Modeling and Simulation of a Mobile Robot for Polar Environments

Thesis Presented by Eric Akers
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Committee Member – Professor Minden
Committee Member – Professor James
Overview

• Introduction
  – PRISM
  – Goal of this thesis
  – Modeling and Simulations
• Model and Design
• Experiments
• Results
• Conclusions
Introduction

PRISM

• Polar Radar for Ice Sheet Measurements
• Goal
  – Measure ice thickness
  – Determine bedrock condition beneath ice sheets
• SAR (synthetic aperture radar) gives a 2D picture
  – Monostatic or bistatic mode
Introduction

PRISM

• Autonomous rover carries necessary radar equipment and antenna
  – Survive for extended periods of time
  – Navigate in sometimes harsh arctic terrain

• Many areas of research involved
  – Robotics
  – Radar
  – Geology
  – Artificial intelligence
Introduction

Goal

• Build an accurate model of the rover
• Test the model to determine how the rover performs and some safe running parameters
  – Knowledge required to keep the rover running for long periods of time
Introduction
Modeling and Simulations

• Modeling Software
  – MSC.visualNastran 4D
  – ADAMS
  – Mechanical Desktop
  – SolidWorks
  – Solid Edge

• Simulation Software
  – MSC.visualNastran 4D
  – ADAMS
  – Khepera and Webots
  – RoboCup
Introduction
Modeling and Simulations

• Related Works
  – Modeling of a Snow Track Vehicle
    • University of Perugia
    • Test and improve on design of snow cat vehicles
  – Simulation of a Three-Wheeled All Terrain Vehicle
    • University of Arkansas
    • Demonstrate handling and suspension of three-wheeled ATVs
Introduction
Modeling and Simulations

• Related Works (continued)
  – Modeling Tracked Vehicles Using Vibration Modes
    • University of Michigan
    • Predict durability of track and the vibration inside the vehicle caused by the track
Model and Design

- Several different versions of the model were created as the design of the rover changed
  - Rover base
  - Wheel and track version
  - Roll cage and completely enclosed frame
Model and Design

• Design objective
  – Dimensions, weight, weight distribution as accurate as possible
  – Specifications manual and measurements
• Problems
  – Weight distribution not completely known
  – Where unknown, equal distribution used
• Objects such as engine, tires, track, and winch all had known weights
Model and Design

• Model consists of objects and constraints
• Constraints “constrain” two objects to allow movement in a specific way relative to each other
  – Revolute joints
  – Solid joints – act as one body
  – Belts and gears
  – Spherical joints
  – Rods and Ropes
Model and Design

- Vehicle before modifications
Model and Design

• Current vehicle
Model and Design

- Old models – different rover base
Model and Design

- Old models – current rover base
Model and Design

- Current model – current rover base
Model and Design

• Antenna modeled simply as a box
  – Dimensions and weight easily changeable

• Antenna Configurations
  • 2m x 4m - 400 pounds
  • 4m x 2m - 400 pounds
  • 2m x 2m - 200 pounds
Experiments

• Knowledge to determine
  – Slope vehicle can climb (pitch)
  – Angle the vehicle can handle (roll)
  – Turn radius

• This information gives us safe running parameters and some handling capabilities of the rover
Experiments

• Model configurations
  – Empty with no antenna
  – With antenna
    • Three different antennas
    • Four different towing mechanisms
  – With antenna and with different load distributions
    • One antenna used for these tests – 2m x 4m at 400 pounds
Experiments

• Antenna towing mechanisms
  – Single rope constraint
  – Two rope constraints
  – Single rod constraint
  – Two rod constraints
• Rope constraint allows a maximum distance between two bodies
• Rod constraint has a maximum and a minimum distance between two bodies
• Both allow rotation on both points of contact
Experiments

• Three different load distributions
  – Three locations for weight (front, middle, back)
  – 100, 400, 400 pounds
  – 100, 500, 300 pounds
  – 200, 400, 300 pounds

• A box with the specified weight was used to add the necessary weight
Experiments

• Experiments performed
  – Flat ground test
    • 15 meters with no obstacles or slope
  – Maximum slope test (pitch)
  – Turn radius test
  – Max roll test (roll)
Experiments

• Same experiments performed on each configurations of the model
• Turn radius experiments performed at different speeds
Results

