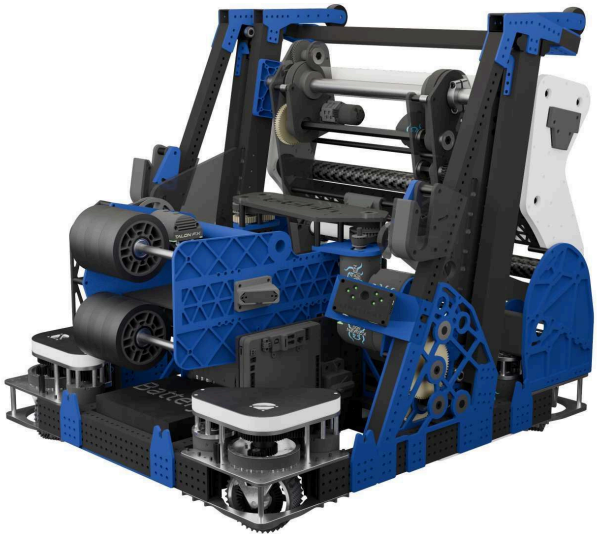


The Highlanders

#4499

2024

Technical Binder

Contents

ANALYSIS

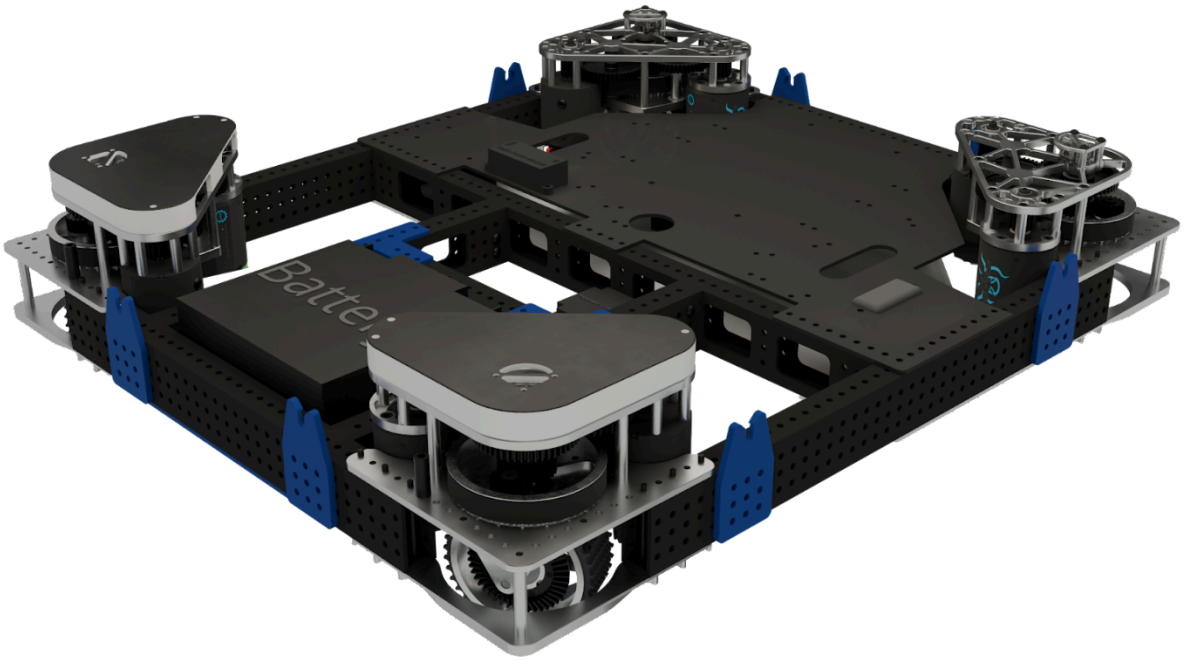
This year, our game focus was to be quick and accurate. To achieve our goals and be adaptable to any alliance, we needed to excel in all parts of the game such as shooting the note. Scoring in the amp and trap, as well as climb. It was crucial for us to be able to meet teams at any level to maximize points and utilize our alliance abilities to the fullest. Having a small robot was necessary because the chain takes up a significant portion of the field. Being a small robot enabled us to overcome this obstacle to increase cycle times. Being able to pick up notes efficiently was also beneficial in improving our cycle time and gaining control of the note with other robots around.

Priorities

1. Omnidirectional fast drive train
2. Be able to pick and shoot as quick as possible
3. Do well in all four aspects of the game
4. At least 4 piece auto
5. Balance on chain
6. Climb and score on the trap
7. Auto align and shoot into the speaker
8.

ROBOT DESIGN

Drive Train



This years drive base is optimized for fast cycles and the ability to fit 2 robots on the chain during endgame.

Being similar to last years chassis, the team was able to devote more time on other subsystems.

Chassis

- Built with 2"x1"x1/8" with standardized hole pattern for easy subsystem mounting
- 25"x29" frame
- 3 crossbeams for better structural integrity and to hold battery

Swerve

- Driven with 4 MK4i-L2.5 modules for maneuverability around the field
- Top speed of 19ft/s

Bumpers

- Obtaining robot frame dimensions in Cad.
- Chopping wood to fit the frame using a chop saw.
- Drilling holes in wood for attachment to frame.

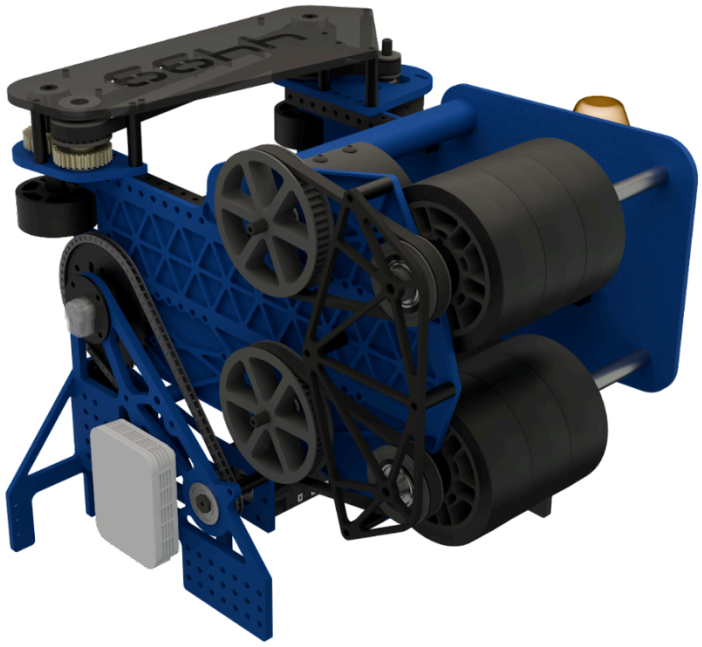
- Using screws and tape pool noodles onto the bumper frame.
- Cutting team numbers and heat pressing onto cordura fabric.
- Stapled cordura fabric onto bumper frame.
- Attaching a bumper to the robot using screws and wingnuts.

Intake

We created an over the bumper intake and rigorously spent a long time perfecting its geometry in CAD so that the intake would fit in frame without taking too much space away from other mechanisms.

- Intake has 145-degree motion from down to up state
- Driven by 25H chain, with the gear reduction on the pivot being 30:1
- Rollers are carbon fiber tubes with silicone tubing around it
- Rollers are driven by a 24:11 reduction
- Pivots on a dead axle with a live axle around the dead axle to ensure smooth note motion
    - Intake plates are made of 2 sandwiched ¼ in UHMW plates
- Intake plates have wires run through them for protection
- Carbon fiber tubes have pulleys epoxied into them
    - Pulleys have nuts inserted into them halfway through printing to secure them to the plate
- Intake plates are held by nut strips on the swerve modules to keep it flush with the side

SHOOTER



Pivot Ratio 75:1 on Falcon 500 and max planetary(0-60 degrees rotation) 25H chain to rotate Flywheel is a dead axle design. Split wheels to add spin on note 30/56 gear up run by 2 krakens Horizontal feeder mechanism running on 3:1 ratio powered by one kraken to index note into shooter.

