



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

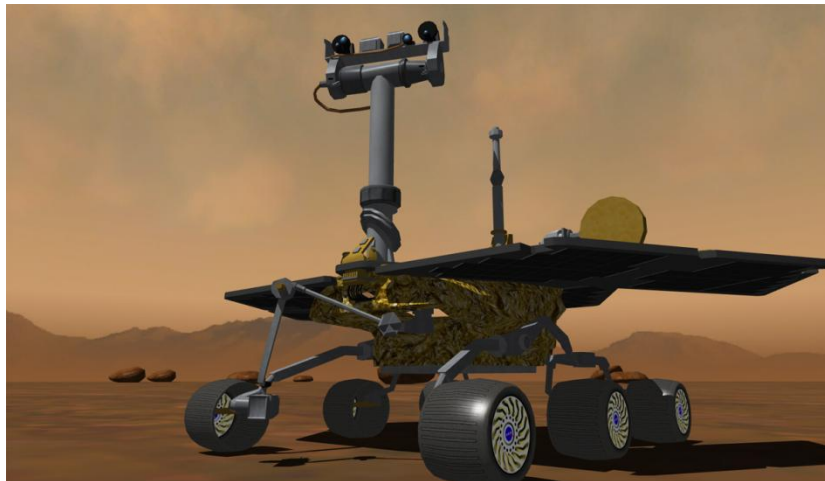
- Benefits of Simulation
 - Test ideas before experimentation
 - Access to data, otherwise unavailable
 - Repeatability/Control over testing environment
 - Safety
 - *Benefits well understood for human-operated vehicles
- Impact of Autonomous Operation
 - Automation introduces additional uncertainty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



- 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



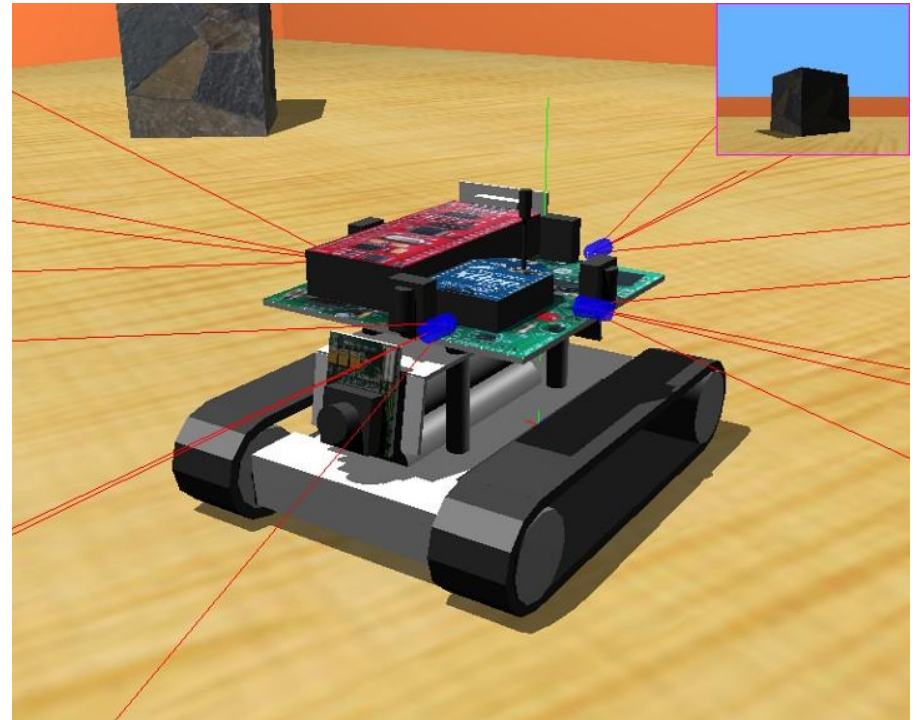
- *USARSim*
 - Open source simulator
 - Supports several sensor and robot types, with ability for users to add more
 - Uses the Unreal Tournament game engine



