Cinema 4 AMRs: Creating a test environment for navigation systems for Autonomous Mobile Robots

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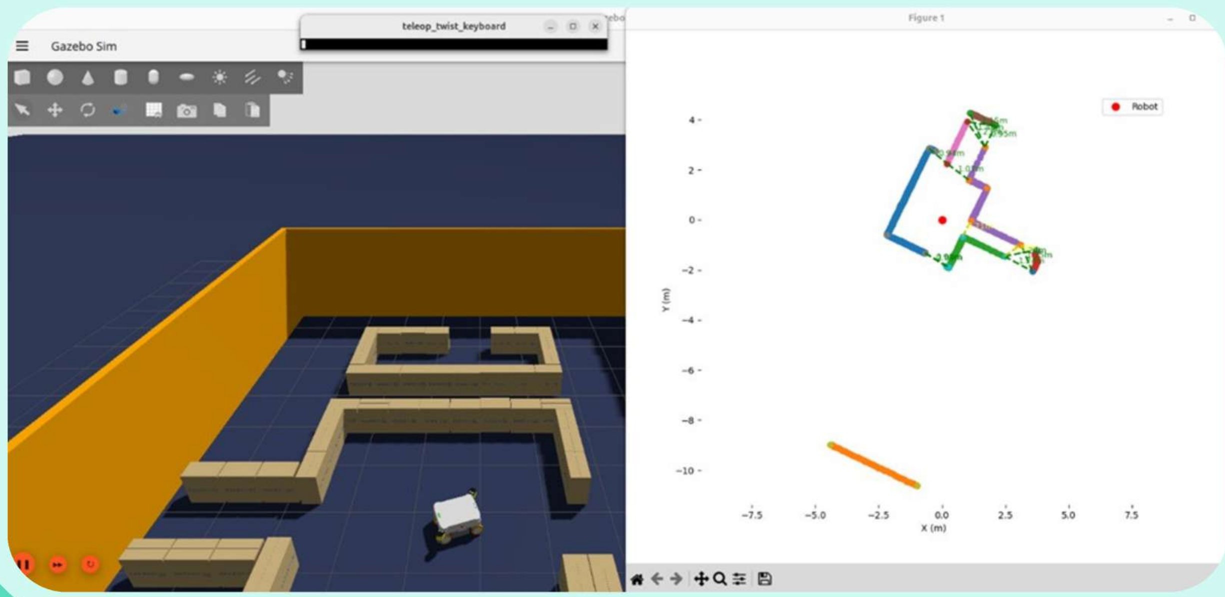
Abstract

This project aims to improve the efficiency, safety, and adaptability of Autonomous Mobile Robots (AMRs) by simulating navigation under environmental and traffic constraints. Environmental factors such as uneven terrain, low-friction floors, and variable pathway widths were modeled to assess their impact on stability and control, while traffic scenarios examined dynamic multi-AGV path planning, intersection coordination, and distributed task execution. Simulations in Gazebo with MPO-700 AMRs and ROS 2 integration enabled pathway classification, LiDAR-based obstacle detection, and real-time navigation. A hybrid workflow combining global optimization, local path planning, and adaptive avoidance achieved faster convergence, shorter paths, and improved performance in crowded environments. Results confirm that AMR navigation is strongly shaped by surface and traffic conditions, and that robust control combined with adaptive planning enhances stability, efficiency, and safety. Future work will scale the framework to larger dynamic networks and validate it on physical AMRs to ensure reliable integration with industrial fleet management systems.

Environmental Challenges

Narrow corridors, wide pathways, and intersections

- Simulate AMR navigation in Gazebo using MPO-700 with dual LiDARs.
- Integrate sensors via ROS 2 for control/data handling; RViz for visualization.
- Use an indoor testbed with narrow corridors, wide pathways, and intersections.
- Convert LiDAR scans from polar to Cartesian coordinates.
- Apply the Ramer–Douglas–Peucker algorithm to reduce point cloud complexity.
- Cluster obstacles with DBSCAN to handle irregular shapes and noise.
- Detect corners via angular analysis to preserve walls and intersections.
- Classify pathways (robot width = 0.5 m): narrow < 0.6 m (red), moderate 0.6–0.8 m (yellow), wide > 0.8 m (green).