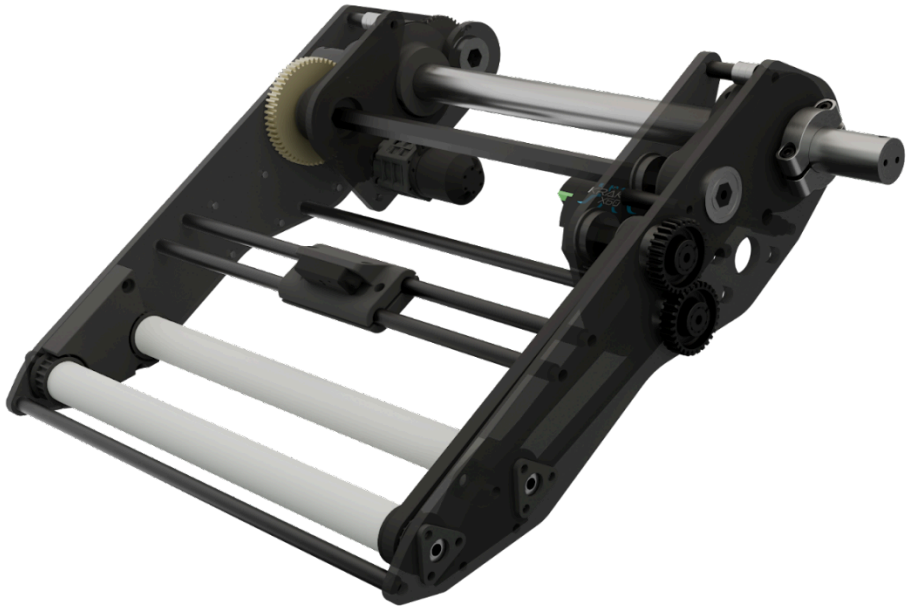
- Many different iterations had led to the final design.
- CAD design sketch created for maximum results.
- CAD issues identified and resolved.
- Then the G-code course shifted to the real world process.
- Pivot between 0-60 degrees.
- Ability to shoot from the opponent's wing line.

ELEVATOR

The elevator is a single stage mechanism used to climb up on the chain and subsequently raise the arm to score the trap.

- Passing point between intake and shooter
- ~23.5 reduction gearbox driving 1.25in spools from 2 Krakens
- Slanted 10 degrees from the base of the robot
- 16.5in extension length
- Spring hooks incorporated to lock onto chain while hanging
- 2 x 1 x 1/16 upright supported by crossbars
- Rope rigging rated for 300 lbs working load (per side)
- Limelights attached to be slanted at 25 degrees upward and 58 degrees outward

AMP/TRAP MECH



Lightweight pivoting used as a pass-off between the intake and shooter. It can be used to place in the amp and trap.

- Applied mechanism to score on amp and trap.
- Developed iteration for achieving feat.
- Ensured the robot's space was adequate.
- Mounted on elevators
- 100:1 gear reduction from neo 550 on 1in round dead axle pivot
- Pass off between intake and shooter
- 3:1 reduction from kraken to power rollers
- Vertically mounted TOF (Time of Flight) sensor to accurately determine the position of the note
- 1in od Silicon on 20mm carbon fiber rollers w/ 3d printed inserts on both sides.

PROGRAMMING

Overview

- Drivetrain - Using a field-centric swerve drive that uses wheel positions, a gyroscope, and vision for odometry.
- Localization - Able to enhance robot control and field positioning using limelight 3's. Ability to automatically line up and range the shooter wherever we are on the field using the distance to the speaker. Untagged April tags in camera view allow for automatically knowing where we are on the field. Localization also helps with autonomous pathing and optimizations to make sure the robot is in the right spot.
- Pre-programmed sequences to automatically set up mechanisms for specific actions.
- Note detection - Note picking in camera frame gives the robot an easy way to pick up notes. The robot can follow notes which allows for the ability to pick up notes that are moved in autonomous.
- Smart Dashboard - PI Indicators in match management shows disconnected motors. It can identify on/off quick connections and potential problems before the match starts.
- Vision - Limelight 3's with a neural network are used to detect notes and robots. Helps prevent collisions with other robots and find where notes are. This allows it to track April tags for localization. Lastly, the robot can find the distance to the speaker to range the shooter.

