

# Deployment and Optimization of a Multi-Robot System for Sample Transfer in an Automated Chemistry Laboratory

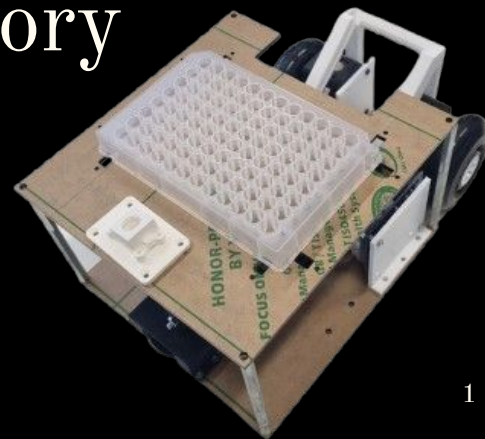
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# Objectives



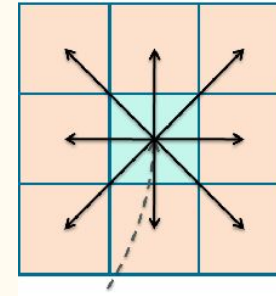
1. Simulating the system
2. Nav2 replacement
3. EdyMobile redesign



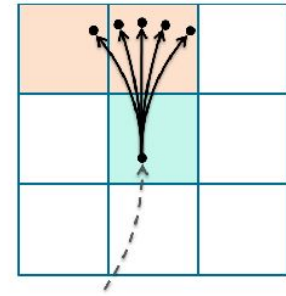
The setting: Swiss Cat+

# Nav2

- Decentralised path planner
