Identification and Control for Riderless Motorcycles

Motivation & Objectives
A motorcycle, like a bicycle, is intrinsically unstable as its dynamics are non-linear and non-minimum phase meaning that it can easily fall over and needs to be controlled to keep its upright position. Unlike a car where the driver only has to take care of the desired trajectory, a motorcycle driver has to maintain the balance of the bike using the steering and moving its body, because yaw (direction) and lean angles are strongly coupled.

This project aims to study the state of the art on motorcycle modeling, design and implement a complete hardware and software set-up on a 1:5 scale ThunderTiger SBS model motorcycle, in order to make it suitable for autonomous motion, identify a mathematical model for the motorcycle through experiments and realize the first control attempts.

Hardware & Software design
The chosen hardware for this project consists in a ThunderTiger motorcycle, which has among other things a carbon fiber frame and front-rear suspensions. The rear wheel is powered with a 230W brushless motor while the front wheel can be steered using a standard RC servomotor. Everything is powered up with a LiPo battery.

A BeagleBone Black (BBB) microcomputer is added on the motorcycle, along with a 9 degrees of freedom Inertial Measurement Unit (Accelerometer, Gyroscope, Magnetometer) and a Global Positioning System (GPS) module.

The motor and the steering servo are also driven by the BBB. An ATmega328P microcontroller is also used to measure the remote control signals and transmit them to the BBB. As for the software, the BBB is running Ubuntu Linux. The Robot Operating System (ROS) is used for the acquisition of the different sensors data, communication with the controller and the actuators, logging of all data during experiments and the communication via Wi-Fi with Matlab on the master computer.

Model identification
The objective of the model identification is to find a mathematical formulation for the roll dynamics of the motorcycle, using the data gathered during outdoor experiments. Especially, it aims to find a linear model that can fit the real data around the upright position at constant forward speed.

To this end, open-loop experiments were conducted, where the bike was manually driven with the remote control, stabilized, and then excited on the steering actuator with a Pseudo-Random Binary Signal (PRBS), while the BBB was logging every data.

Several approaches and algorithms were then used to compute mathematical models minimizing the norm between the real and the estimated output. Grey-box identification starts for example from a given bicycle state-space model and then optimizes the parameters. Black-box techniques such as ARX, ARMAX, OE, BJ and Subspace methods were also used to identify either polynomial or state-space models.

Time- and frequency-domain validations were then conducted along with statistical validation to assess the performance of the different identified models. Among all the identified models, the Box-Jenkins model and the 4th-order subspace model were the bests, with around 59% and 48% of fit in time and frequency domain respectively.

Controller simulations and experiments
Based on the previously identified mathematical models, a discrete Proportional-Integral-Derivative (PID) controller was designed as a first control attempt to stabilize the bike. The design of this controller was mainly focused on the robustness, taking into account the approximation of each identified models.

The designed controller has a gain margin of 7.47dB and a phase margin of 64.6° for reasonable overshoot and rise time values (7% and 1.2sec). Simulations established that the controller is able to follow roll angle references without exceeding the steering servo real capabilities (left-hand side figure).

This controller could then be coded and implemented in the ROS system on the BBB and tested in reality. The conducted experiments (right-hand side figure) showed the ability of the controller to stabilize the real motorcycle while maintaining a constant heading angle (straight line). This controller allows then to validate the identification process and leaves the door open for the design of more complex controllers capable of path-following with the motorcycle.

Author: Julien Leimer
Master thesis
Fall semester 2015

Supervisor: Prof. Colin Jones
Assistants: Luca Fabiatti, Harsh Shukla