- Empty model configuration

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat ground test</td>
<td>5.88 seconds</td>
</tr>
<tr>
<td>Max slope test</td>
<td>18 degrees</td>
</tr>
<tr>
<td>Max roll test</td>
<td>58 degrees</td>
</tr>
</tbody>
</table>
Results

- With antenna configuration

<table>
<thead>
<tr>
<th>Test with single rope</th>
<th>2 x 4</th>
<th>4 x 2</th>
<th>2 x 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat ground</td>
<td>6.26 s</td>
<td>6.24 s</td>
<td>6.02 s</td>
</tr>
<tr>
<td>Max slope</td>
<td>10 degrees</td>
<td>11 degrees</td>
<td>14 degrees</td>
</tr>
<tr>
<td>Max roll</td>
<td>58 degrees</td>
<td>58 degrees</td>
<td>58 degrees</td>
</tr>
</tbody>
</table>
### Results

- **With antenna configuration**

<table>
<thead>
<tr>
<th>Test with two ropes</th>
<th>2 x 4</th>
<th>4 x 2</th>
<th>2 x 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat ground</td>
<td>6.24 s</td>
<td>6.24 s</td>
<td>6.02 s</td>
</tr>
<tr>
<td>Max slope</td>
<td>11 degrees</td>
<td>11 degrees</td>
<td>14 degrees</td>
</tr>
<tr>
<td>Max roll</td>
<td>58 degrees</td>
<td>58 degrees</td>
<td>58 degrees</td>
</tr>
</tbody>
</table>
### Results

- **With antenna configuration**

<table>
<thead>
<tr>
<th>Test with single rod</th>
<th>2 x 4</th>
<th>4 x 2</th>
<th>2 x 2</th>
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</thead>
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<td>Max roll</td>
<td>58 degrees</td>
<td>58 degrees</td>
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</tbody>
</table>
Results

- With antenna configuration

<table>
<thead>
<tr>
<th>Test with two rods</th>
<th>2 x 4</th>
<th>4 x 2</th>
<th>2 x 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat ground</td>
<td>6.24 s</td>
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<tr>
<td>Max roll</td>
<td>58 degrees</td>
<td>58 degrees</td>
<td>58 degrees</td>
</tr>
</tbody>
</table>
Results

• With load distribution configuration

<table>
<thead>
<tr>
<th>Test</th>
<th>Load 1</th>
<th>Load 2</th>
<th>Load 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat ground</td>
<td>6.06 s</td>
<td>6.06 s</td>
<td>6.06 s</td>
</tr>
<tr>
<td>Max slope</td>
<td>13 degrees</td>
<td>13 degrees</td>
<td>13 degrees</td>
</tr>
<tr>
<td>Max roll</td>
<td>46 degrees</td>
<td>46 degrees</td>
<td>46 degrees</td>
</tr>
</tbody>
</table>
Results

• Weight is the single largest factor in how the rover performs
  – Antenna shape had little effect
• Slower speed better (turning)
• Two rods and two ropes better than single rod and single rope towing mechanisms
• No steep hills while towing the antenna
Results
10 km/hr vs 2 km/hr with two ropes
Results

1 Rope vs 2 Ropes at 8 km/hr
Results

- Simulation from successful test
Results

• Turn radius simulations
  – 1 day for each series at all speeds
  – 2 weeks to finish all turn radius tests

• Average of 5 simulations for both max slope and max roll tests
Conclusions
Contributions

• Make decisions on the design and construction of the rover
• Give some approximate safe running parameters
• Give approximation of how vehicle handles while towing the antenna
Conclusions

Limitations

• Model and terrain an approximation of the world
  – Results are also an approximation

• Environment and terrain
  – Bumps, holes, obstacles
  – Actual terrain may vary greatly and cause rover to perform better or worse an some areas
  – Wind and blowing snow not accounted for
Conclusions
Limitations

• Model
  – Two motors instead of one
  – No testing of torque, all kinematics tests
  – Shape, weight, and weight distribution differences could cause incorrect results
Conclusions

Future Work

• Modeling of bumpy environment and testing how the different antennas handle
  – Modeling an environment with bumps and holes will allow a larger variation of results between the antenna towing mechanisms

• Make improvements to the simple antenna towing mechanisms
Conclusions
Future Work

• Any major changes such as adding accumulation radar to the front and depth sounder antennas to the sides
• Add more environmental conditions such as wind to the simulation
Questions

• Thank you to the committee members, the PRISM robotics team, my wife Vicki, and all who have attended