- *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

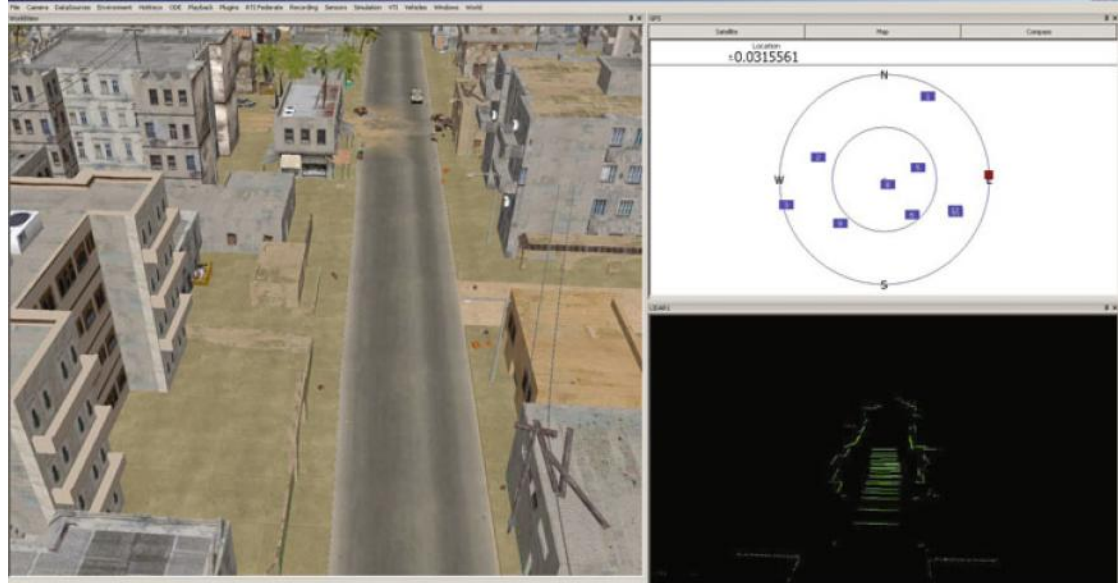


- *Webots*
 - Commercially available through Cyberbotics
 - Library of sensors, robots, indoor and outdoor objects.
 - Physics-based simulations through the *Open Dynamics Engine*, an open source rigid-body dynamic simulator





- **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

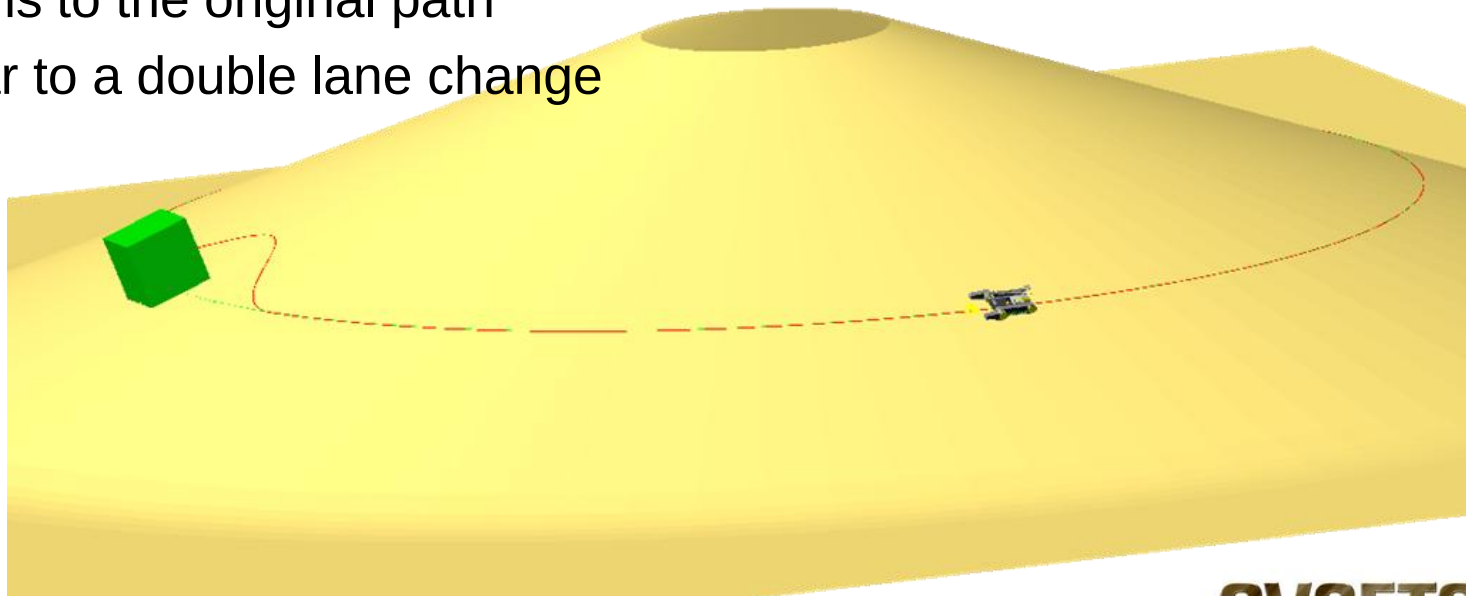


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- Develop and demonstrate a high-fidelity integrated simulation architecture that includes sensors, controllers, and a detailed vehicle model.
- Demonstrate a level of fidelity that could allow engineers to be able to assess the effect of specific 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.

