DEVELOPMENT OF HIGH FIDELITY MOBILITY SIMULATION OF AN AUTONOMOUS VEHICLE IN AN OFF-ROAD SCENARIO USING INTEGRATED SENSOR, CONTROLLER, AND MULTI-BODY DYNAMICS

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GVSETS

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Contents

- Background
- Objectives
- Simulation Setup
- Results
- Conclusions & Future Work

Background

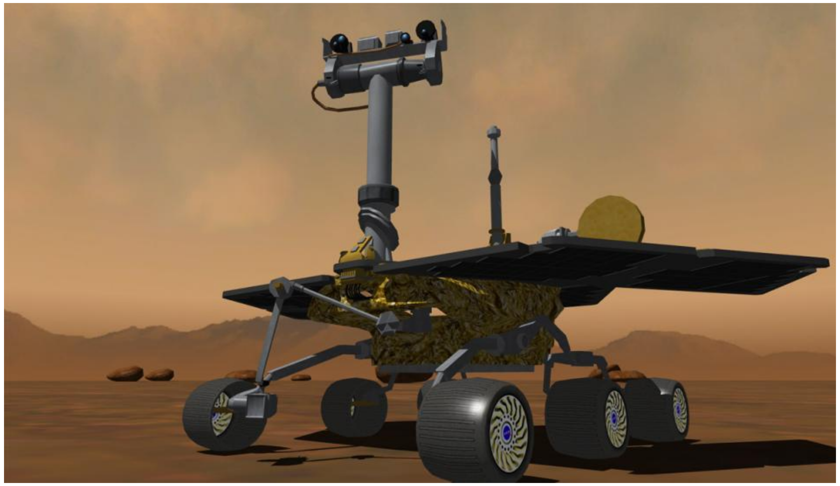
- Benefits of Simulation
  - Test ideas before experimentation
  - Access to data, otherwise unavailable
  - Repeatability/Control over testing environment
  - Safety
  - *Benefits well understood for human-operated vehicles
- Impact of Autonomous Operation
  - Automation introduces additional uncertainty in operation
  - Additional modeling of environmental parameters (ie reflectivity)
  - Sensor modeling
  - Control system modeling and development
  - Cannot neglect vehicle dynamics

Importance of Simulation Fidelity

- Performance evaluation requires entire system accuracy
  - Controller
  - Vehicle dynamics
  - Sensor measurements
- For example:
  - Unmodeled system dynamics can lead to inaccurate traction limitations and/or response times
  - Consequently there may be unanticipated problems with the controller software that are uncovered during the hardware prototype testing of the vehicle system

Literature Review

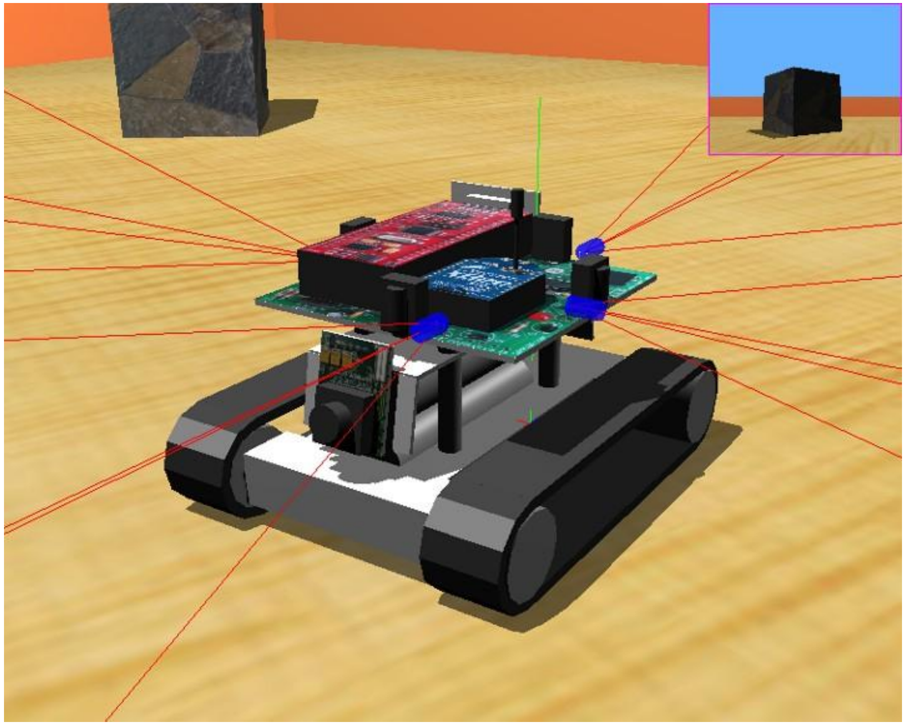
- *USARSim*
  - Open source simulator
  - Supports several sensor and robot types, with ability for users to add more
  - Uses the Unreal Tournament game engine