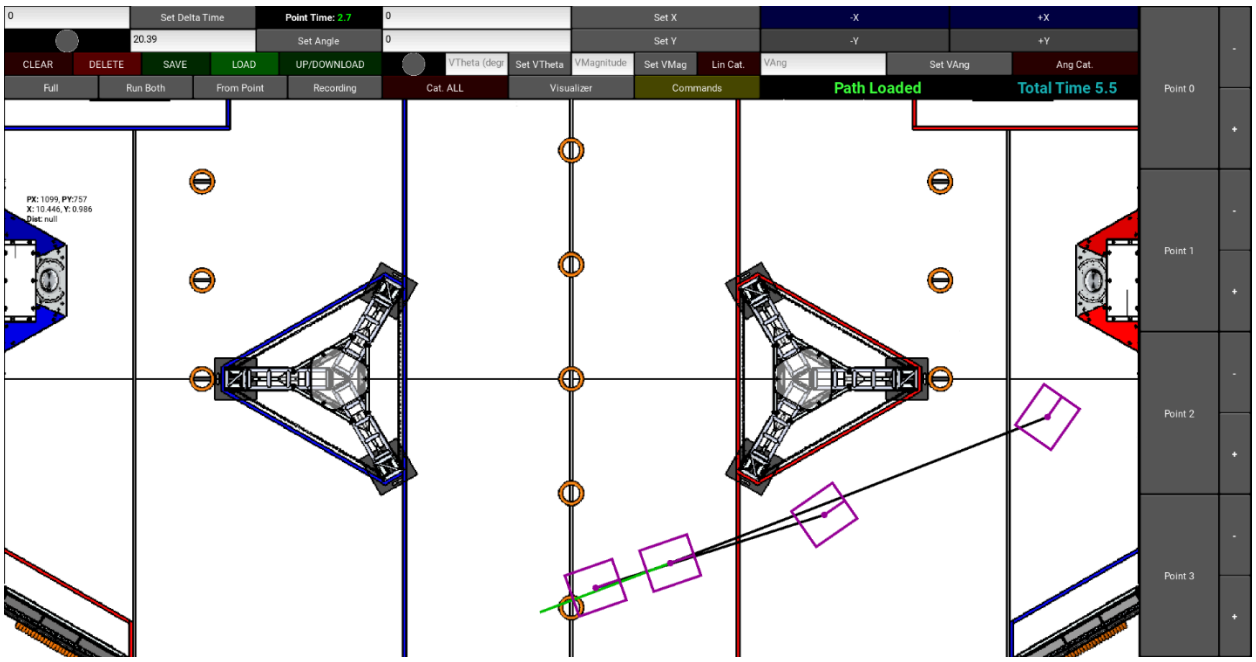
Autonomous

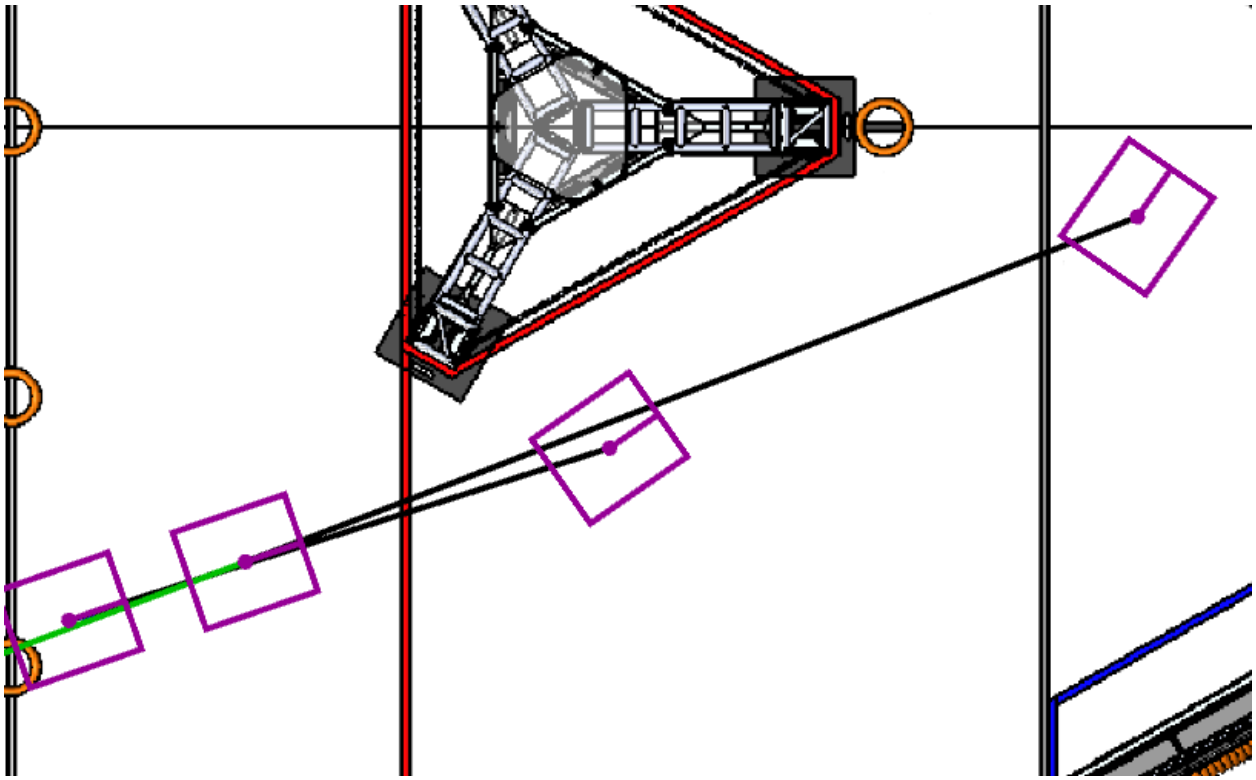
Our autonomous plan is as follows: during the autonomous period, we aim to score as many notes as we can into the speaker for as many points as possible.

Autos:

- 5 piece that scores the 3 spike marks and 1 from the center line.
- 3 piece that scores 2 from the center line.

PATHING TOOL





Set Up

Install Python 3.10.2

Clone the “2023-Pathtool” repository on HighlandersFRC GitHub

Navigate inside of the 2023-Pathtool folder

In a command line, navigate to the desired parent folder and run “pip install -r requirements.txt”

To launch the application run “python main.py”

Design Requirements and Solutions

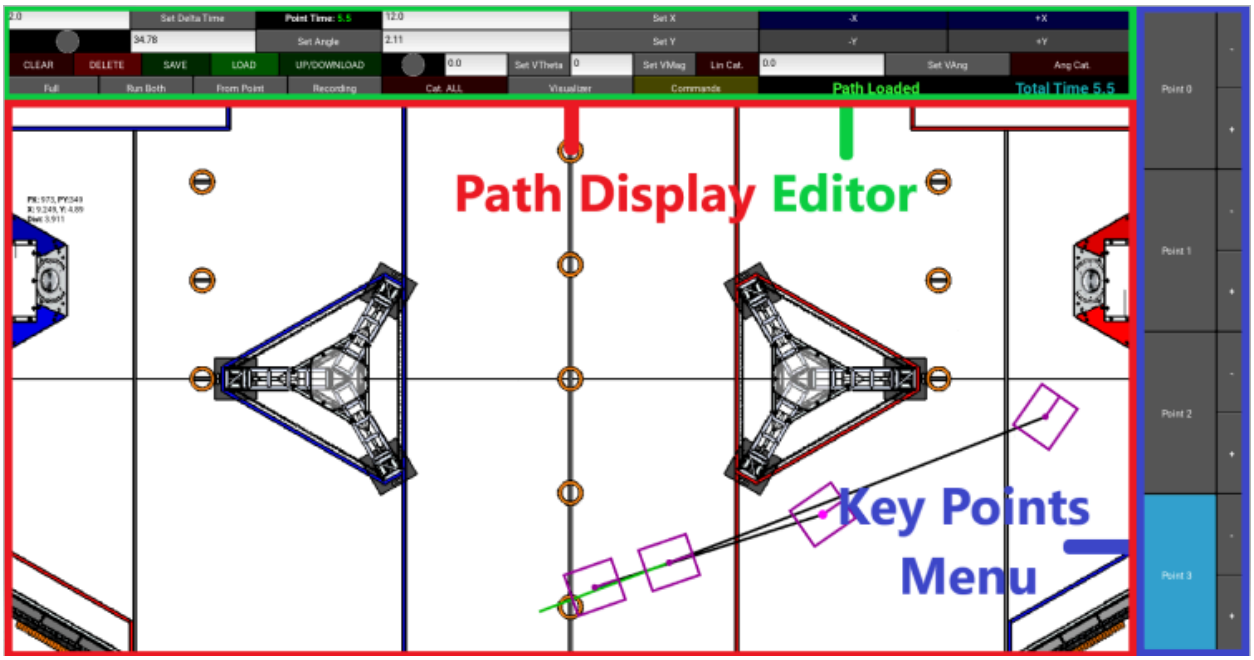
Before we started work on creating the new pathing tool, we set a couple of requirements that the tool must meet:

- Be user friendly (intuitive controls/displays)
- Generate path equations with control over linear and angular position, velocity, and acceleration at each key point in the path
- Upload and download these paths to the RoboRio onboard the robot
- Display useful feedback information to guide the creation of paths
- Be flexible as an application in order to make adjustments/expansions of the path tool easier

To meet these requirements we implemented the following solutions:

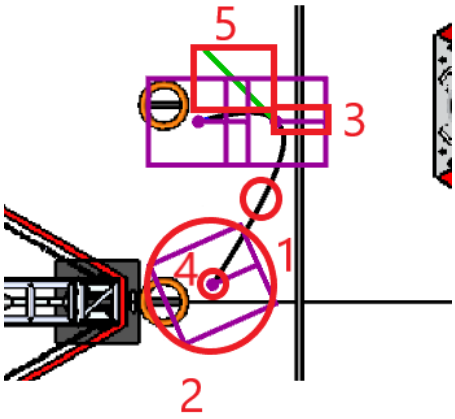
- Get feedback from using the path tool
- Use quintic Catmull-Rom hermite splines to generate path equations
- Use paramiko, a python ssh library, to handle file transfer
- Implement feedback tools such as path animations, graphs and animations of recorded odometry data, coloring the path to highlight when the path exceeds physical capabilities (linear acceleration, linear velocity) of the robot, and others
- Use kivy, an open source Python GUI framework, to create a modular interface for the path tool

Labeled Diagrams and Descriptions



Section	Function
Path Display	Displays the current path, allow creation of new key points, display animations and recorded odometry.
Editor	Edits parameters of individual key points, displays information (action status, total time) and provides access to popup menus for file handling and the visualizer.
Key Points Menu	Allows for easy selection of key points, and allows key points to be switched in index.

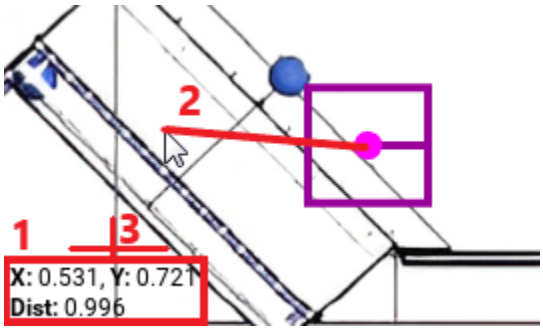
Path Display



1 - Path Line	Curve that shows what path the robot should follow. Sections colored red indicate a linear velocity higher than the set physical limit. Sections colored blue indicate linear acceleration higher than the set physical limit. Sections colored magenta indicate both of the above. Sections colored black indicate neither.
2 - Robot Indicator	Shows where the edges of the robot should be at that key point.
3 - Robot Angle Indicator	Shows at what angle the robot should be facing at that key point.
4 - Selected Point Indicator	Indicates that that key point is currently selected.
5 - Linear Velocity Indicator	Indicates the magnitude and direction of the robot's linear velocity at that key

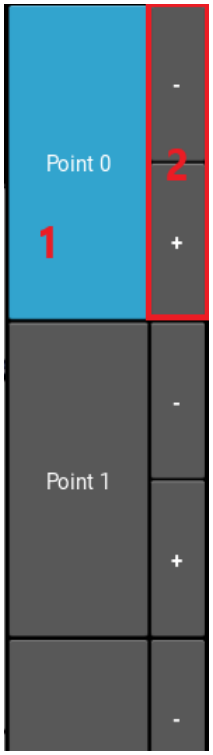
	point.