- Behaviour tree
- Path tracker



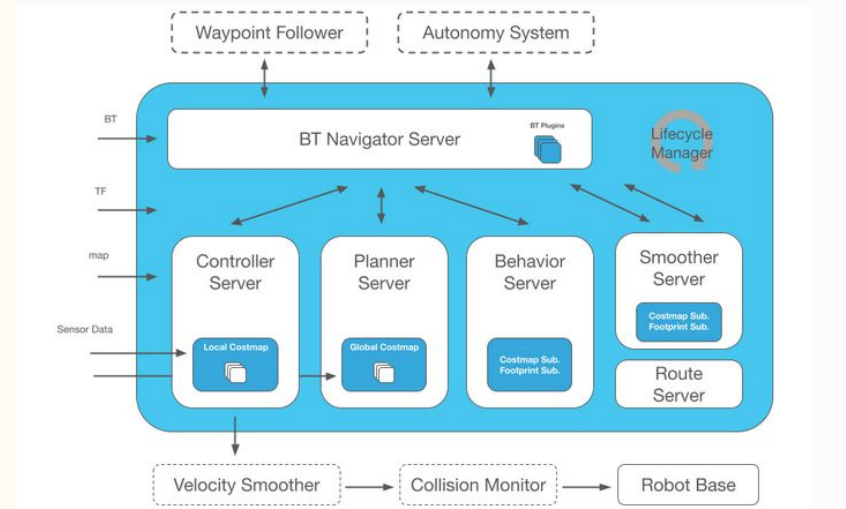
(a) regular A\*



(b) Hybrid A\*

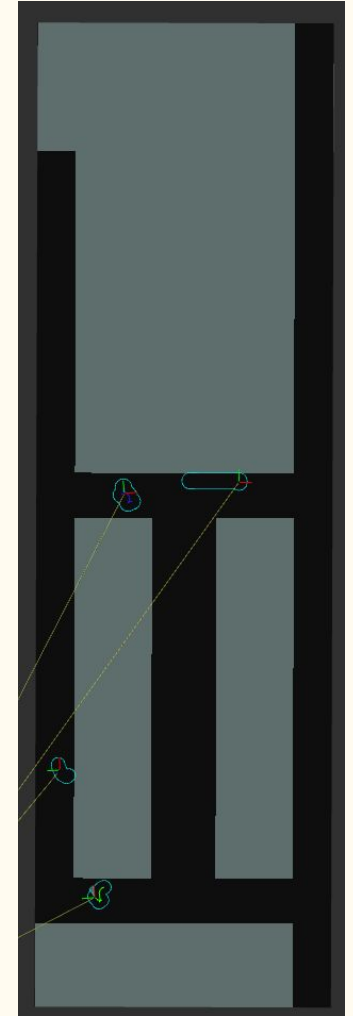
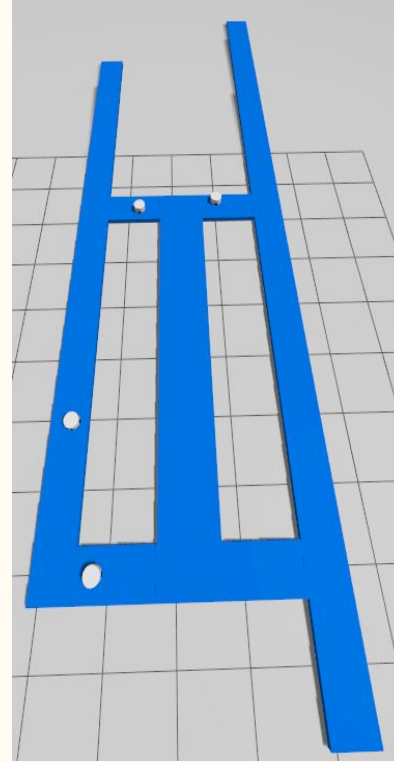
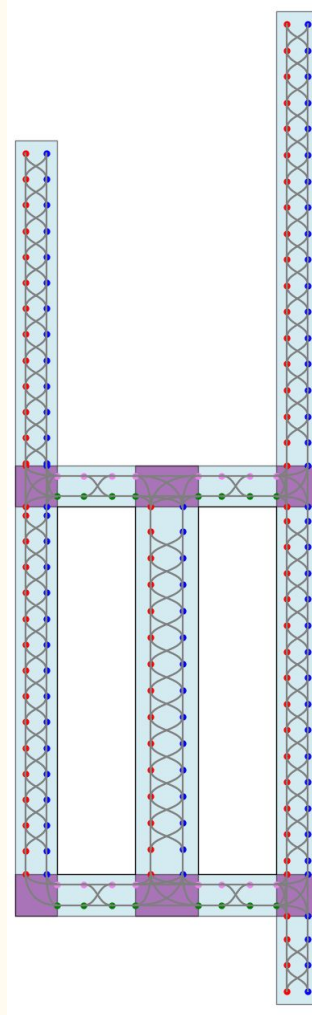
Petereit, Frey, Kopfstedt, Beutel 2012

- For dynamic, unstructured environments
  - Computationally intense
  - Unexpected behaviours
- Bloated
- Steep learning curve