- *Microsoft Robotics Developer Studio*
  - Commercially available
  - Uses NVIDIA's PhysX to model physics behavior and the Microsoft XNA Framework to provide real-time 3D graphics rendering.
  - Includes pre-modeled robots, sensors, and environments

Literature Review

- *Webots*
  - Commercially available through Cyberbotics
  - Library of sensors, robots, indoor and outdoor objects.
  - Physics-based simulations through the *Open Dynamics Engine*, an open source rigid-body dynamic simulator



Literature Review

- *VANE*
  - High fidelity simulation environment for ground robotics developed by the U.S. Army Engineer Research and Development Center
  - All efforts are being made to represent the environment, sensors, and their interactions as accurately as possible
  - Requires a supercomputer to handle its complex virtual environment modeling

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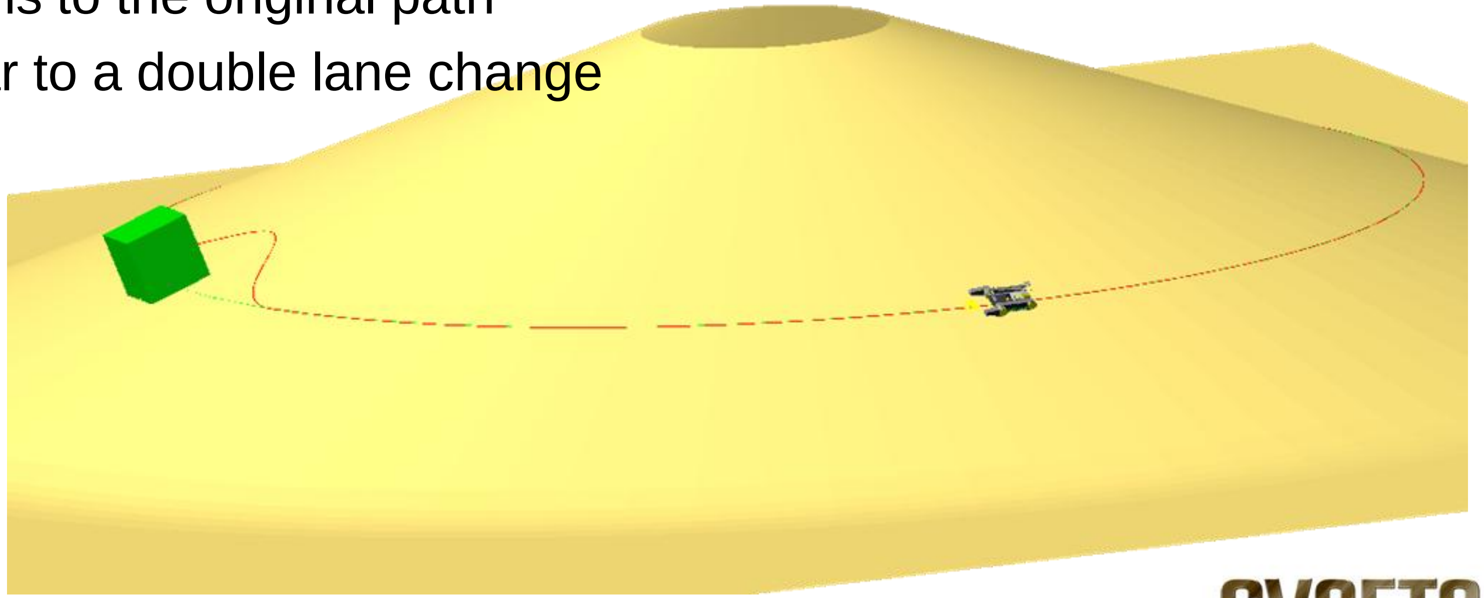
Objectives

- Develop and demonstrate a high-fidelity integrated simulation architecture that includes sensors, controllers, and a detailed vehicle model.
- Demonstrate a level of fidelity that could allow engineers to be able to assess the effect of specific changes to the vehicle system, such as a change in track design or in controller firmware.
  - It is understood that simulation at this level of detail occurs much more slowly than real-time. The intent is to use this environment as an engineering tool rather than for training or other real-time applications.