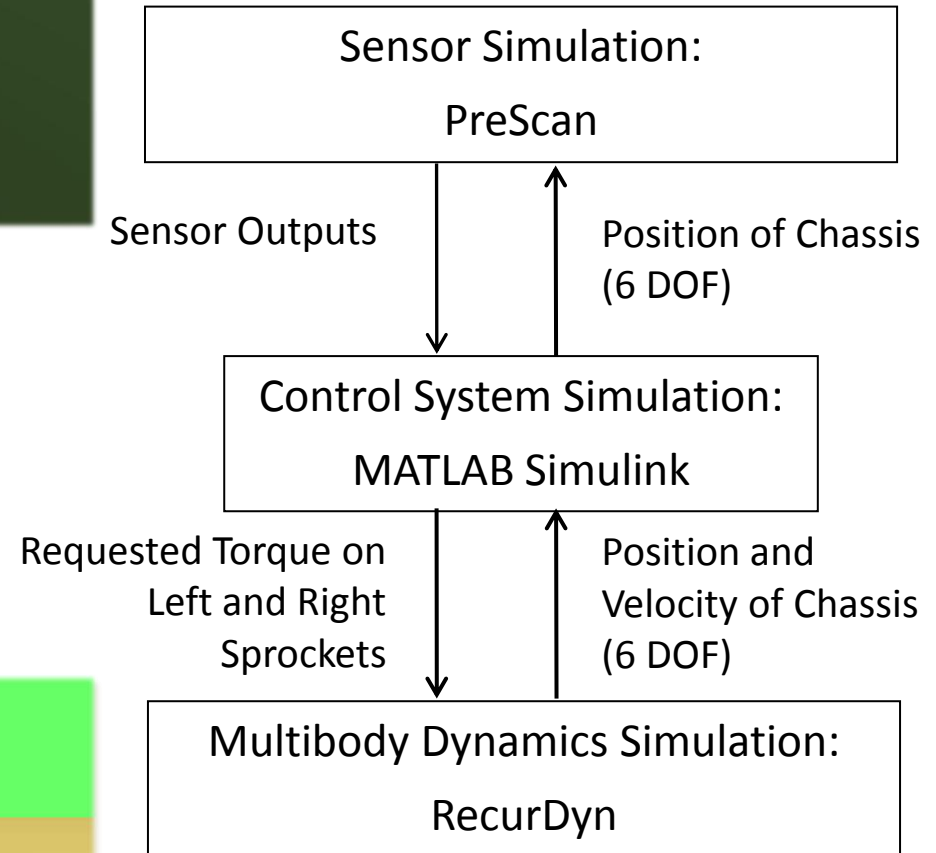
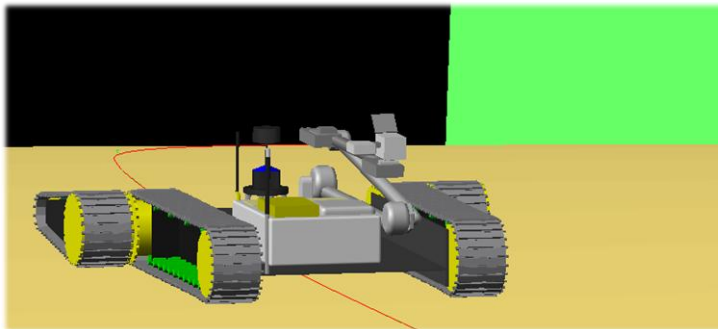
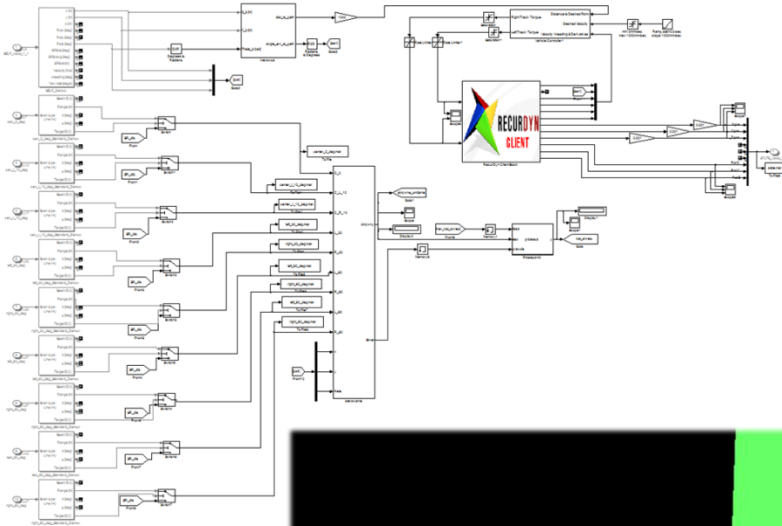


- Experimental Setup:
 - Small tracked vehicle, similar in size and shape to PackBot
 - Travels along a predetermined path
 - Hill with 20 degree slope
 - Avoids an obstacle along original path
 - Returns to the original path
 - Similar to a double lane change