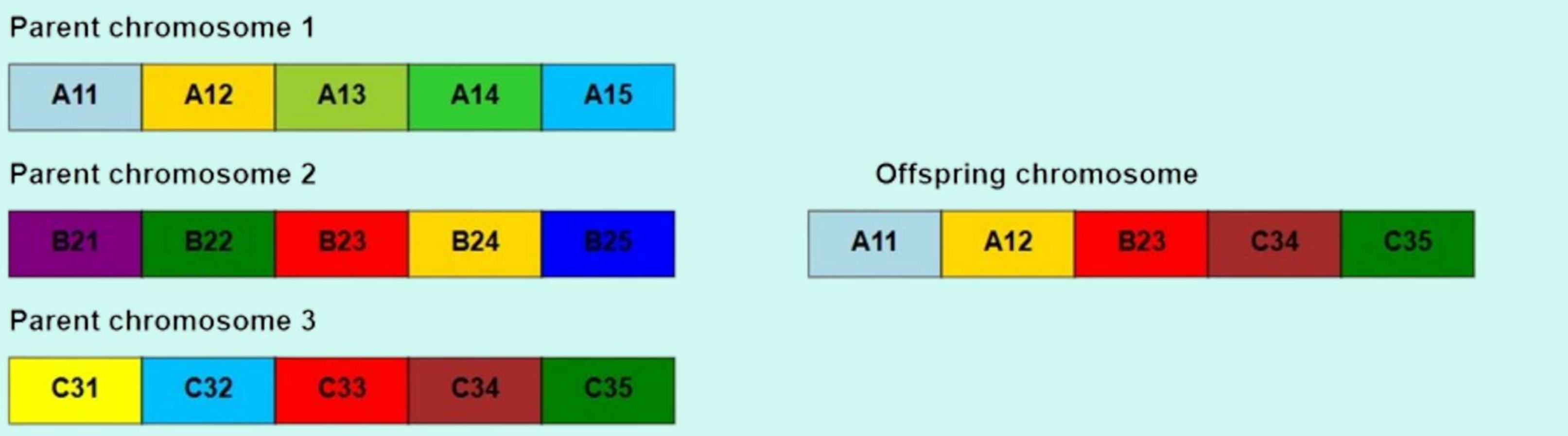


- Robotics simulation for AMR navigation, visualizing real-time LiDAR data processing and pathway classification in an indoor testbed environment.

Traffic Analysis

GA Workflow for Convoluted Multi-AGV Path Planning for Intersections and Roundabout Pathways

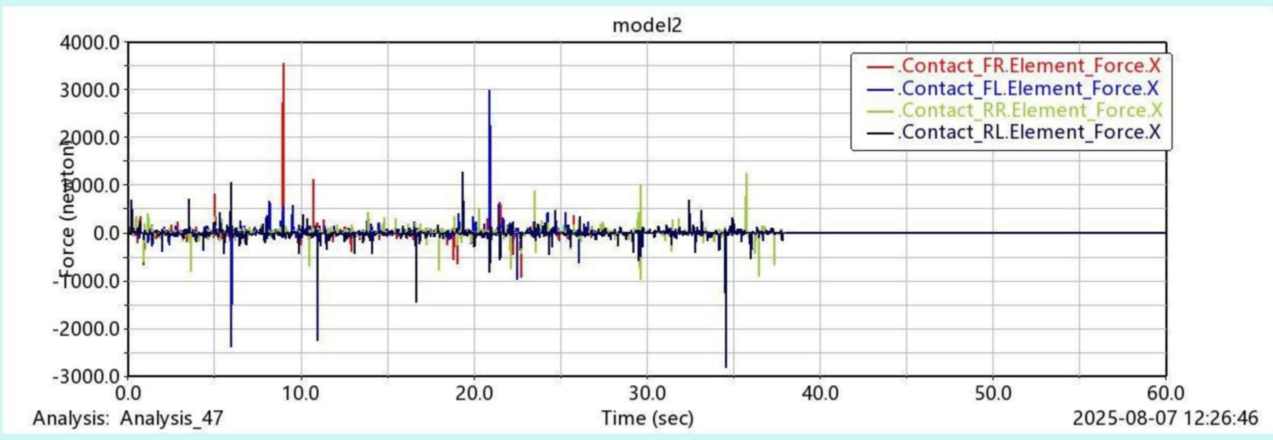
- Set up by Grid map, start/target nodes; avoid collisions; minimize total & longest path.
- Initialization by generating initial feasible multi-AGV paths.
- Fitness Method by Ranking by total + longest path length (shorter = better).
- Operators by Selection → Three-Exchange Crossover → Mutation.
- Constraints by removing/fixing invalid or colliding paths.
- Iterate by repeating until the best solution is found.
- Output would be Collision-free, balanced, optimized paths.