Scenario

- Experimental Setup:
  - – Small tracked vehicle, similar in size and shape to PackBot
  - – Travels along a predetermined path
    - Hill with 20 degree slope
  - – Avoids an obstacle along original path
  - – Returns to the original path
  - – Similar to a double lane change



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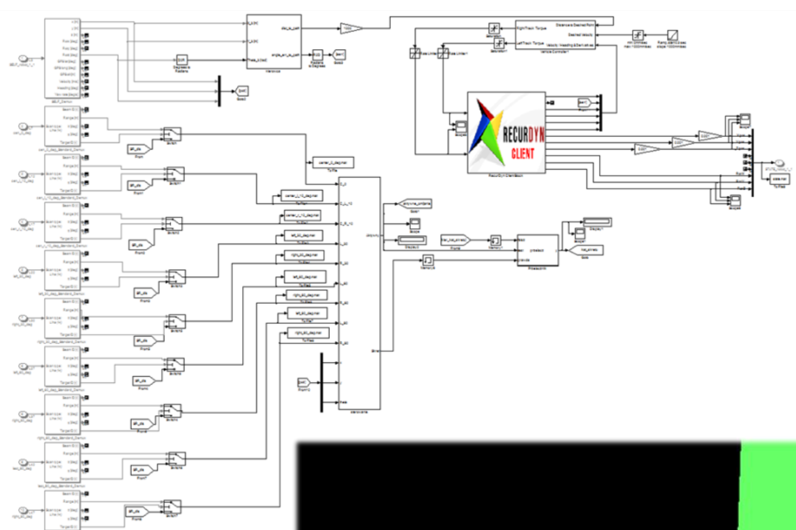
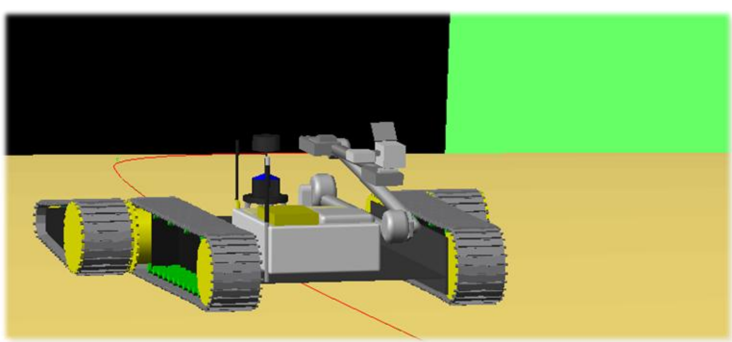
Software Architecture





Sensor Simulation:
PreScan

↓ Sensor Outputs ↑ Position of Chassis (6 DOF)

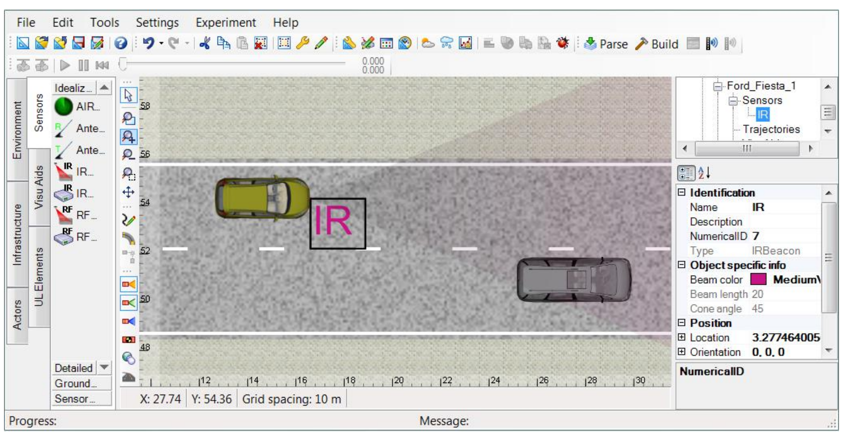
Control System Simulation:
MATLAB Simulink

↓ Requested Torque on Left and Right Sprockets ↑ Position and Velocity of Chassis (6 DOF)

Multibody Dynamics Simulation:
RecurDyn

Sensor Simulation

- PreScan
  - For designing and evaluating Advanced Driver Assistance Systems (ADAS) and Intelligent Vehicle (IV) systems
    - Based on sensor technologies such as radar, laser, camera, ultrasonic, GPS and C2C/C2I communications.
  - From model-based controller design (MIL) to real-time tests with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) systems.