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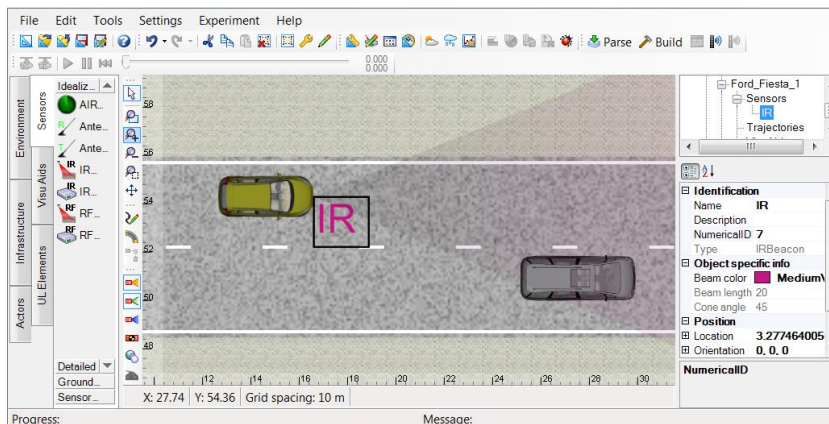
Software Architecture





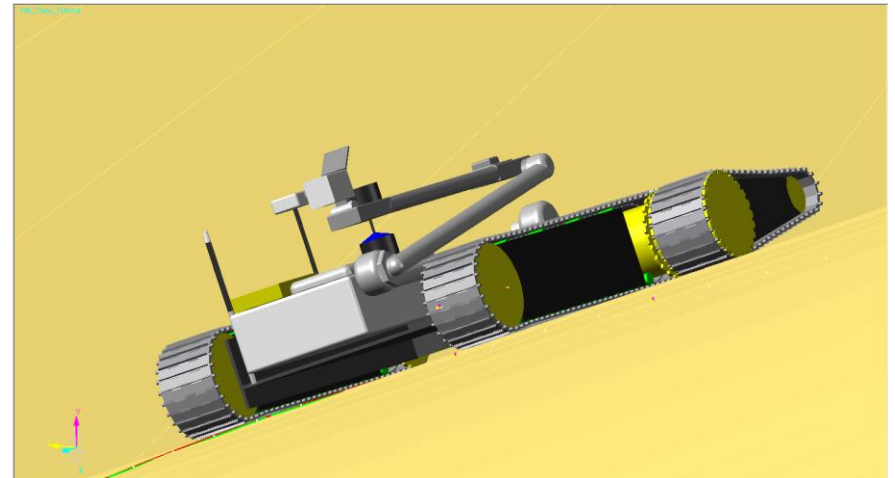
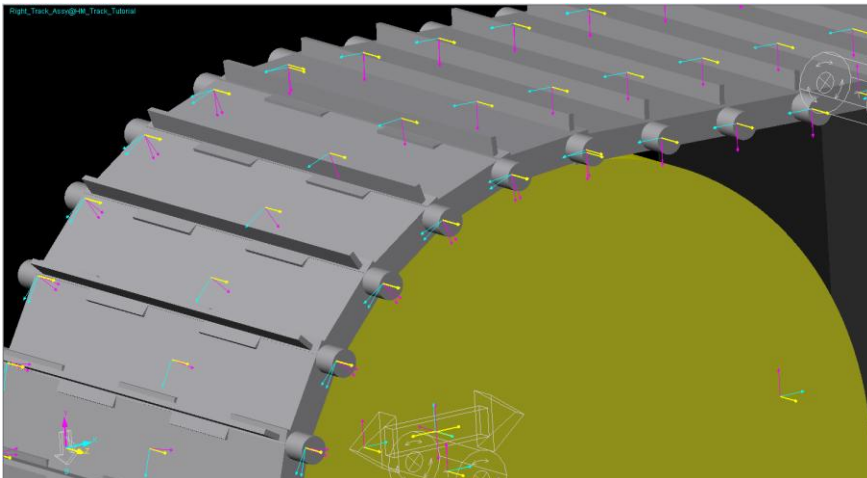
- PreScan

- 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.