Cursor Position and Measuring



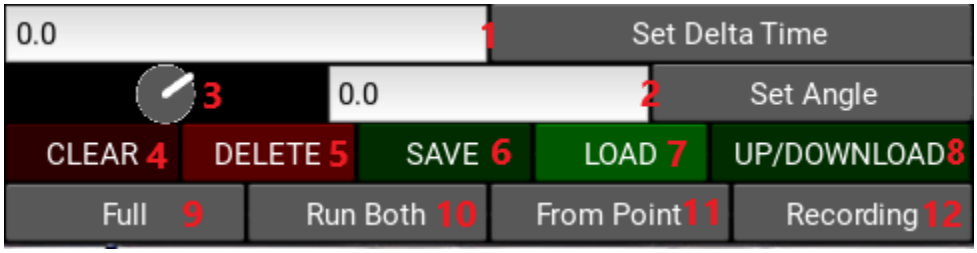
1 - Position and Measurement Text	Displays the position of the cursor (x, y) in meters as well as the distance from the cursor to the selected key point, in meters.
2 - Distance being measured	This is not shown in the actual tool, but the line drawn in the diagram indicates what distance is being measured
3 - Origin point	This is the point at (0, 0). The tool uses a right-handed coordinate system with x as the horizontal axis and y as the vertical axis, which means that x increases as points move from left to right, and y increases as points move upward.

Key Points Menu



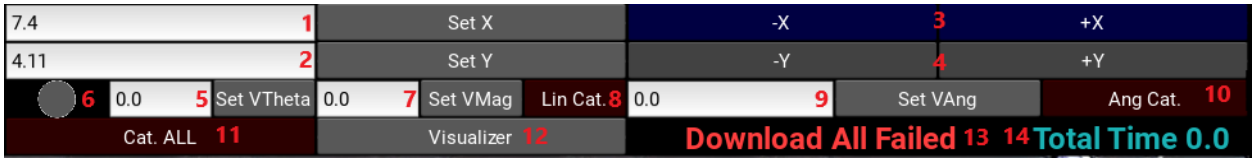
1 - Select Point Button	Selects the key point of the same index, useful for selecting key points that are very close to each other.
2 - Reindex Point Button	Switches the selected key point with the point before or after it, controlled with the buttons labeled “+” and “-”. This is useful for inserting key points into the middle of a path.

Editor



1 - Delta Time Input	Type in and press the button to set delta time. Delta time is the time in seconds since the previous key point.	**7 - Load Button**	Opens the file manager popup to load a saved path.
2 - Angle Input	Type in and press the button to set the angle. This is the angle in degrees of the selected key point.	**8 - Upload / Download Button**	Opens the file manager popup to upload the current path, upload all saved paths including the current one, or download all paths on the RoboRIO.
3 - Angle Dial	Press and drag the dial manually to set the angle of the selected point.	**9 - Full Animation Button**	Runs the entire animation of the current path.
4 - Clear Button	Deletes all key points.	**10 - Parallel Animations Button**	Runs the recording animation in parallel with the animation of the current path. A recording must be displayed on the field in order to do this.

5 - Delete Button	Deleted the selected key point.	**11 - Animation From Point Button**	Runs the animation of the current path starting at the selected key point. A key point must be selected in order to do this.
6 - Save Button	Opens the file manager popup to save the current path.	**12 - Recording Animation Button**	Runs the animation of the recording currently displayed on the field. A recording must be displayed on the field in order to do this.

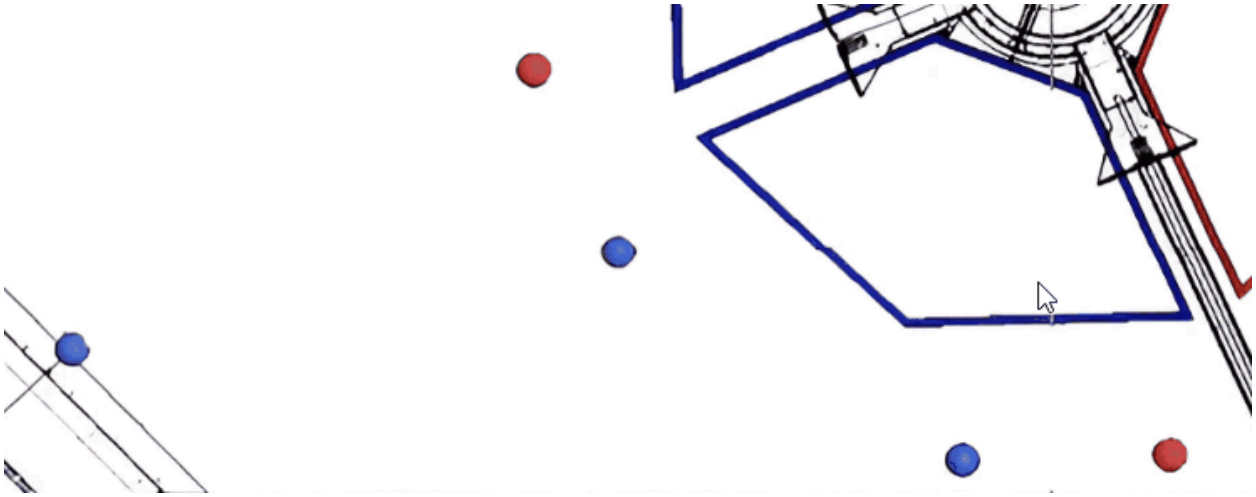


1 - X Input	Type in and press the button to set the x coordinate of the selected key point in meters.	**8 - Linear Velocity Catmull-Rom Button**	Convert the linear velocity equations of the path into Catmull-Rom splines.
2 - X Adjust	Pressing the **-X** button subtracts 0.025 meters from the selected key point's x coordinate, and pressing **+X** adds 0.025 meters.	**9 - Angular Velocity Input**	Type in and press the button to set the angular velocity of the selected key point.
3 - Y Input	Type in and press the button to set the y coordinate of the selected key point in meters.	**10 - Angular Velocity Catmull-Rom Button**	Convert the angular velocity equations of the path into Catmull-Rom splines.
4 - Y Adjust	Pressing the **-Y** button subtracts 0.025 meters from the selected key point's y coordinate, and pressing **+Y** adds 0.025 meters.	**11 - Catmull-Rom All Button**	Convert all linear and angular equations of the path into Catmull-Rom splines.

5 - Velocity Theta Input	Type in and press the button to set the velocity theta of the selected key point. The velocity theta is the angle at which the robot will be moving at the selected key point.	**12 - Visualizer Button**	Opens the visualizer popup menu.
6 - Velocity Theta Dial	Press and drag to manually set the velocity theta.	**13 - Status Label**	Displays the status of the last major path operation. This includes information about uploading, downloading, saving, loading, displaying recording on field, updating recordings, clearing recordings, and clearing RoboRIO recordings.
7 - Velocity Magnitude Input	Type in and press the button to set the velocity magnitude of the selected key point. The velocity magnitude is the linear velocity that the robot will have at the selected point.	**14 - Total Path Time Label**	Displays the total time duration of the path in seconds.

The 2023 Path Tool is capable of creating, refining, debugging, and transferring autonomous path files. Here is a guide that will explain how best to take advantage of the features it has to offer, shown with an example path.