Multibody Dynamics Simulation

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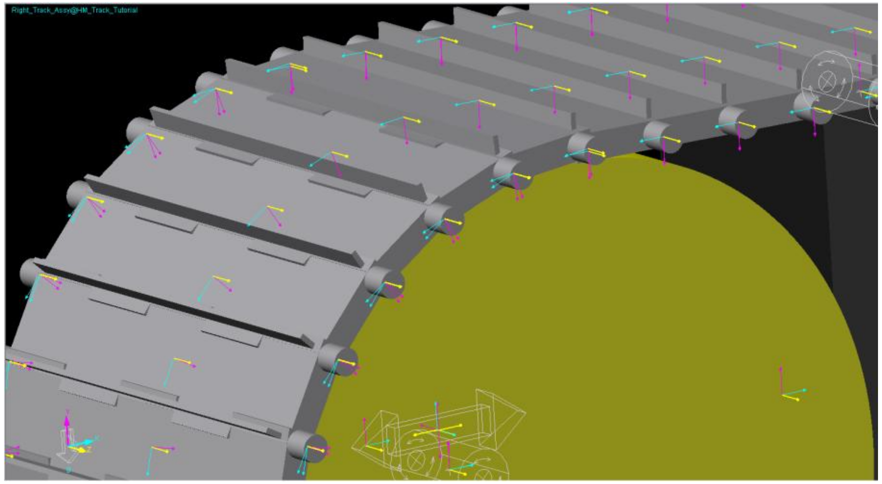
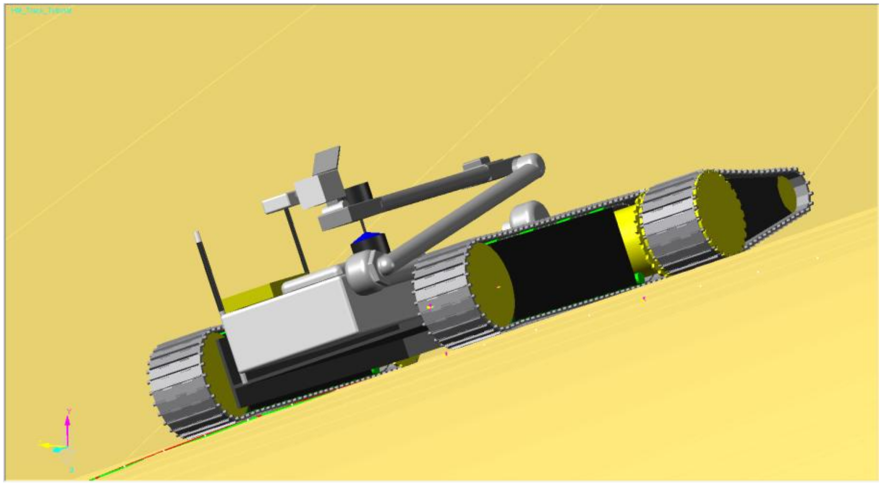
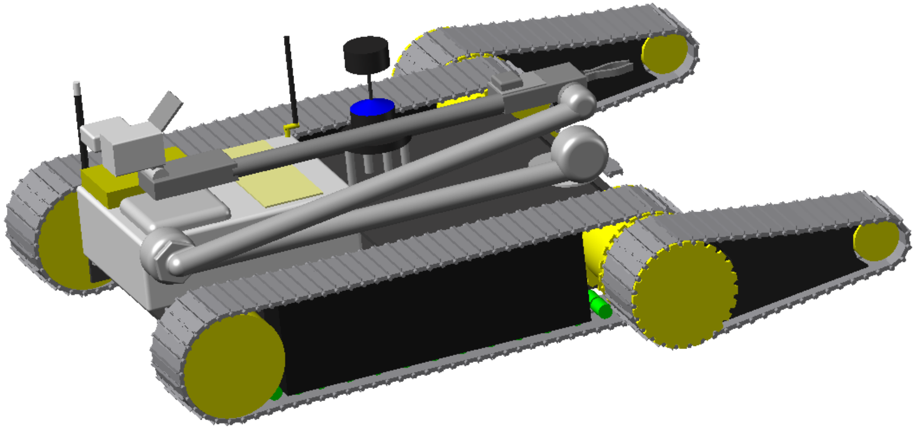
- RecurDyn
  - Dynamic Rigid & Flexible Body Analysis
  - Hybrid implicit/explicit integrator reduces computation time
  - Toolkits add functionality
    - Track toolkit allows easy and detailed modeling of the robot's tracks, with the ability to include soft-soil interactions
    - Multi-core parallel processing enables efficient contact calculations





