Improving skid-steering on a 6x6 all-terrain vehicle

A preliminary experimental study
Introduction to the problem

- Two existing principles for steering a wheeled vehicle
  - Ackermann steering
  - Skid-steering

- Our purpose
  - To keep the robustness and mechanical simplicity of skid-steering vehicles
  - Trying to minimize the energy consumption of such vehicles during steering

- A complex phenomenon, difficult to model
- Preliminary experimental results to check consistency
  - Evaluate the ripping forces
  - Try to minimize them...
  - ...by adjusting normal contact forces
Ackermann steering

- Ackermann (1817) / Jeantaud (1870)
- For wheeled vehicles that steer with **minimal skid**
- With \( N \) axles, \((N-1)\) axles must steer at least
- Mostly for hard ground

- **Minimal skid vs. complexity**

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Improving Skid-steering
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Introduction
- Ackermann
- Skid-steering

Vehicle
Experiment
Results
Conclusion
Future work

For wheeled and tracked vehicles
Mechanical simplicity (no steering mechanism, only suspension)
Wheels cannot roll laterally
Mostly for low friction / soft grounds

Simplicity vs. turning resistance

Two versions of the same mobile mortar
Ackermann and Skid-steering tracked, Patria AMOS

Amphibian ATV, Oasis LLC Max 6x6
Tracked tractor, Caterpillar D6R III
Mobile robot, Pioneer 3 AT
AT wheelchair, Modul Evasion

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Overview of the 6x6 Kokoon vehicle

- An **ATW (All-Terrain Wheelchair)**
- **6x6** transmission and **2x1330W electric engines**
- Oleo-pneumatic **suspension** on all wheels
- **Climbing** capacity: 20cm obstacles, 36% slopes
- **Speed**: 8 km/h    **Autonomy**: 4h
Overview of the 6x6 Kokoon vehicle

- Multiple functions

  - Sliding sport seat
  - Top case or transporting platform
  - Lead batteries 24V 160Ah
  - 2 DC electric engines of 1330W each
  - 6x6 all-terrain vehicle
  - Independent oleo-pneumatic suspensions

- **Skid steering** for robustness and all-terrain mobility

- A **reconfigurable** vehicle

- A research platform with **sensors**

**Introduction**

**Vehicle**

- Overview
- Transmission
- Suspension

**Experiment**

**Results**

**Conclusion**

**Future work**
Belt transmission: 3 wheels at the same speed
Compatible with suspension displacements
Good efficiency
Clutching
Improving Skid-steering

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**Introduction**

**Vehicle**

- Overview
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**Experiment**

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**Vehicle suspension**

- **6 Independent wheels**
  - Length = 175 cm
  - Width = 103 cm
  - Track width = 93 cm
  - Wheel base = 47 cm
  - Wheel diam. = 40 cm
  - Wheel width = 7 cm

- **Trailing arm suspensions**
  - Robust
  - Easy to adjust
  - Oleo-pneumatic shock-absorber

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The force plate

- **Steady-state** circular turning
- A force plate to measure contact reaction forces

- \( Rx \) longitudinal force provided by the engines
- \( Ry \) lateral force due to ripping
- \( Rz \) normal force due to mass dispatching
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Introduction
Vehicle
Experiment
• Force plate
• Mass
• Suspensions
• Turning
Results
Conclusion
Future work

A six-component force plate (TSR, France)

Force measurement ranges:

\[
\begin{align*}
R_x: & \ 1000N \\
R_y: & \ 900N \\
R_z: & \ 2000N
\end{align*}
\]

3 two-component strain gauge transducers at 120°

3 tangential components (\(R_x-R_y\))

3 normal components (\(R_z\))

Acquisition chain: 6 channels, 16 bits, 100Hz, Labview

Wrench = 6x6 Calibration matrix \(x\) Tensions

\[
\begin{bmatrix}
F_x \\
F_y \\
F_z \\
M_x \\
M_y \\
M_z
\end{bmatrix} = \begin{bmatrix}
V_1 \\
V_2 \\
V_3 \\
V_4 \\
V_5 \\
V_6
\end{bmatrix} \cdot C
\]

Introduction

Vehicle

Experiment

• Force plate

Results

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Mass dispatching

- Centre of mass is computed with the CAD model
- Hypothesis: uniform density in each part
- Empty mass: 367 kg
**Mass dispatching**