# Simulation setup

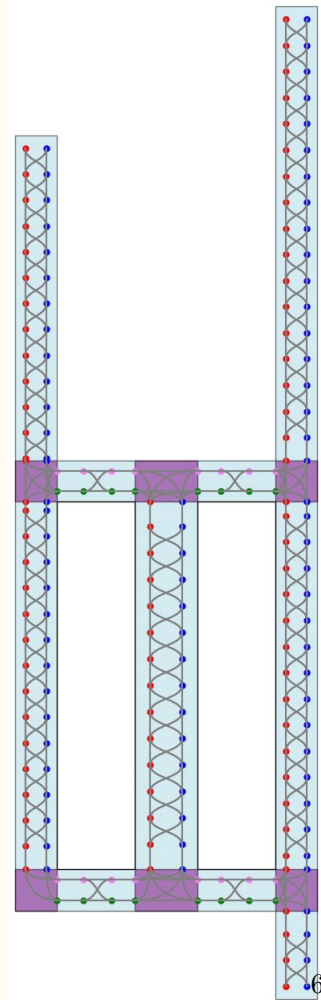
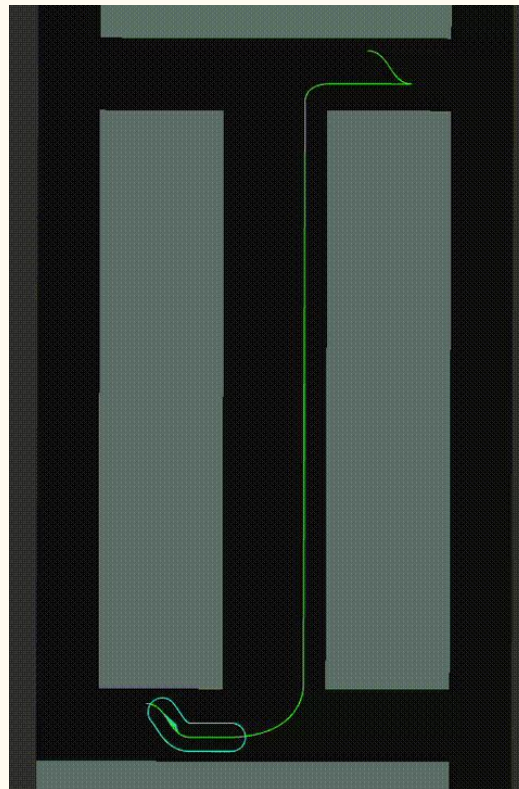
- Python visualisers
  - Path planning correctness
- Gazebo
  - Multi-agent behaviour
  - Path tracking
- Ros visualisation (Rviz)
  - Behaviour tree data





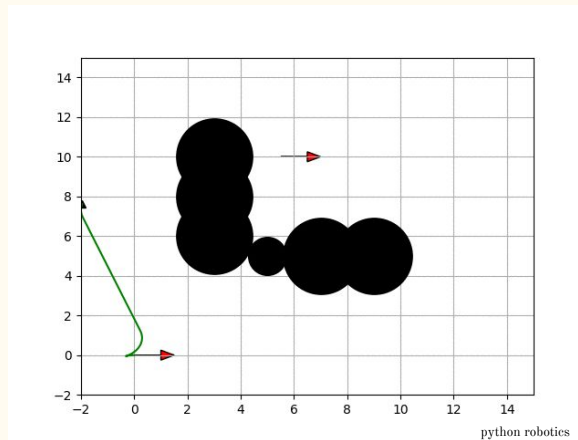
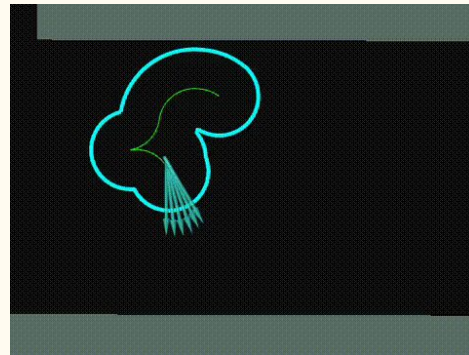
# Path Planning - RoadTrack

- Lane-based path planning
- Automatic generation based on road size
- Suitable for axis aligned roads
- Long distance path planning at lower computational complexity
- Uses A\* algorithm with L2 heuristic