- Genetic algorithm crossover process for an AGV path. It combines segments from three different "parent" paths to create a new "offspring" path. This allows the algorithm to explore and create new, more efficient path combinations by mixing the best parts of existing solutions.

Low-Friction Surface Analysis

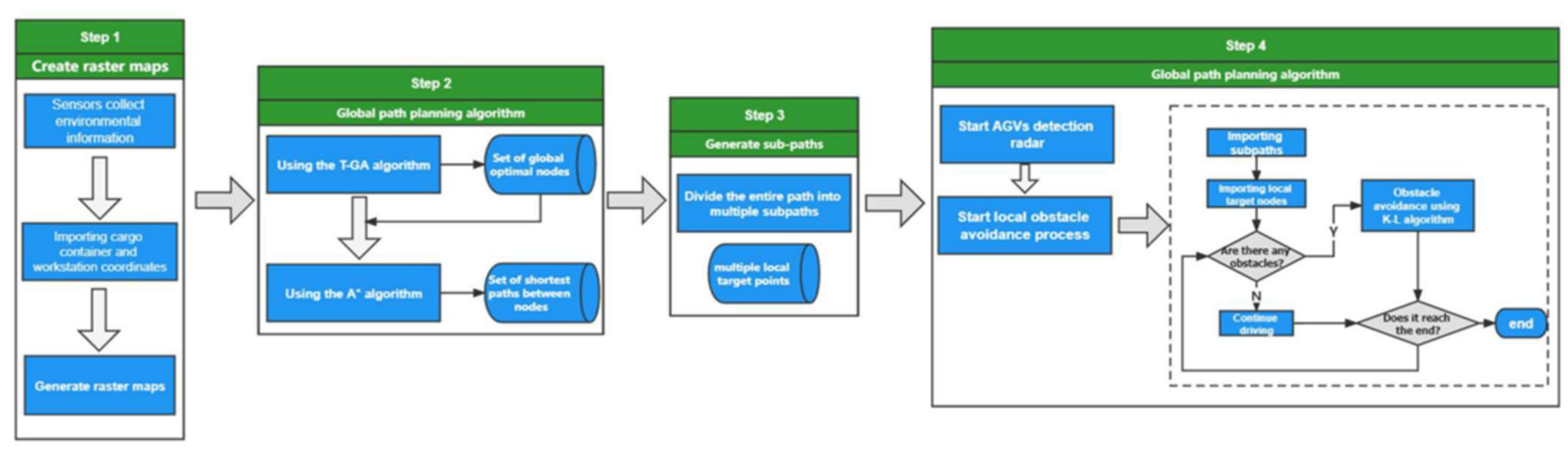
- Simulate wheel-ground interaction on a low-friction floor in MSC Adams. Observe high-amplitude longitudinal force fluctuations → slip and uneven traction .
- Note degraded odometry accuracy and navigation stability .
- Detect uniformly low drive torques → reduced traction and force transmission .
- Conclude limited acceleration capability and reduced control precision .