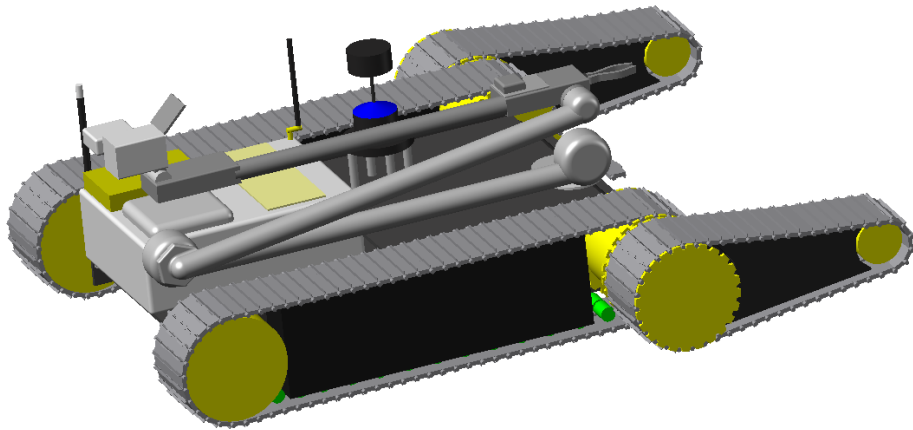


- RecurDyn
 - Dynamic Rigid & Flexible Body Analysis
 - Hybrid implicit/explicit integrator reduces computation time
 - Toolkits add functionality
 - Track toolkit allows easy and detailed modeling of the robot's tracks, with the ability to include soft-soil interactions
 - Multi-core parallel processing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



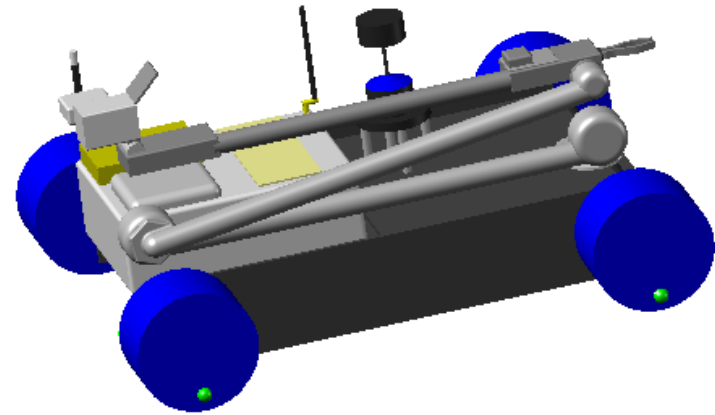


High-Fidelity



- Tracks
- Track links modeled individually
- Computationally intensive

Simplified



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

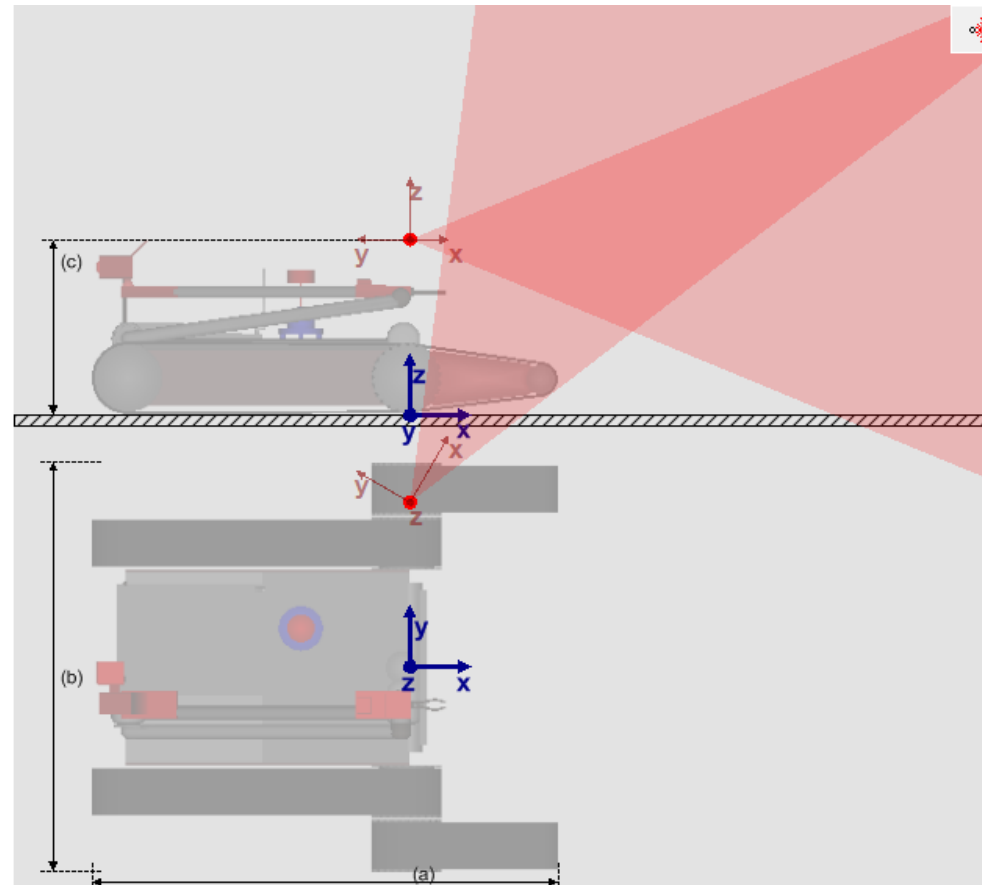
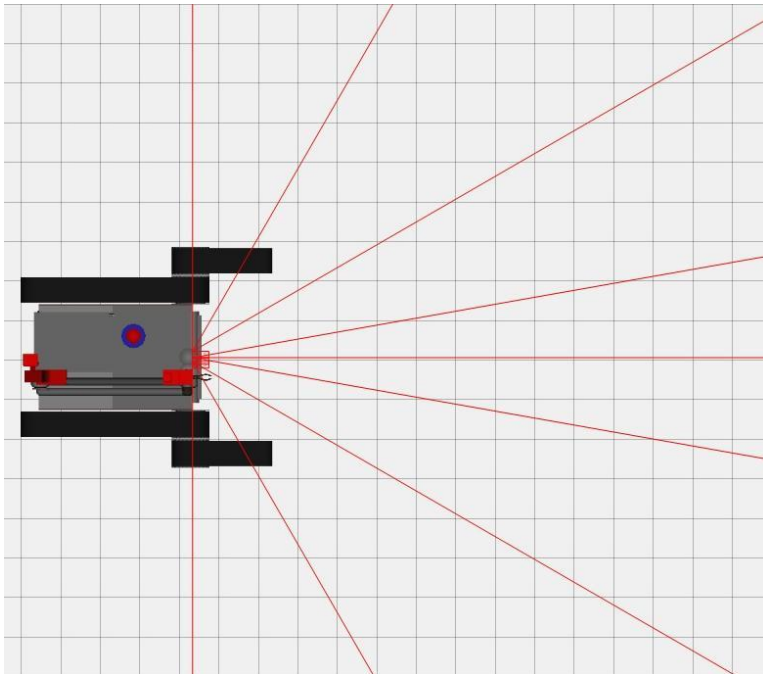
Sensor Definition

