Assessment of Energy Efficient Planning

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Robotics Collaborative Technology Alliance

- Fundamental and applied research to change robots from tools into teammates
  - Universities & Labs (e.g. FSU, CMU, UCF, Upenn, JPL)
  - Companies (GDLS, RR)

- ARL develops technology and assesses RCTA partners work
• Skid steer vehicles turn by having wheels/tracks slip and/or skid
  • Robust and easy to maintain
  • Sharp turns increase motor torque (maybe beyond limit)
  • Result can be higher energy use
  • Idea: plan a path reducing sharp turns
  • Gain: potentially more energy efficient and fewer collisions

• FSU/CMU developed a planner intended to plan paths constrained by keeping turns within torque limits.
• These limits are terrain dependent, so learning is required to inform the constraints.
• Start with theoretical model of robot dynamics (requires friction).

• Power model: torque as learned function of commanded turn radius.

• Models are combined to create constraint for turn radius.

• Path planning samples possible paths, with a heuristic preference for energy efficient ones, rejecting those that violate constraint.

• Details “Learning of Skid-Steered Kinematic and Dynamic Models for Motion Planning” Camilo Ordonez, Nikhil Gupta, Brandon Reese, Neal Seegmiller, Alonzo Kelly, Emmanuel Collins
\[
\begin{bmatrix} v_y \\ \psi' \end{bmatrix} = \frac{r}{\alpha B} \begin{bmatrix} \frac{\alpha B}{2} \\ -1 \\ \frac{\alpha B}{2} \\ 1 \end{bmatrix} \begin{bmatrix} \omega_l \\ \omega_r \end{bmatrix}
\]

- \(\alpha\) is terrain parameter
- \(r\) is wheel radius
- \(\omega\) is angular wheel velocity

Basis for dynamic model

Assume motion in a plane
Goal of Experiment

• Primary:
  • Does energy efficient planning (EE) use less energy than minimum distance planning (MD)?
    - Compare difference in energy use of EE and MD paired by course

• Secondary:
  • Does energy efficient planning (EE) use less energy than energy efficient planning without learning (EE*)?
    - Compare difference in energy use of EE and EE* paired by course
  • Does energy efficient planning result in fewer collisions (if any occur)?
    - Comparison method TBD
Equipment

Robot
- Clearpath Robotics Husky
- Stereo for visual odometry
- Lidar for obstacle detection
Recording
- Energy expended
- # collisions

Course factors
- Asphalt & Grass
- Configuration of Cardboard Obstacles
- Time for at most 40 runs (tropical storm)
Design

- 36 Runs
  - 18 Asphalt / 18 Grass
- Different terrain for variability
- 16 Configurations of obstacles
- Terrain & Configuration constitute blocks
- Planner order randomized within block
- 4 configurations included Energy Efficient planning without learning

<table>
<thead>
<tr>
<th>Surface</th>
<th>Obstacles</th>
<th>Planner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>Config 1</td>
<td>Min. Distance</td>
</tr>
<tr>
<td>Grass</td>
<td>Config 1</td>
<td>Energy Eff.</td>
</tr>
<tr>
<td>Grass</td>
<td>Config 1</td>
<td>Energy Eff. No learn</td>
</tr>
</tbody>
</table>
Terrain Effects

- Left: Difference in energy use by pairs
  Energy Efficient – Minimum Distance
- Possible difference by terrain
- Below: Energy used on each terrain
- More energy used on asphalt then grass
Points represent observed difference in energy use (EE – Min Dist) within a pair.
• With extreme points
  • 16 pairs
  • 95% CI (-262, 1812) Joules of energy savings for EE
  • average of differences -775 Joules
  • Paired t-test: p-value 0.13

• Without extreme points
  • 14 pairs
  • 95% CI (-39, 1458) Joules of energy savings for EE
  • average of difference -710 Joules
  • Paired t-test: p-value 0.06
<table>
<thead>
<tr>
<th>Terrain/Planner</th>
<th>Min. Distance</th>
<th>Energy Efficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>5 / 8</td>
<td>0 / 8</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0 / 8</td>
<td>0 / 8</td>
</tr>
</tbody>
</table>
• Does energy efficient planning work better with learning than without?
  • Virtually certain the answer would be yes at the outset
  • Really just a sanity check
  • 4 Pairs (2 sided t-test)
  • 95% CI (-137, 2644) Joules energy savings with learning
  • p-value 0.06
Conclusions

• Potential energy savings
  • Real life vs simulation
  • Seeing the whole map vs having it revealed
  • Extreme points are not measurement errors
  • Might see substantial savings with human checking

• Evidence for better collision avoidance on grass
  • Possibly to other slippery surfaces
• We would like to test the algorithm further over a larger (sloped) course

• Test is of planning algorithm, not platform specific

• Try with a tracked platform or legged robot

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