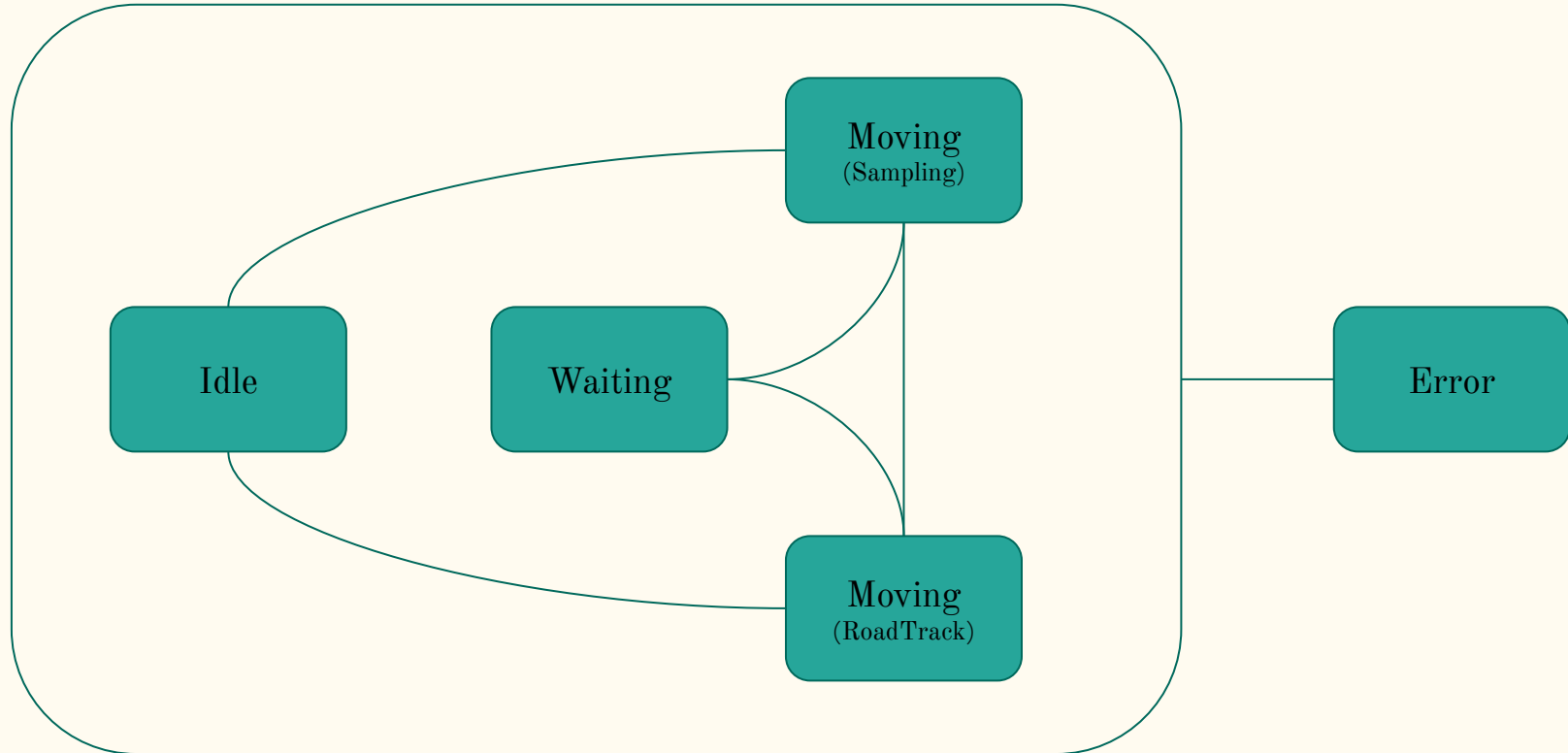


# Path Planning - Sampling

- Non-holonomic constraints of moving in and out of RoadTrack
- RRT\* with Reeds-Shepp path
- High computational complexity
- Short distance travel
  - 1.5 to 3 times robot length



