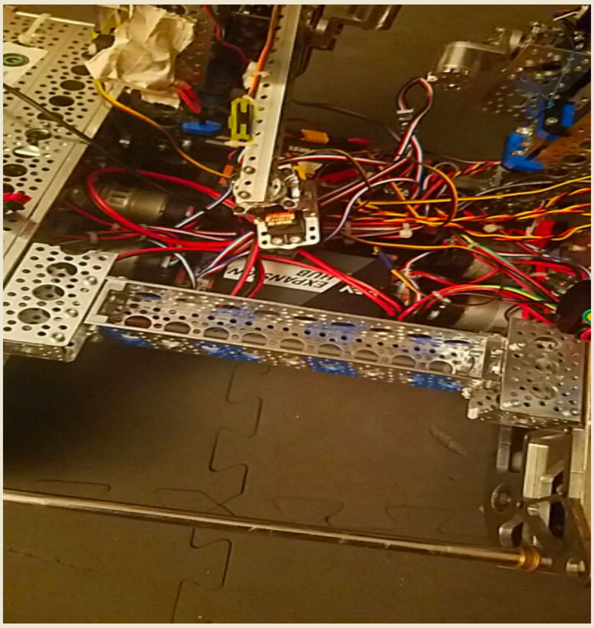
5) All wires should be as short as they can comfortaby be, meaning that you should try to keep wires as short as possible to avoid entanglement.

6) You should try to keep sensor or data cables away from motors to reduce magnetic interference.

7) Wires should be kept away from moving mechanisms to avoid getting them tangled inside the mechanism, preventing it from accomplishing its desired state.

8) Don't forget that cables and wires are fragile and you should treat them accordingly, do not abuse them and refrain from placing them in an area where they might constantly get hit.

9) Keep wires out of pinch points where a mechanism could squeeze them, this is especially important in hinged mechanisms, such as arms.



WRONG

RIGHT