Steerability Analysis on Slopes of a Mobile Robot with a Ground Contact Arm

Jesús M. García
Universidad Nacional Experimental del Táchira, San Cristóbal, Venezuela

Jorge L. Martínez, Anthony Mandow and Alfonso García-Cerezo
Dpto. Ingeniería de Sistemas y Automática, Universidad de Málaga, Spain
1. THE LAZARO MOBILE ROBOT
2. NAVIGABILITY INDICES
3. TIP-OVER AVOIDANCE
4. EXPERIMENTAL RESULTS
5. CONCLUSIONS
1. THE LAZARO MOBILE ROBOT
THE LAZARO MOBILE ROBOT

- Specially designed to have an additional contact point with the ground

Four-wheeled skid-steered vehicle

Two degrees of freedom arm, whose end-effector is a caster wheel
Supporting forces of the wheels: $F_{1z}$, $F_{2z}$, $F_{3z}$, $F_{4z}$ can be estimated knowing the pitch and roll angles on the plane, angle $\theta_1$, length $d_2$ and the force exerted by the caster wheel $F_{5z}$.
2. NAVIGABILITY INDICES
**Tip-over stability index**: based on the minimum supporting force $F_{\text{min}}$ that depends on the number of contact points with the ground.

\[ I_t = \frac{F_{\text{min}}}{|W|/2} \]

*Denominator normalize index between 0 and 1*

**Four contact points**: $F_{\text{min}}$ is calculated as the minimum supporting forces of the axes between adjacent traction wheels.

Supporting forces of the axis between adjacent wheels $i$ and $j$:

\[ F_{ij} = F_{iz} + F_{jz} \]
- **Three contact points:** $F_{min}$ is calculated as the minimum supporting forces of the three wheels in contact with the ground.

- **Five contact points:** *It is an intermediate case between four and three contact points.*
**Steerability index:** calculated as the minimum supporting forces of the longitudinal axes of the vehicle

\[ I_s = \frac{\text{min}(F_{14}, F_{23})}{|\vec{W}|/2} \]

*The caster wheel does not provide traction*
3. TIP-OVER AVOIDANCE
- **COG control strategy**: COG is modified by actuating on arm rotation $\theta_1$ without additional contact with the ground ($F_{5z}=0$)

**Optimal $\theta_1$ for every combination of pitch and roll angles**
**Additional contact strategy**: by exerting a certain force $F_{5z}$ against the ground with the caster wheel.

**Optimal $\theta_1$ angles**

**Optimal $F_{5z}$ forces**
Static comparison: Additional contact strategy obtains the best values for tip-over prevention. COG control achieves the best results for steerability.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Tip-over</th>
<th>Steering</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>σ</td>
</tr>
<tr>
<td>Fixed COG</td>
<td>0.392</td>
<td>0.241</td>
</tr>
<tr>
<td>COG control</td>
<td>0.524</td>
<td>0.255</td>
</tr>
<tr>
<td>Additional contact</td>
<td>0.603</td>
<td>0.179</td>
</tr>
</tbody>
</table>

Mean and standard deviation of the navigation indices
4. EXPERIMENTAL RESULTS
ADAMS simulations: straight line motion along an undulating ramp
EXPERIMENTAL RESULTS

- **Downward motion**

*Navigation with an additional ground contact point*
EXPERIMENTAL RESULTS

- **Downward motion**

- **The $\theta_1$ angle and the $F_{5z}$ force**

- **The tip-over and steering indices**
EXPERIMENTAL RESULTS

- Upward motion

*Navigation with an additional ground contact point*
**EXPERIMENTAL RESULTS**

- **Upward motion**

The $\theta_1$ angle and the $F_{5z}$ force

The tip-over and steering indices
5. CONCLUSIONS
The effect on vehicle steerability of an arm ground contact have been analyzed

The case study of the mobile robot Lazaro whose end-effector is a caster wheel have been presented

- Simulation results with ADAMS show that tip-over can be improved with an additional ground contact but it can also provoke a loss in steerability

- COG control of the on-board arm obtains goods results both in tip-over and steering indices
CONCLUSIONS

Future work

► To complete navigability analysis with an sliding index

► To obtain real data from experiments with Lazaro

Thank you! ¡Gracias!