# Fleet manager - finite state machine





# Fleet manager - Behaviour Tree

- Modular and reusable
- Scalable
- Clear visual representation
- Parallelism



Fallback node: fails when all fails, or succeeds when one succeeds



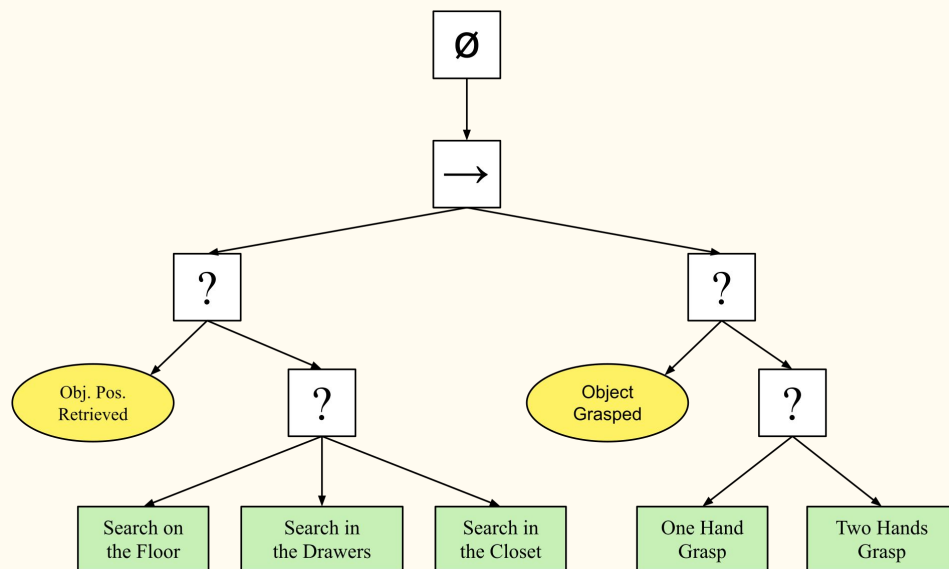
Sequence node: succeed when all succeeds, or fails when one fails



Action node: succeed when action is done, or fails when action is impossible

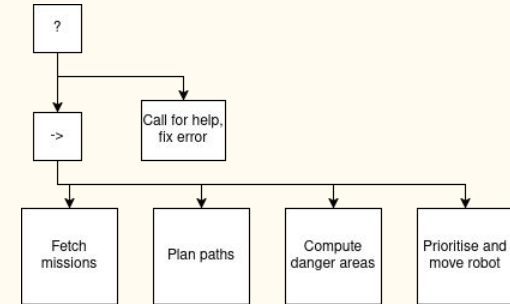


Conditions node: succeed when condition met, or fails when condition not met



# Fleet manager - Main tree

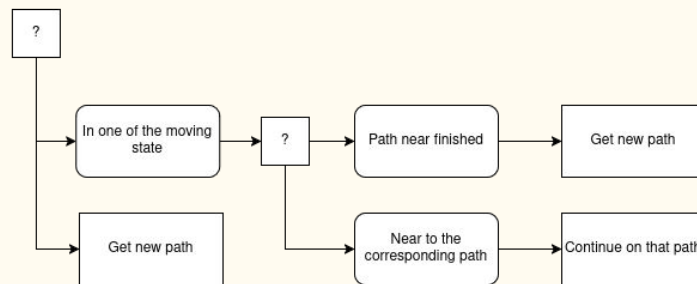
- Objectives
  - All robots have appropriate paths planned
  - No collisions will occur
  - User informed if robot has reached its goal
- Fetch missions
  - Current positions
  - Goals
  - Static obstacles
- Plan paths
  - RoadTrack or sampling
- Compute danger areas
  - Reserved regions where the robot will operate in
- Prioritise and move robot
  - Determines which robot moves or waits



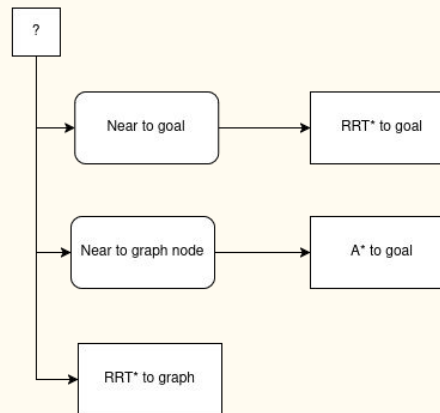
# Fleet manager - plan paths subtree

- Determines which path planner to use
  - RoadTrack for long distances
  - RRT\* for short distances
- RRT\* used for
  - Moving to RoadTrack
  - Moving from RoadTrack to goal