Create a path

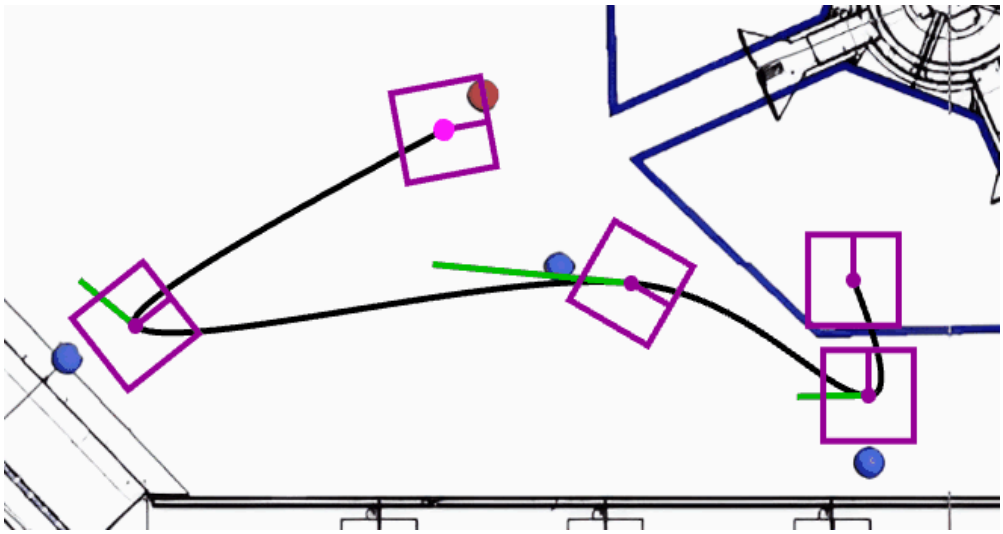


Left-click on the picture of the game field to create new key points. These key points are what define any given path.

Edit key points

Use controls in the editor and key point menu to select each key point and edit its parameters to your liking. In the example above, each point is rotated, the timings are adjusted, and the whole path is optimized with the Catmull-Rom button.

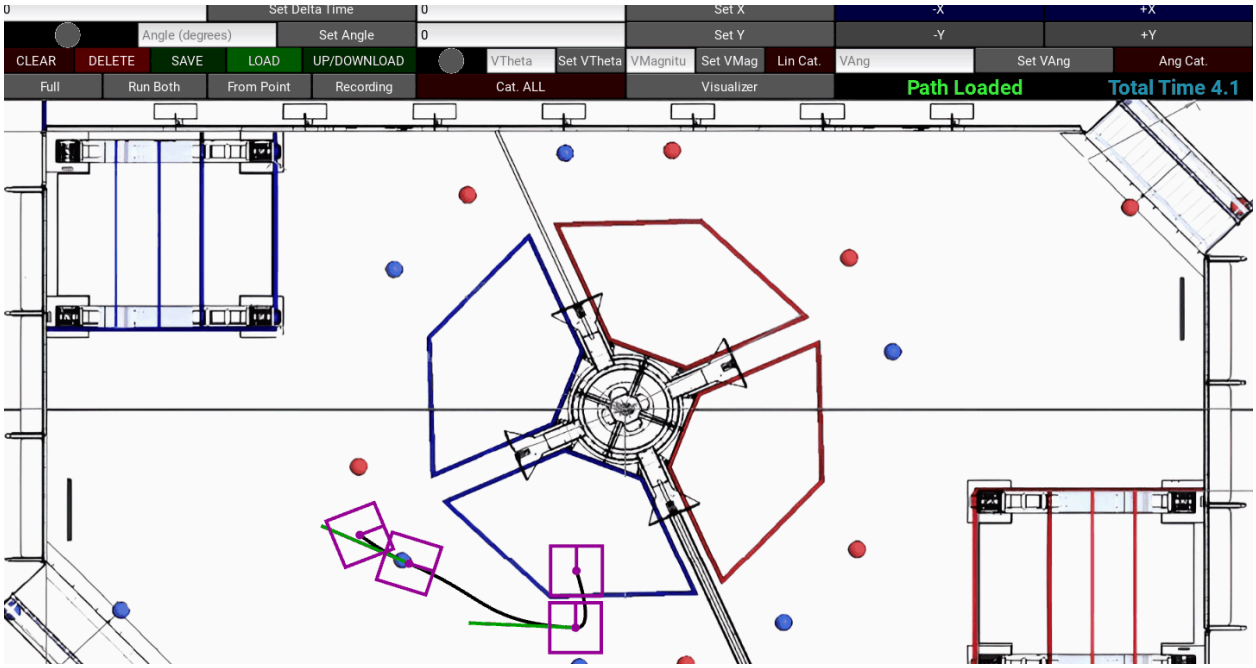
Make sure it looks right



Full

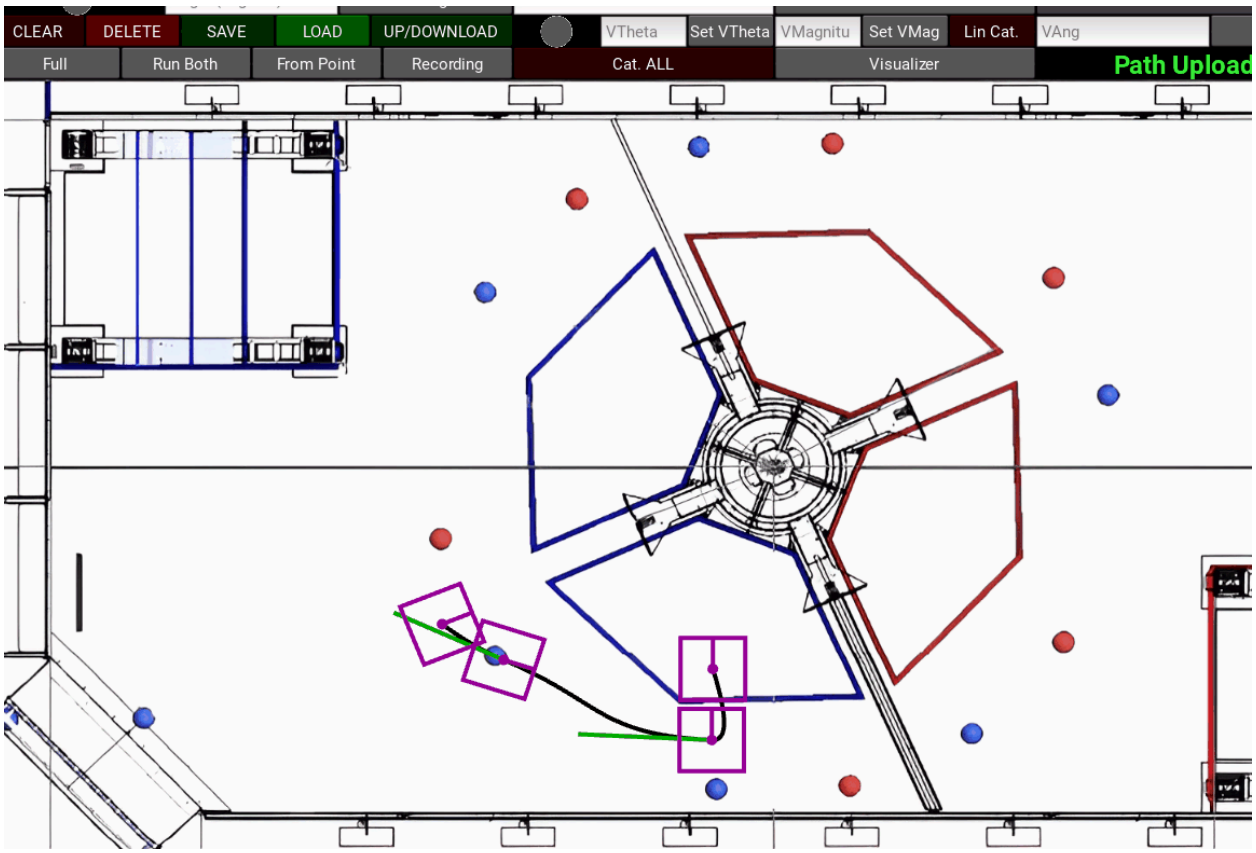
Run the full animation to double check that the path should run how you want it to.

