Problem Statement: Riderless bicycle control

This course project aims to develop an autopilot for a rider-less bicycle (as in Ref. 1), to keep it in upright position with respect to some specified speeds. The details on bicycle dynamics can be found in Ref. 1. Considering the following quantities: i) states: roll angle, roll rate, steer angle, and steer rate; ii) input: steering torque and iii) output: roll angle. The dynamics of the bicycle can be expressed as a fourth order linear model as in Ref. 1. The linear model is velocity dependent (often referred to as a linear parameter varying model), where one can obtain linear time-invariant state space models corresponding to the different fixed velocities. For this project, consider the following three fixed velocities: $v_1 = 0$ meter per second (mps), $v_2 = 3.5$ mps and $v_3 = 5$ mps.

The following tasks need to be performed in this project. You may use MATLAB, Scilab or any other computing software.

1. Obtain state space models and transfer functions of the bicycle at velocities: v_1, v_2 and v_3. Compute poles and zeros, and the eigenvalues of system matrix A, for the obtained three state space models and transfer functions.

2. Show the time response of system, for: i) zero input with (any) non-zero initial states and ii) unit step input.

3. Analyze stability (asymptotic stable, marginally stable, BIBO stable) of bicycle corresponding to the velocities: v_1, v_2 and v_3.

4. A control system (autopilot) needs to be designed to keep the bicycle in vertical upright position. Is it possible to stabilize the bicycle (keep the bicycle in vertical upright position), with the help of appropriate automatic control action (steering torque provided by the actuator), at velocities: v_1, v_2 and v_3. If yes, then design such feedback controllers. Take your own design specifications in terms of steady-state error, damping ratio, and settling time, and then, design controllers to achieve these objectives. Three different controllers may be proposed for velocities: v_1, v_2 and v_3. Implement the designed controllers, and show the step input response of the closed-loop system. You may use "sisotool" available in MATLAB (or similar simulation software), for designing controllers.

Ref.1: V. Cerone, D. Andreo, M. Larsson and D. Regruto, "Stabilization of a Riderless Bicycle [Applications of Control]," in IEEE Control Systems Magazine, vol. 30, no. 5, pp. 23-32, Oct. 2010, doi: 10.1109/MCS.2010.937745.