Plan path for robot\_i

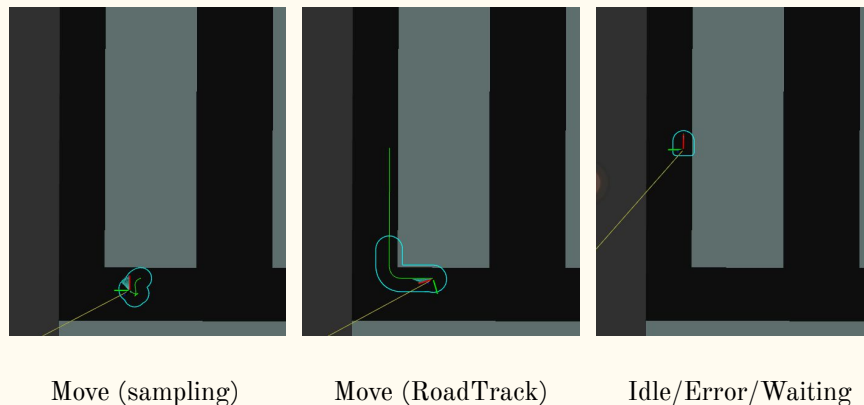


Get new path



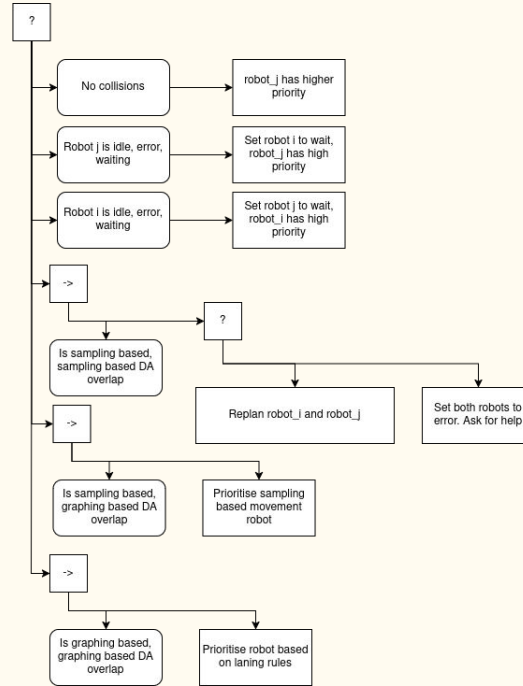
# Fleet manager - compute danger area subtree

- Each state provides a different danger area
- These sizes are tunable

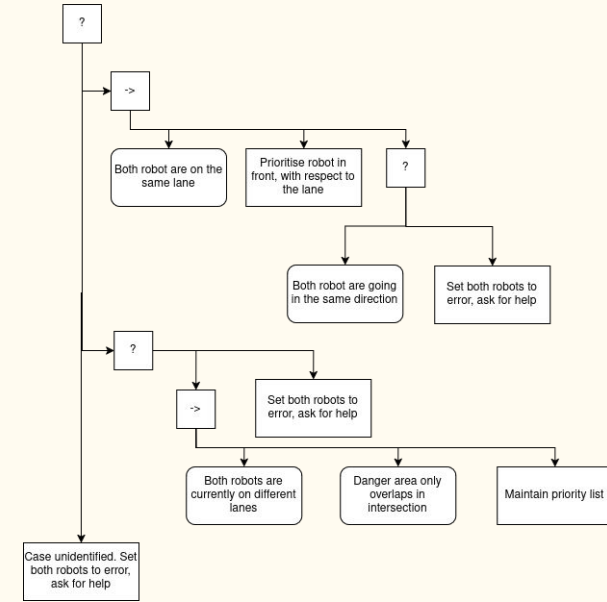


# Fleet manager - prioritise and move subtree

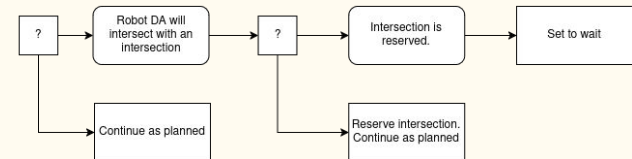
- Gives priority to non-moving robots
- Gives priority to sampling robot
- Lowest priority to robots on RoadTrack
- Provides priority to robots ahead in RoadTrack lanes
- Reserves RoadTrack intersections to prevent collisions