- Experimental measurement
- 6 scales with the same height

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**Introduction**

**Vehicle**

**Experiment**

- Force plate
- Mass
- Suspensions
- Turning

**Results**

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**Future work**

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**Good correlation**

Experiment / CAD
Improving Skid-steering

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Suspension reconfiguration

Reconfigurable suspension

- **Reference** configuration
  - Three identical suspensions

- **Includes a 83kg driver**

- **Modified** configuration
  - Differentiated suspensions

- **Central suspension becomes more loaded**

- **A new mass dispatching**

Reference dimensions

- Adjustment with $h_s$
  - **Initial** $h_s = 145\text{mm}$
  - **New** $h_s = 045\text{mm}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_s$</td>
<td>180 mm</td>
</tr>
<tr>
<td>$h_{s\text{ std}}$</td>
<td>145 mm</td>
</tr>
<tr>
<td>$h_{s\text{ mod}}$</td>
<td>45 mm</td>
</tr>
<tr>
<td>$l_s$</td>
<td>210-280 mm</td>
</tr>
<tr>
<td>$l_2$</td>
<td>170 mm</td>
</tr>
<tr>
<td>$l_a$</td>
<td>350 mm</td>
</tr>
<tr>
<td>$e$</td>
<td>15 mm</td>
</tr>
</tbody>
</table>

Introduction

Vehicle

Experiment

- Force plate
- Mass
- Suspensions
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Turning experiment

- **Three** types of trajectories for the **external** wheels

<table>
<thead>
<tr>
<th>Radius R</th>
<th>Infinite (=&gt; straight line)</th>
<th>6m</th>
<th>3m</th>
</tr>
</thead>
</table>

- Acquisition at 100Hz is enough for low speed (around 4-5 kph)

- Duration: from **1.5s** (straight line) to **2.5s** (3m turn)

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**Improving Skid-steering**

**Fauroux / Vaslin / Douarre**

- Introduction
- Vehicle
- **Experiment**
  - Force plate
  - Mass
  - Suspensions
  - Turning
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- Conclusion
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**Lines drawn with flour**

- **R = 3m**
- **R = 6m**

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Typical curves

- Curves of $Rx$, $Ry$, $Rz$ are provided
- One or two wheels on the force plate at the same time
- Five zones appear on the time axis
- Average values on each zone (vibrations on gravel and electric perturbations)

$Rz1 = 627N$  \hspace{0.5cm} $Rz2 = 972N$  \hspace{0.5cm} $Rz3 = 905N$  \hspace{0.5cm} (one side only)

- Main results:
  - Wheels 2 and 3 prevail for $Rz$ -> confirms weight dispatching
  - Wheels 1 and 3 prevail for $Ry$ and turning moment
  - Wheel 2 generates most of the traction force $Rx$ (belt sliding ?)
Results for reference vehicle

- Influence of radius R
- Rz does not change with R
- Ry is quasi null in straight line
- Ry increases when R decreases
- Rx is quasi null in straight line
- Rx increases when R decreases
- This phenomenon was experienced by the driver
Results for modified vehicle

A 38% decrease of $R_x$ on Wheel 2

A 36% decrease of $R_y$ on Wheel 3

Turn is shorter on modified vehicle

Improving Skid-steering

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- Introduction
- Vehicle
- Experiment
- Results
  - Curves
  - Reference
  - Modified
  - COP
  - Explanation
- Conclusion
- Future work
Centre of pressure (COP)

- **COP** = the point where the moment of contact wrench is null
- **Phases** are visible (one or two wheels on the force plate)
- The COP follows **circles** => Trajectories were correct

![Graph showing COP movement](image)

- **X (cm)**
- **Y (cm)**

**Phases**
- Going straight
- Turn R=6m
- Turn R=3m

**COP** = the point where the moment of contact wrench is null

**Phases** are visible (one or two wheels on the force plate)

The COP follows circles => Trajectories were correct
Physical explanations

- Strong influence of mass dispatching on turning ability
- Analogy with the behaviour of a road tire

- Lateral force $R_y$ increases with normal force $R_z$
- Lateral force $R_y$ depends also on slip angle $\alpha_s$
- Linear behaviour up to $\alpha_{sl}$
- During skid-steering, two slip angles $\alpha_{s1}$ and $\alpha_{s3}$ appear on wheels 1 and 3
Conclusion

- **Skid-steering** can be greatly **improved**...
- ...only by **minor** adjustments on the suspensions
- **10cm** adjustments only decreased normal force of **30%** on front and rear axles
- Propulsion forces decreased of **30%** when steering
- **Multi-axles vehicles** without steering systems are **robust**. They can now be **efficient** when skid-steering
Future work

- Replace belts by chains to suppress sliding
- Add 6 force sensors inside the wheels for continuous measurement
- Build analytical model
- Towards an active correction system

Acknowledgement

ANVAR : French National Agency for Development of Research
TIMS Research Federation
Mobility pole
Michelin Company

...and many more on www.kokoon.fr.st

3 Videos