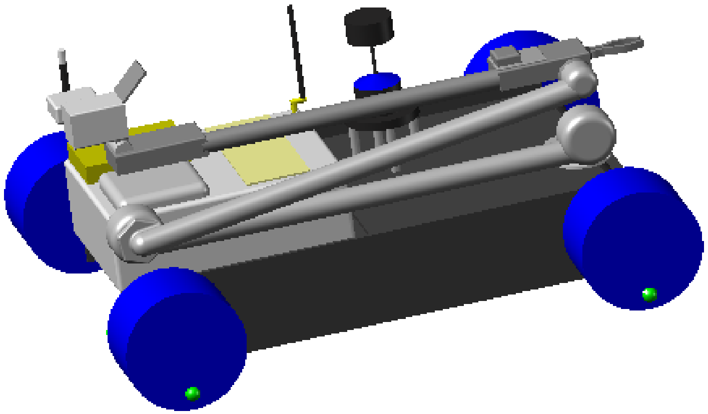
Vehicle Models

High-Fidelity



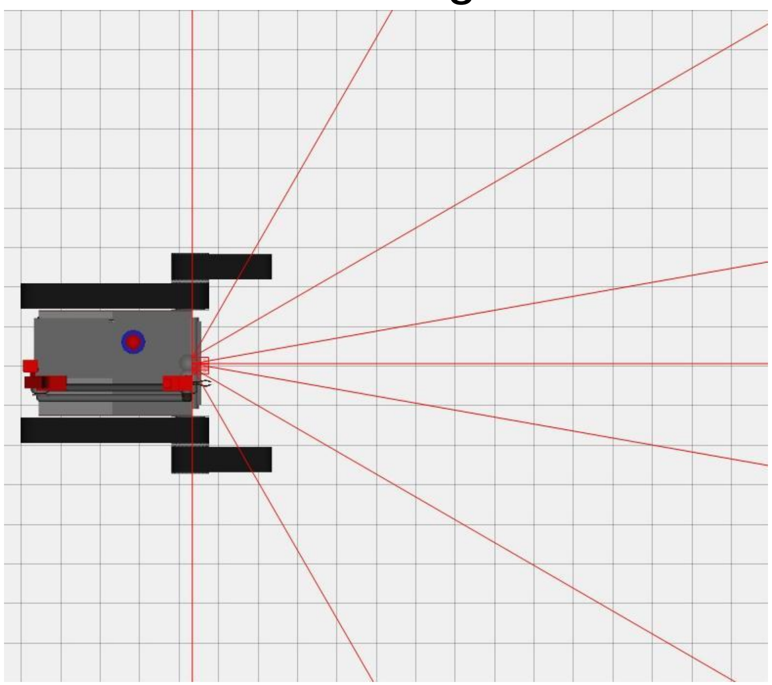
- Tracks
- Track links modeled individually
- Computationally intensive

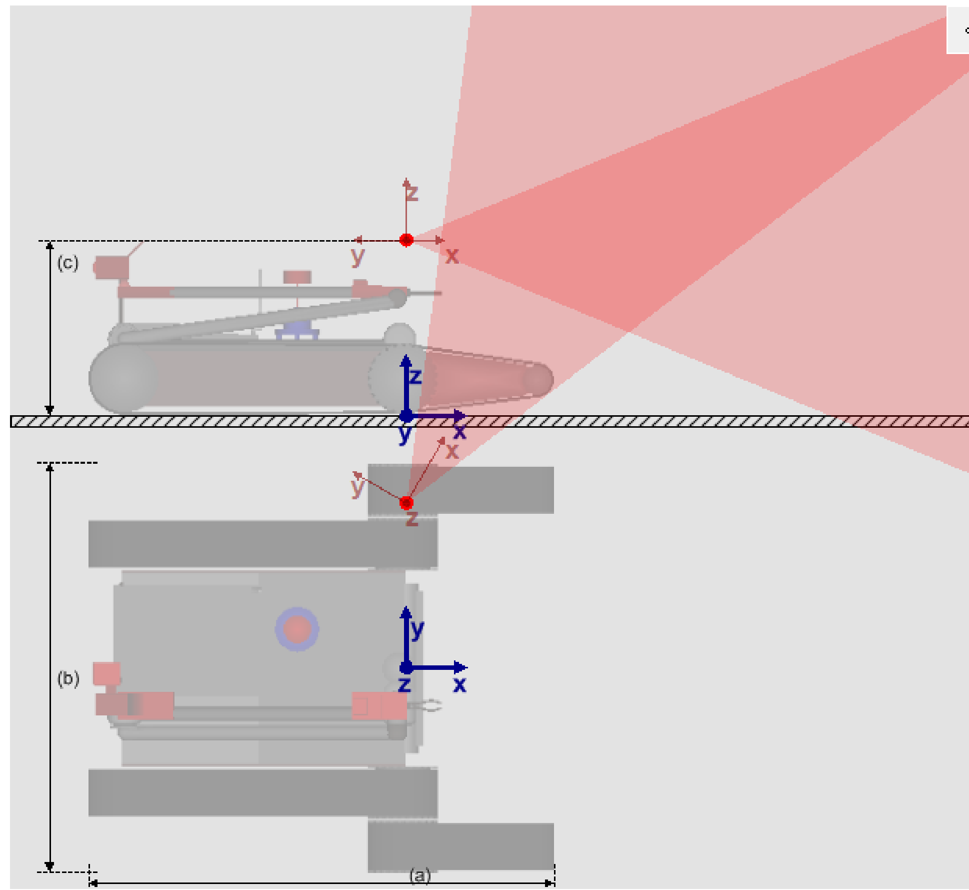
Simplified



- Wheels
- Significant reduction in computation time
- Useful for early control debugging