Laning rules

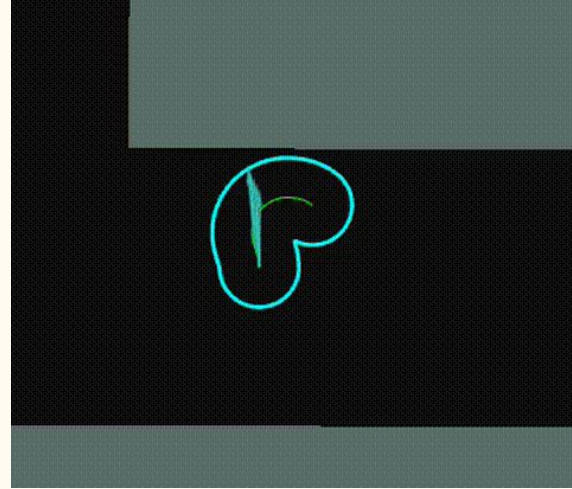


Reserve intersection



# Path Tracker - MPC

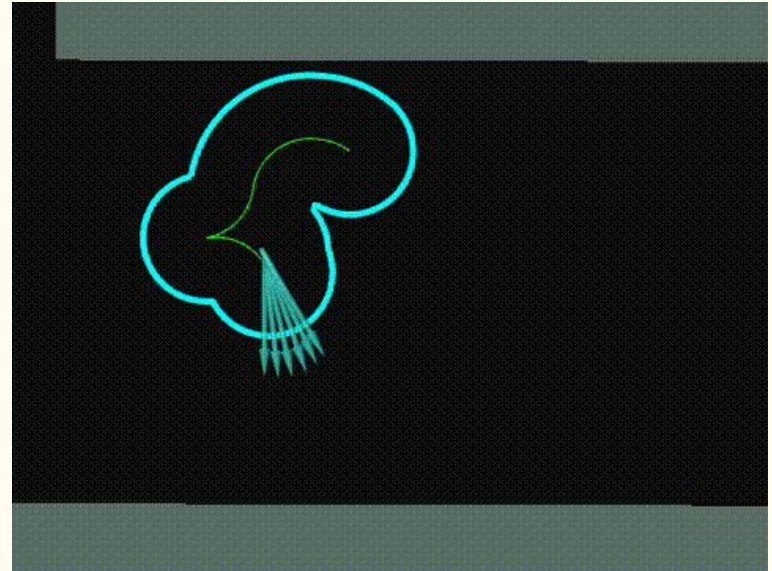
- MPC objective
  - Position Error
  - Orientation Error
  - Control Effort
  - Control Smoothness
- MPC constraints
  - System Dynamics
  - Velocity Constraints
    - Magnitude
    - Direction
  - Rate of Change Constraints





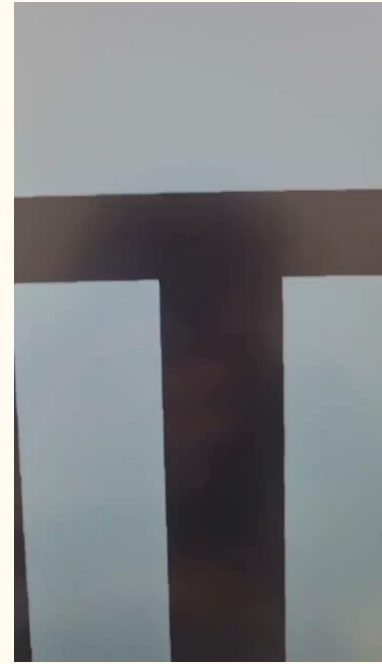
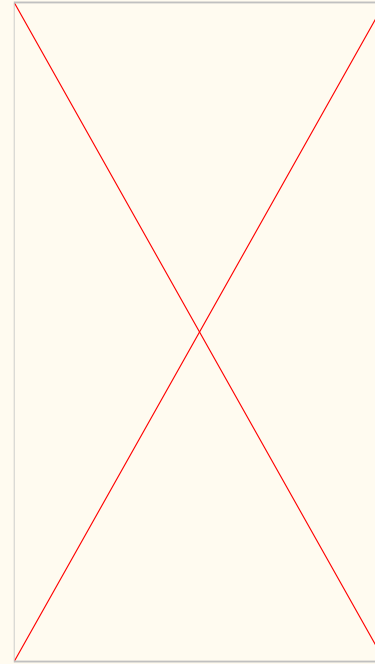
# Path Tracker - MPC