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MODELING AND SIMULATION, TESTING AND VALIDATION



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





- 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

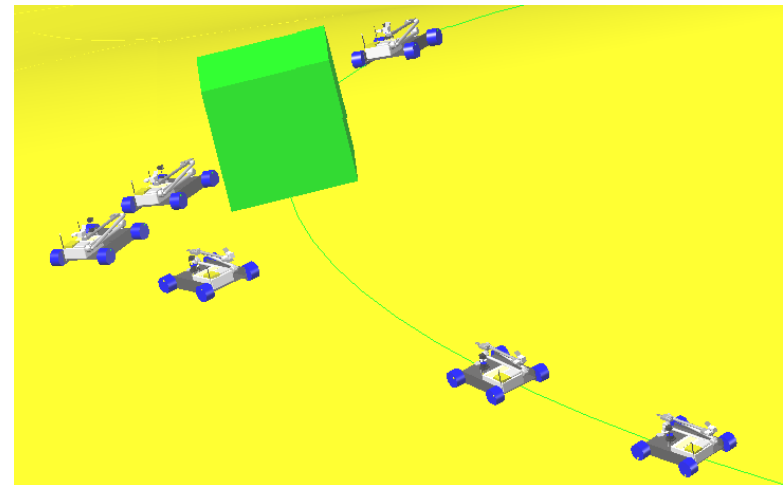
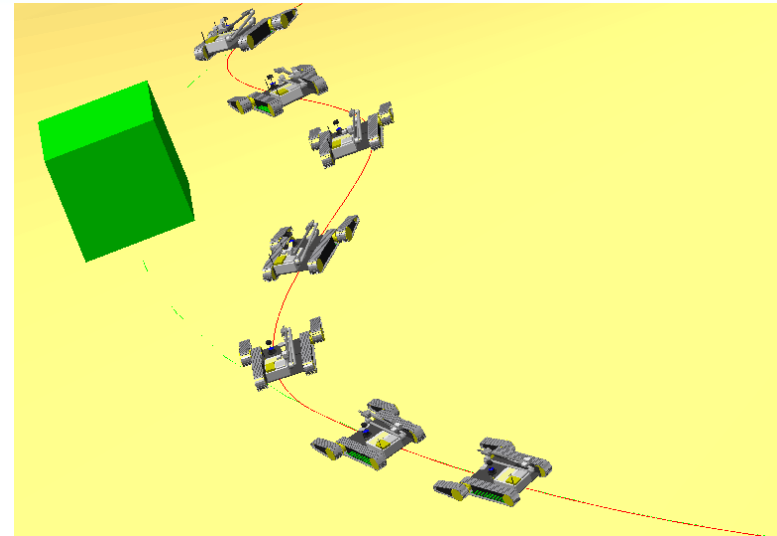