- 9 range sensors
  - 10m range
  - Single beam
  - Line scanning





Controllers

- High Level: Navigation (Algorithm-based)
  - Inputs: Predetermined desired trajectory, Current position, Sensor signals
  - Outputs: Desired future location
- Vehicle Stability (PID-based)
  - Inputs: Desired yaw rate, Current yaw rate
  - Output: Reduction in desired velocity
- Low Level: Trajectory Following (PID-based)
  - Input: Angle toward desired location, Desired forward velocity
  - Output: left/right track torque

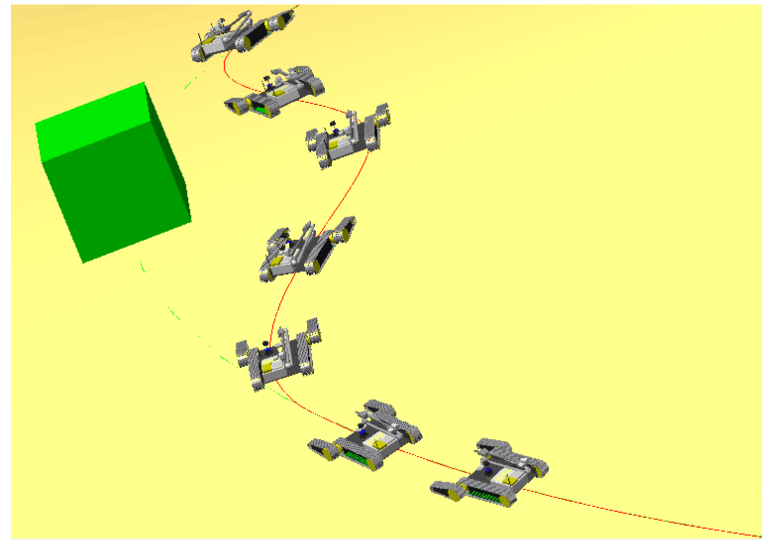
Obstacle Avoidance

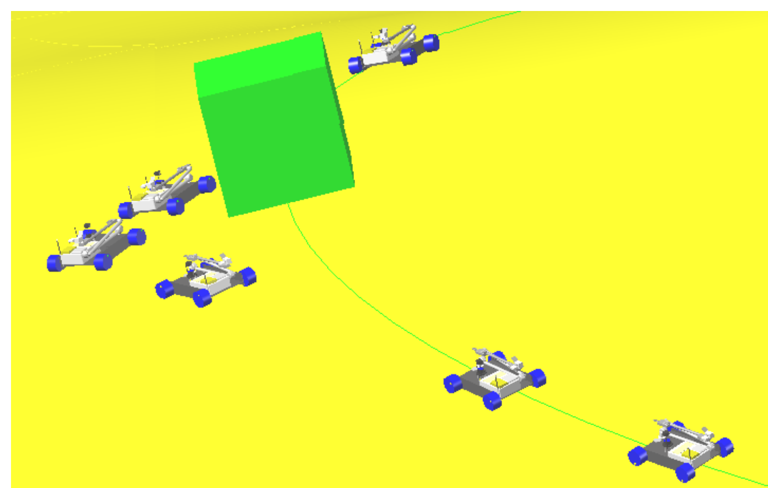
- Stage 1: Original Path
  - Follow prescribed path, using torque controller to maintain desired trajectory
- Stage 2: Obstacle Detection
  - An obstacle is detected by the range sensors within a predetermined distance
- Stage 4: Circumvent Obstacle
  - The vehicle avoids the obstacle by turning until parallel to the obstacle
  - The vehicle drives along side the obstacle until the obstacle has passed
- Stage 5: Return to Original Path
  - When a clear path toward the original trajectory is available, the vehicle moves toward the next point along the path

Contents

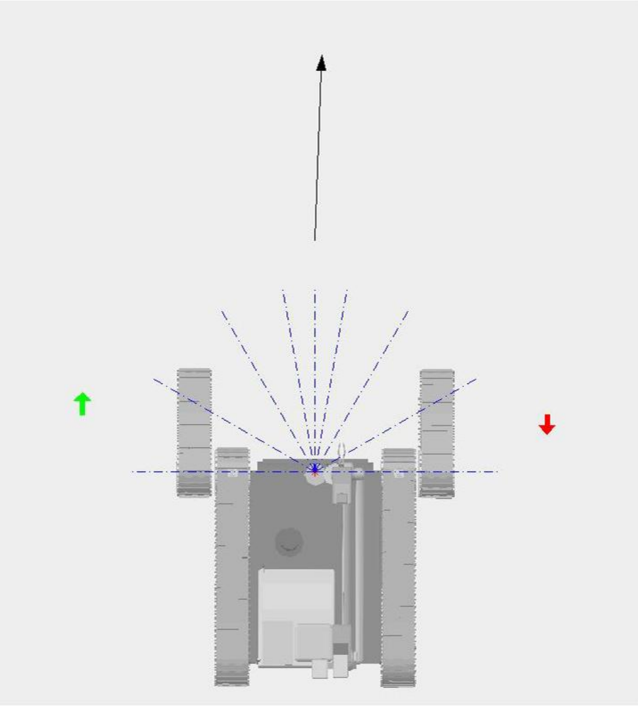
Results

- Predefined path
  - Detailed track model, predefined avoidance path
- High-Fidelity
  - Detailed track model, autonomous operation
- Simplified
  - Simplified wheel model, autonomous operation