- The fluctuation, leading to poor odometry and limited acceleration,
- Besides, spikes and dips originate from low-friction simulated surface.

GA-KL Path Planning suitable for Dynamic Map Planning

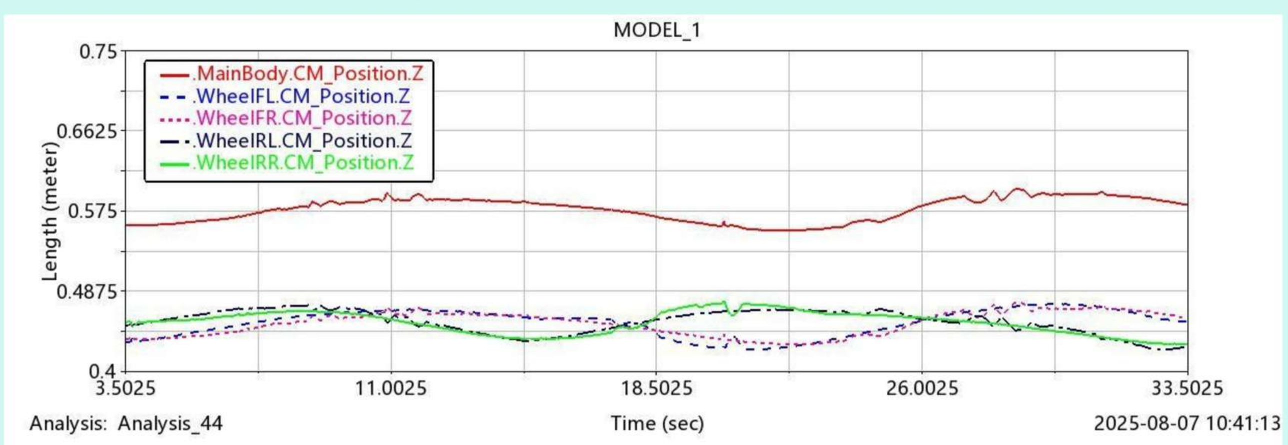
- The goal is to merge global efficiency with real-time obstacle avoidance.
- T-GA, an improved Genetic Algorithm, plans smooth, low-congestion routes and schedules vehicle departures on a raster map.
- K-L uses a combination of Kohonen clustering and adaptive SA Q-learning, with potential-field rewards for fast, safe avoidance.
- Workflow is followed, T-GA plans → A* follows in normal flow → K-L handles dynamic obstacles/congestion → return to A*.
- Results are ~6% faster convergence, 4–8% shorter paths, and ~12% faster in crowded areas.



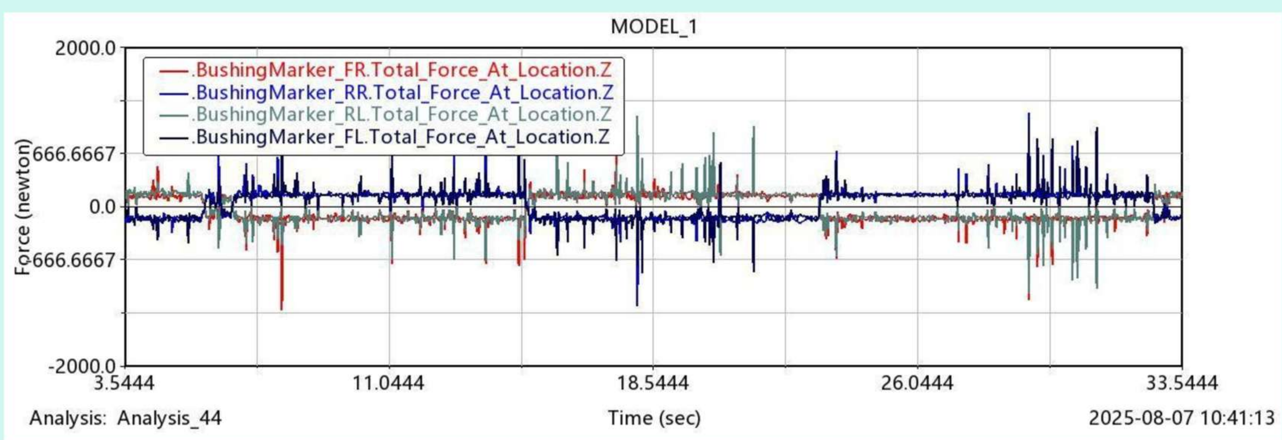
- Create raster maps from sensor data and coordinates which serve as the environment's representation.
- Use a T-GA for global path optimization and an A* algorithm for generating the shortest paths.
- Divide the path into smaller, more manageable sub-paths.
- Implement a local obstacle avoidance process using a K-L algorithm for real-time navigation around obstacles.

