Object-Oriented Decomposition of Tire Characteristics Based on Semi-Empirical Models

Markus Andres, Dirk Zimmer and François E. Cellier

September 21, 2009
1. Tire Modeling

2. Motivation for this Work

3. Decomposition into Objects

4. The Implemented Model
   - The Communication Structure
     - A Vertical Dynamics Class
     - A Friction Class

5. Exemplary Results

6. Roundup

7. Thanks
A Simplified Cross-Section of a Tire

Figure: Basic structure of a steel-belt tire.
Tire Modeling

- The tire’s duties:
  - Generate driving forces
  - Long lifetime
  - Small rolling resistance
  - Damping and acoustic properties
  - Reliable operation under differing environmental conditions
  - ...
The tire’s duties:
- Generate driving forces
- Long lifetime
- Small rolling resistance
- Damping and acoustic properties
- Reliable operation under differing environmental conditions
- ...

Result
The tire is composed of a number of rubber composites, combined with steel elements making it very difficult to be described precisely.
State of the Art

There are numerous types of tire models suiting strongly differing needs.

- Simple models of ideal (non-slipping) tires.
- Semi-empirical single contact point models\(^1,^2\).
- Discretized multibody models (e.g. FTire).
- Models based on finite element analysis (FEA).

\(^1\)Pacejka (2006): *Tyre and Vehicle Dynamics.*
State of the Art

There are numerous types of tire models suiting strongly differing needs.

- Simple models of ideal (non-slipping) tires.
- Semi-empirical single contact point models\(^1,2\).
- Discretized multibody models (e.g. FTire).
- Models based on finite element analysis (FEA).

Vehicle Simulation

Semi-empirical single contact point models provide a very good trade-off between computational effort and accuracy.

\(^1\)Pacejka (2006): *Tyre and Vehicle Dynamics*.
Semi-Emprical Models

... are based on physical considerations, like those emerging from multibody dynamics which get enhanced with empirical formulas representing measurement results covering e.g. slip characteristics.
Terms and Definitions

**Semi-Emprical Models**

...are based on physical considerations, like those emerging from multibody dynamics which get enhanced with empirical formulas representing measurement results covering e.g. slip characteristics.

**Single Contact Point Models**

...apply forces and torques at a single point rather than an area (the tread area).
Motivation for Building a new Framework for Modeling Tires

- Existing models are often implemented in a flat and unstructured fashion.
- This results in models that are difficult to understand, maintain and customize.
- Implementations in Modelica have been made\(^3,4,5,6\).

---

\(^3\) Andreasson (2003): *VehicleDynamics Library*.
Utilize the capabilities of Modelica regarding object-orientation in tire modeling.

Create a structure that can cover different tire models overcomes the formerly mentioned problems.
Utilize the capabilities of Modelica regarding object-orientation in tire modeling.

Create a structure that can cover different tire models overcomes the formerly mentioned problems.

Note!

This work concerns itself less with modeling new tire properties, but more with an improved organization of existing knowledge.
Wheel Properties Decomposition

Figure: Composition of wheels and properties of tires.
Tire Properties Decomposition

Figure: Properties shown in relation to closely related classes of the semi-empirical contact point model.
Tire Properties Decomposition

**Figure:** Final decomposition of the tire properties.
The Implemented Model

Figure: Structure of a tire model in Dymola 6.1 based on the MultiBondLib\textsuperscript{7}.

The Communication Structure

<table>
<thead>
<tr>
<th>Top Level Icon</th>
<th>Second Level Icon</th>
<th>Contained Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Unit Vector Signals (UV)</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal eLong[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal eLat[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal eN[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal ePlane[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal eAxis[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Contact Property Signals (CP)</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal xCP[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal rCP[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal lCR;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal bCR;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal penetrationDepth;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BooleanSignal Contact[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Sensor Value Signals (SV)</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal eAxis[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal RBelt[3,3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal wBelt[3];</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RealSignal xBelt[3];</td>
</tr>
</tbody>
</table>

Top Level Icon | Contained Variables
---|---------------------|
|                  | RealSignal vLong; |
|                  | RealSignal vLat; |
|                  | RealSignal vN; |
|                  | RealSignal fLong; |
|                  | RealSignal fLat; |
|                  | RealSignal fN; |
|                  | RealSignal tLong; |
|                  | RealSignal tLat; |
|                  | RealSignal tN; |

Figure: The elements contained in the Tire Bus.

Figure: The elements contained in the Contact Point Connector.
The Vertical Dynamics Class

Figure: An exemplary class describing vertical dynamics, partly using the *BondLib*.$^8$

---

$^8$Cellier/Netbot (2005): *The Modelica Bond-Graph Library*.
**The Friction Class**

**Figure:** Classes that determine the frictional behavior of the tire.
The bicycle models are ideally rigid.

The initialization is identical for both.

Slim tires with differing frictional classes are mounted.

This can be realized by a few clicks in the tire model.
Animation: Four-Wheeled Vehicle

- A very basic unsprung vehicle model.
- It is accelerated by a torque acting on the rear tires.
- Vehicle understeers at higher velocities.
- A torque impulse makes the vehicle drift.
Uneven surfaces are included in the library.

Vertical dynamics allow the tire to lift from the ground.
The freely available Library *Wheels and Tires* provides:

- A framework for the implementation of tire models or parts of these.
- A well-defined and expandable structure that allows a convenient customization.
- A number of predefined ready-to-use tire models.
- *Test Bench* models for testing of basic tire properties.
- Examples showing the application of the tire models.

---

9 Andres (2009): *Object-Oriented Modeling of Wheels and Tires in Dymola/Modelica*. 
The freely available Library *Wheels and Tires* provides:

- A framework for the implementation of tire models or parts of these.
- A well-defined and expandable structure that allows a convenient customization.
- A number of predefined ready-to-use tire models.
- *Test Bench* models for testing of basic tire properties.
- Examples showing the application of the tire models.

Further Work:

- Implement further tire models in the existing structure.
- Use as many “real world” parameters as possible.
- Add effects due to temperature changes.
- A detailed list of possible enhancements can be found in the corresponding master’s thesis\(^9\).

\(^9\)Andres (2009): *Object-Oriented Modeling of Wheels and Tires in Dymola/Modelica.*
The End


Zimmer, Dirk/Otter, Martin (2009): Real-Time Models for Wheels and Tires in an Object-Oriented Modeling Framework. No address in, Accepted for publication in Vehicle Dynamics