Upload to RoboRio



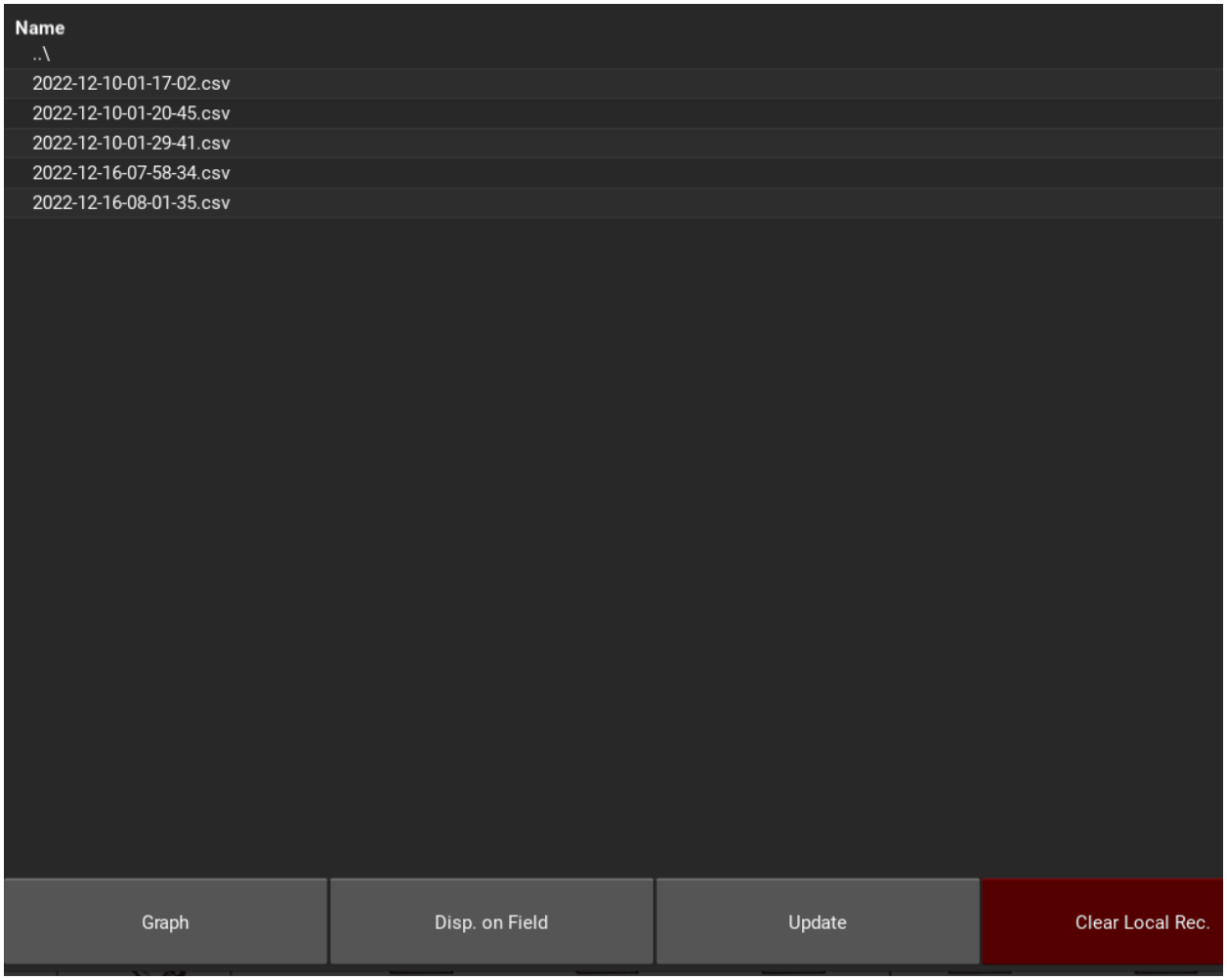
Click the Upload/Download button and upload the path to the RoboRio (must be connected to the robot).

Download recorded odometry

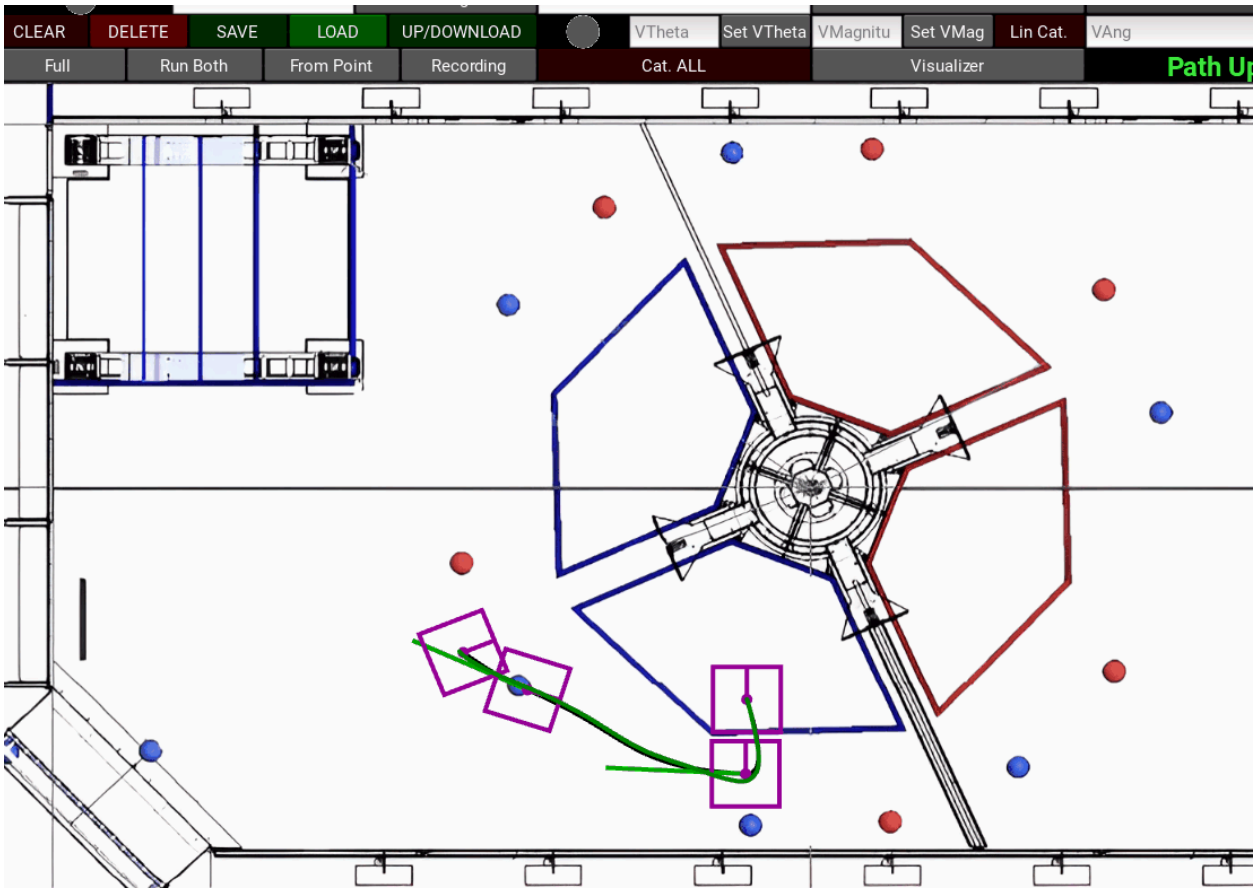


Click the Visualizer button, then click the Update button. This will download all odometry recordings from the RoboRio (must be connected to the robot).