Uneven Surface Analysis

- The analysis confirms the vehicle is on uneven terrain.
- The top graph shows the wheels have much larger vertical oscillations than the vehicle body, indicating they are actively moving over bumps and dips.
- The bottom graph displays large, erratic force spikes and drops on the suspension bushings. These are caused by sudden impacts with bumps and the wheels momentarily lifting off the ground as they fall into dips.
- The asymmetric and chaotic nature of the forces across the four wheels further proves the vehicle is not on a flat, even surface.

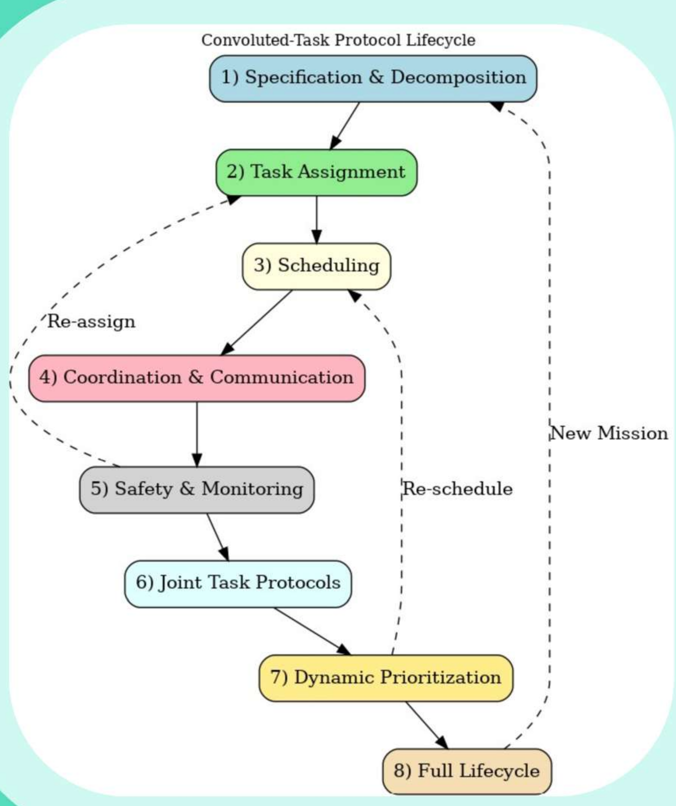


- The body line is much smoother than the wheel lines, demonstrating effective suspension isolation.



- Large, asymmetric spikes and drops, confirming uneven terrain loading and wheel unloading, which leads to reduced traction.

Convoluted Tasks



- A mission is first broken down into sub-tasks, then assigned to agents. The tasks are scheduled, and the agents execute them with coordination and communication. The process is continuously monitored for safety. As tasks are completed, their priority is dynamically adjusted. The cycle concludes upon completion, ready to start a new mission.

Adaptive Feedback Loops

- Re-assign: Return to Assignment due to coordination issues.
- Re-schedule: Return to Scheduling when priorities shift.
- New Mission: Restart the full cycle.

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