Autonomous Operation



Simulation Comparison

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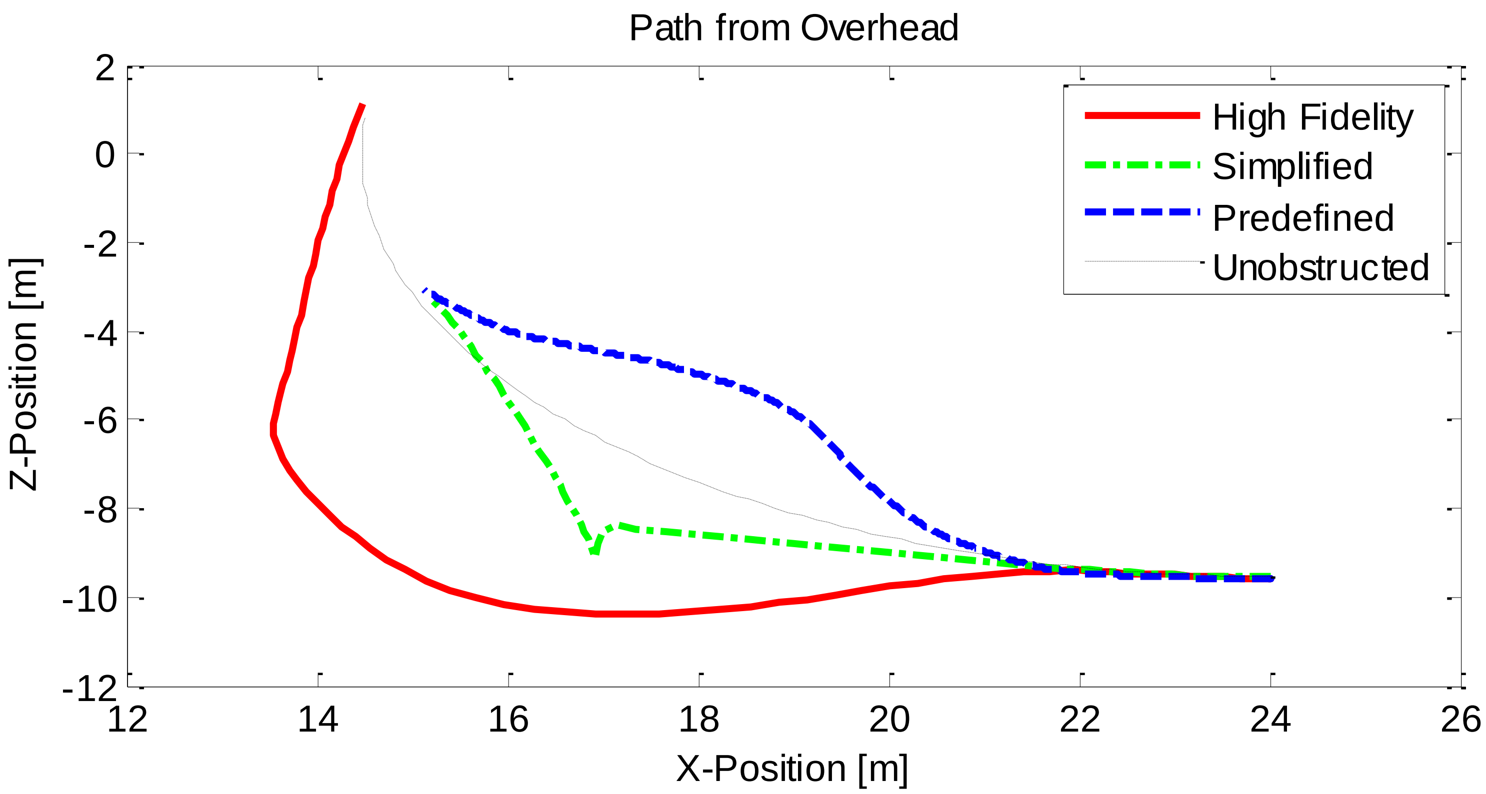
- Trajectory differences based on simulation type:



Simulation Comparison

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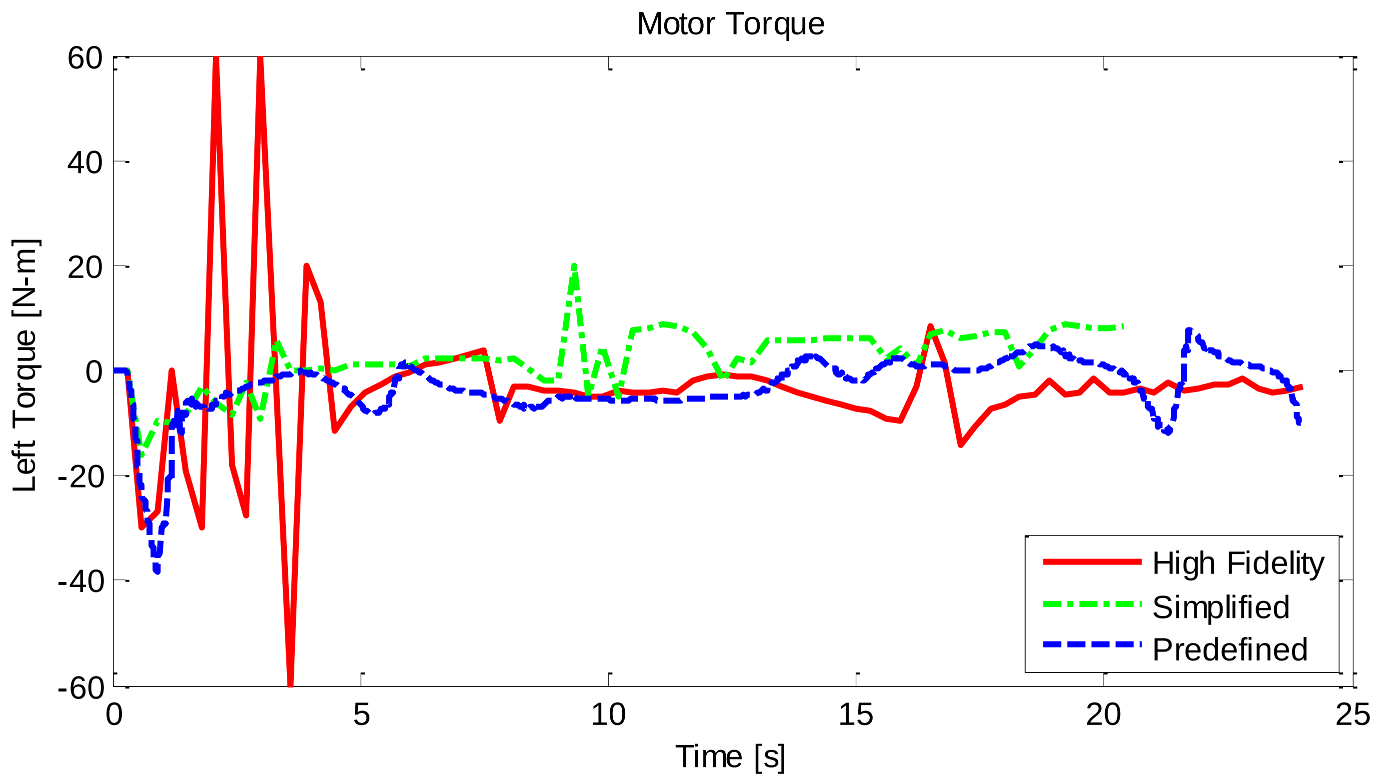
- Motor torque differences based on simulation type:



- Average power requirements (W):
  - High Fidelity: 86.4 Simplified: 42.8 Predefined: 27.6

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Conclusions

- Successful completion of the main goal:
  - Couple three software packages responsible for modeling different aspects of the robot – traction, control, and sensing
  - Simulation using autonomous navigation increases overall system fidelity
- Challenges:
  - Simulation time of the detailed track robot
    - Controller design requires simulation iterations
    - Use of the simplified robot model necessary for early-stage development
  - Vehicle trajectory control
    - Nonlinear and easily made unstable
    - PID controller not robust to system changes
  - Traction control
    - Wheel/Track slip remained near 1, indicating poor traction and loss of control

Future Work

- Potential Applications
  - Virtually test the applicability of a robot to a specific task
    - Develop control algorithms and test virtually before development
    - Save time and expense
  - Test “in the lab” operating procedures of new equipment.
  - Potential for high fidelity real-time simulation
    - Tune a simplified vehicle model using data from high fidelity simulations
- Simulation Improvement
  - Add model complexities to improve result accuracy
    - Soft-soil modeling using Bekker equations instead of a rigid ground assumption
  - Develop better controllers
    - More intelligent navigation
    - More robust trajectory tracking

Questions?

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