- Stage 1: Original Path
 - Follow prescribed path, using torque controller to maintain desired trajectory
- Stage 2: Obstacle Detection
 - An obstacle is detected by the range sensors within a predetermined distance
- Stage 4: Circumvent Obstacle
 - The vehicle avoids the obstacle by turning until parallel 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

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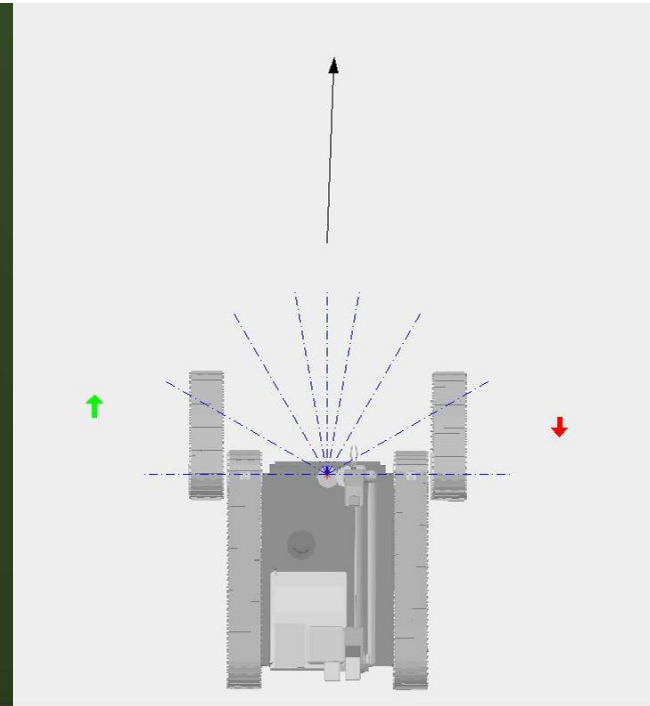


- Predefined path
 - Detailed track model, predefined avoidance path
- High-Fidelity
 - Detailed track model, autonomous operation
- Simplified
 - Simplified wheel model, autonomous operation