- $N = 5$  performs well
  - Lowered computational resource
- Reeds-Shepp path
  - Badly conditioned for MPC
  - Causes robot to be stuck
  - Forward kick



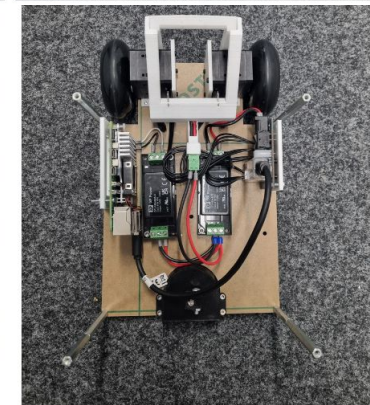
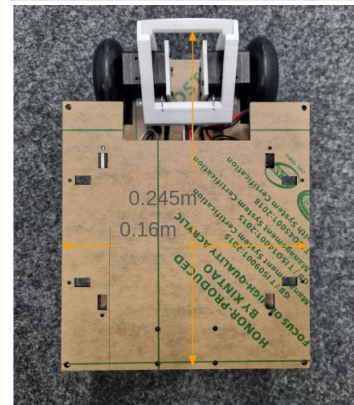
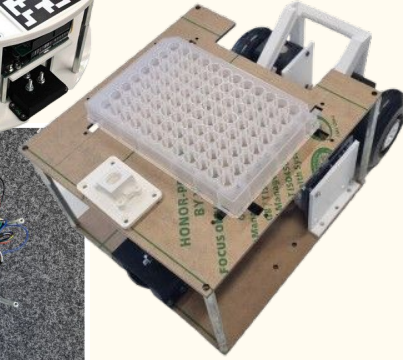
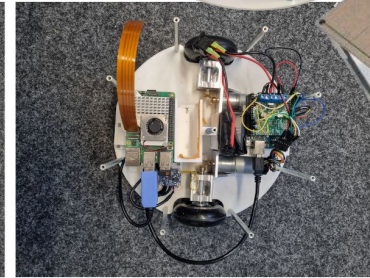
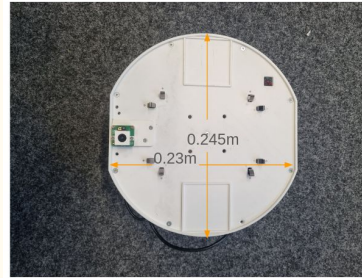
# Results

- RRT\* - orientates successfully
- RoadTrack - navigates successfully
- BT - Prevents same lane collision
- BT - Prevents collision in intersections
- BT - Prevents collision with stationary vehicle
- MPC - works well mostly, but higher lookahead time can cause oscillation
- FM - Handles multiple vehicles at once



# EdyMobile Redesign

- Width decreased by 30%
  - 23cm to 16cm
- Incorporated bigger battery
  - Increased charge cycle
- 3 wheel design
  - No more slip



# Recap - The fleet manager

- Replaced all parts of Nav2 - Path planner, tracker and behaviour tree
  - From decentralised to centralised control
  - More structured approach to navigation
- Ready to run from a docker container
  - Minimal user input
- Adaptable behaviour tree
  - Expandable to cover unseen cases, or extra features

# Q&A