Compare odometry to path



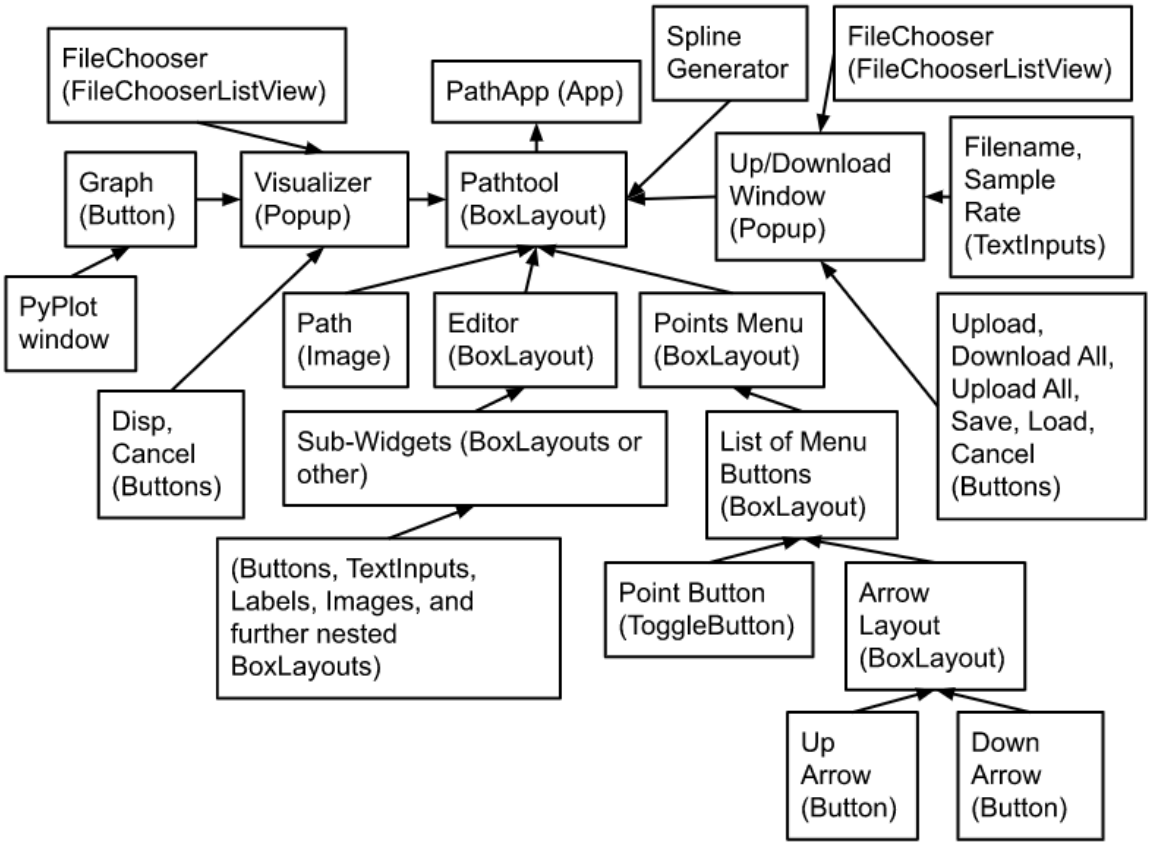
After selecting the desired odometry recording file (the recording files are named by the time the autonomous was run in the example, but they could be named anything after being generated in robot code), click the Display on Field button. This will draw the recorded odometry as a green path. With the recorded odometry and the path file loaded, click the Run Both button to run the animations of both at the same time. This is useful for visually comparing what the robot recorded that it did and what it was supposed to do. Keep in mind that the recorded odometry is not absolute truth; if the odometry accumulates error during the autonomous, the recorded odometry may look like it followed a different path than what the robot actually did.



Click the Visualizer button, then click the Graph button. A graph of the recorded x, y, and theta odometry will pop up. If a path file is loaded (as shown in the example above) , partially transparent lines representing the ideal x, y, and theta will be graphed as well. This is useful for identifying drift in the path, and other debugging such as tuning PIDs.

Code Structure

The code for the 2023 Path Tool is written in Python 3.10.2 and uses Kivy 2.1.0 for the GUI framework. Kivy implements a system of widget for constructing GUIs, which provides flexibility and modularity.



This diagram shows the tree of ownership that organizes the different parts of the path tool. The PathApp stores an instance of the Pathtool, which in turn stores instances of the Path, Editor, and Points Menu widgets, which contain nested sub-widgets. For sub-widgets contained in the Editor to control aspects of the Path widget, call-back commands are passed from the Pathtool down to the sub-widget. The sub-widgets can then call that call-back and the Pathtool will update the appropriate widget.

There are also two static method files, Convert and File Manager, that perform extra functions for classes that import them. Convert contains methods for conversion between meters and pixels on the image of the field, calculates distances, and more. The File Manager is used to

read, write, and transfer files between the RoboRIO and the local system, as well as parsing save files and recording files into usable forms.

Path Generation

The 2023 Path Tool uses quintic Hermite splines to interpolate between key points in a path. This has the benefit of smooth, continuous motion which reduces robot error when following the path.

Position Equations

There are 3 separate piecewise position equations, which are for x, y, and theta respectively.

Velocity and Acceleration Equations

The first and second derivative equations of the position equations, which represent velocity and acceleration as a function of time, are calculated to provide feedback on the path. This feedback is useful for optimization such as reducing peak accelerations and velocities. The line representing the path is also colored to show where the path is exceeding the kinematic limitations (maximum velocity and acceleration) of the robot. However, the maximum velocity and acceleration of the robot is not separated between x and y components. It is instead an absolute magnitude that is independent of direction.

To generate an equation that gives linear velocity and acceleration as a function of time we must take the first and second derivatives of the distance equation:

$$D(t) = \sqrt{x(t)^2 + y(t)^2}$$

$$V(t) = \frac{d}{dt}[D(t)] = \frac{x(t)x'(t)+y(t)y'(t)}{\sqrt{x(t)^2+y(t)^2}}$$

$$A(t) = \frac{d}{dt}[V(t)] = \frac{x(t)^3x''(t)+x(t)^2y'(t)^2+x(t)^2y(t)y''(t)-2x(t)y(t)x'(t)y'(t)y(t)^2x(t)x''(t)+y(t)^2x'(t)^2+y(t)^3y''(t)}{(x(t)^2+y(t)^2)\sqrt{x(t)^2+y(t)^2}}$$

Rather than calculating these monstrous derivatives for each section of the piecewise equations by substituting in the original x and y equations along with their first and second derivatives, each of the original equations is evaluated at the given time and then substituted in.

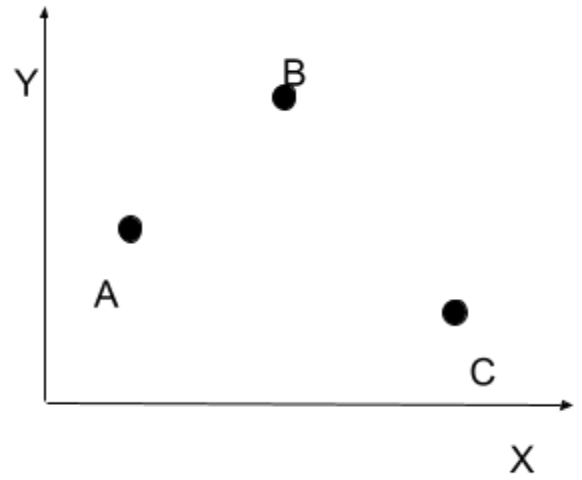
```
x = float(np.polyval(xEquation, time))
```

```
y = float(np.polyval(yEquation, time))

vx = float(np.polyval(xVelEquation, time))

vy = float(np.polyval(yVelEquation, time))

ax = float(np.polyval(xAccelEquation, time))

ay = float(np.polyval(yAccelEquation, time))

return (x ** 3 * ax + x ** 2 * vy ** 2 + x ** 2 * y * ay + y ** 2 * x * ax - 2 * x * y * vx * vy + y ** 2
* vx ** 2 + y ** 3 * ay) / ((x ** 2 + y ** 2) * math.sqrt(x ** 2 + y ** 2))
```

Sampling these linear velocity and acceleration equations by time will give the magnitude of linear velocity and linear acceleration respectively.