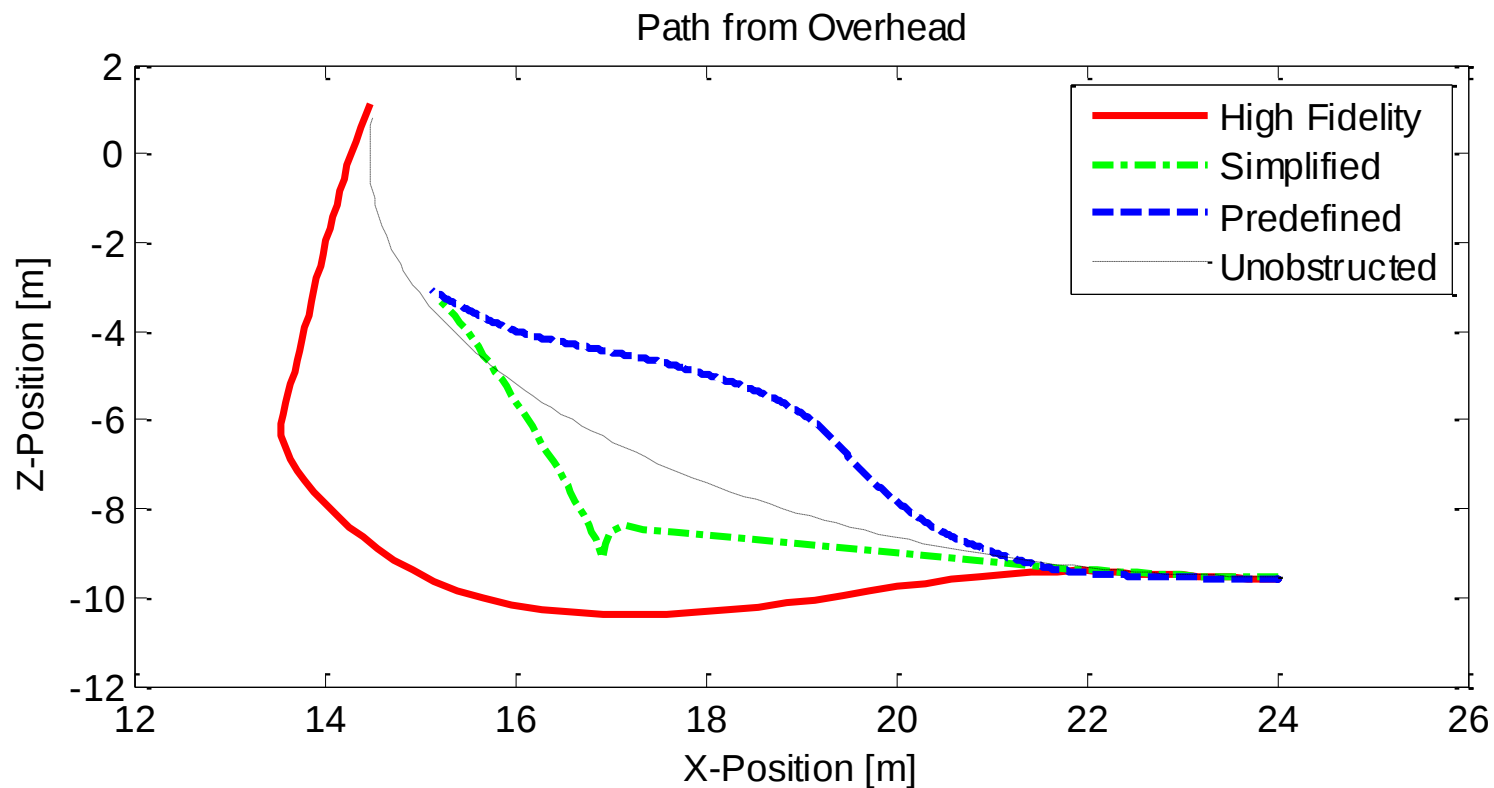
Autonomous Operation

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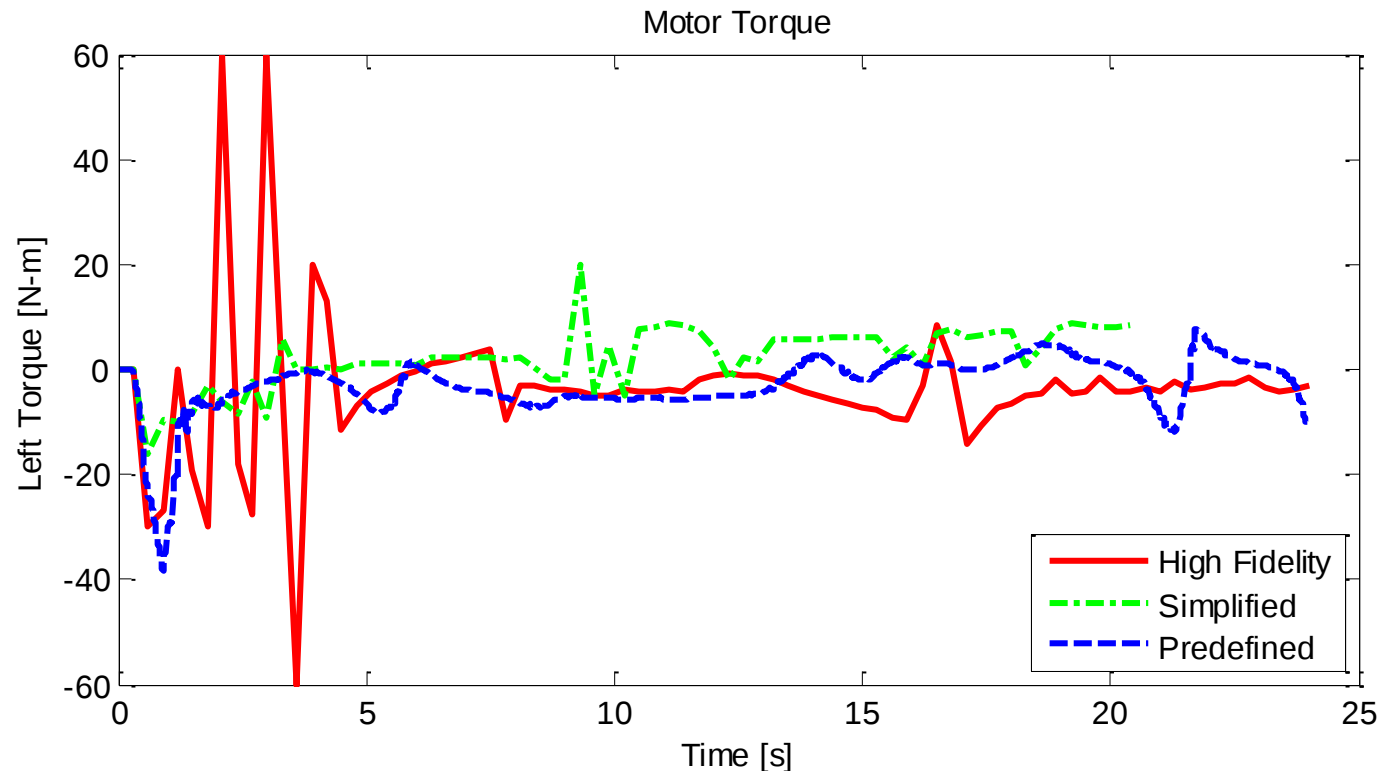


- Trajectory differences based on simulation type:





- 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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- 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

- 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



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MODELING AND SIMULATION, TESTING AND VALIDATION

Questions?

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