Catmull-Rom Splines

The linear and/or angular components of a path can optionally be converted into Catmull-Rom splines, which helps to smooth out corners by optimizing the velocities of key points interior to the path (key points that are not the first or last point). The math to calculate these velocities is fairly simple, just set the velocity of the key point equal to the average velocity based on the key points before and after it.



In the example above, the x-velocity at key point B could be determined with the following equation:

$$x'_B = \frac{x_C - x_A}{t_C - t_A}$$

Angle Optimization

Since quintic Hermite splines interpolation angles between key points as a continuous quantity, the direction of robot rotation between key points is often not optimal because the 180/-180 degree flipping point is not taken into account. To fix this, the angles of the key points are optimized sequentially by determining which direction requires the least amount of rotation to reach the next angle. If rotation in the positive direction is optimal, the angle of the next key point will be an increase from the current angle, and if negative rotation is optimal, the next

angle will decrease. This ensures that the generated path equations will not cause the robot to rotate more than 180 degrees between key points.

```
for i in range(1, len(self.key_points)):
        p1 = self.key_points[i - 1]
        p2 = self.key_points[i]
        p2.angle %= 2 * math.pi
        if p2.angle - p1.angle > math.pi:
            p2.angle -= 2 * math.pi
        elif p2.angle - p1.angle < -math.pi:
            p2.angle += 2 * math.pi
```

Path Save Files

Path files are saved both locally and remotely on the RoboRIO (under the /home/lvuser/deploy/ folder) in JSON files in the format shown below:

```
{
   "meta_data":{
      "path_name": str,
      "sample_rate": float
   },
   "key_points": [
      {
         "index": int,
         "time": float,
         "delta_time": float,
         "x": float,
         "y": float,
         "angle": float
         "velocity_magnitude": float,
         "velocity_theta": float
      },
      ...
   ],
   "sampled_points": [
      {
         "time": float,
         "x": float,
         "y": float,
         "angle": float
      },
      ...
   ]
}
```

There are 3 components of a save file: meta-data, key points, and sampled points.

The meta-data specifies the name of the path and the sample rate (in seconds) that interpolated points are sampled at.

The key points are only included to allow paths to be downloaded and reconstructed by the path tool.

The sampled points are interpolated points in a list for the robot code to follow (in our case with a PID on the drivetrain).

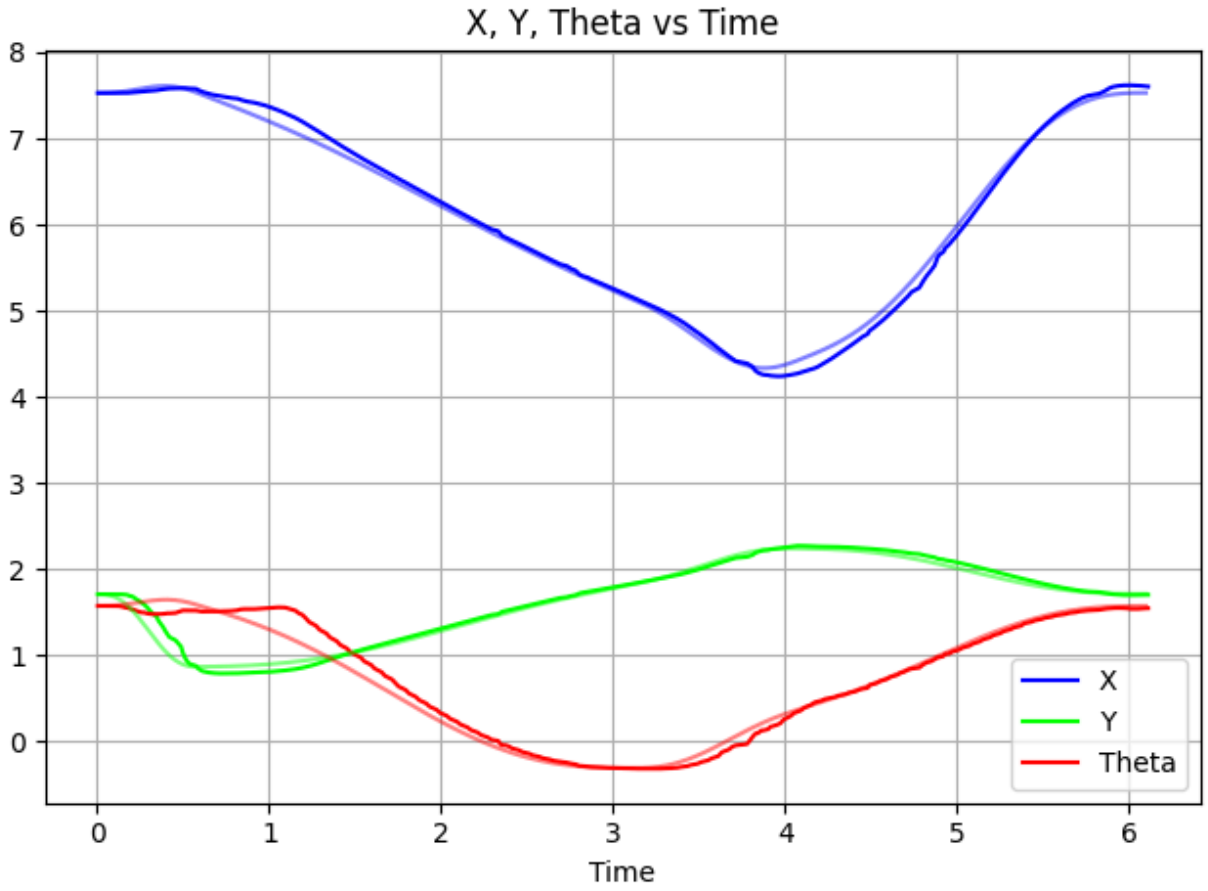
It is important to note that the permissions of the /home/lvuser/deploy/ directory must be changed to allow read and write privileges to all users. To do this, navigate to /home/lvuser/ and run chmod 777 lvuser/.

Recordings

The path tool also has the ability to download and parse CSV files containing recorded odometry information from the robot during an autonomous. Recording files are located under the /home/lvuser/deploy/recordings/ directory. The format for odometry recording files is shown below:

```
time (float), x (float), y (float), theta (float)
```

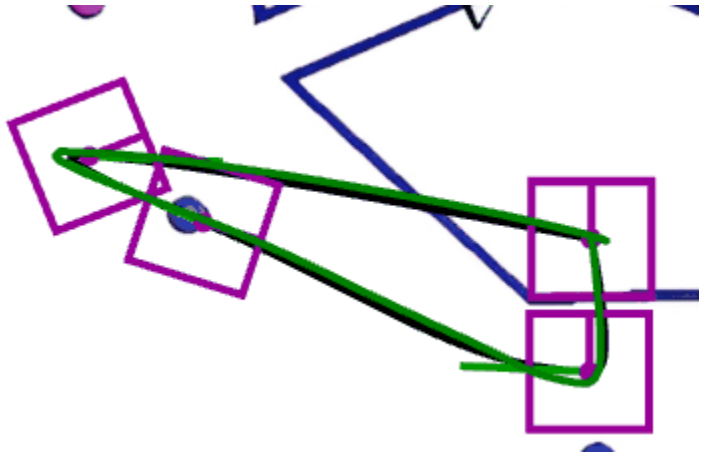
Odometry Graph



Upon selecting a recording file and pressing the graph button, a PyPlot window will pop up displaying a graph of the odometry x, y, and theta over time. The translucent lines are plots of the ideal x, y, and theta over time. These reference lines will only show up if a path is currently loaded in the path tool. Having these reference curves is very useful for tuning drivetrain PID values and identifying areas of the path prone to error.

Recording Animation

Recorded odometry can also be played back as an animation which is very nice for visualizing what the robot thinks it did during the autonomous. Both the animation of the ideal path and the recorded path animation can be played at the same time to help contrast.



The green robot marker represents the recorded odometry and the blue robot marker represents the ideal path.