Bicycle and Motorcycle Dynamics 2010
Symposium on the Dynamics and Control of Single Track Vehicles,
20 - 22 October 2010, Delft, The Netherlands

Speed-Adaptive Path-Following Control of a Riderless Bicycle via Road Preview

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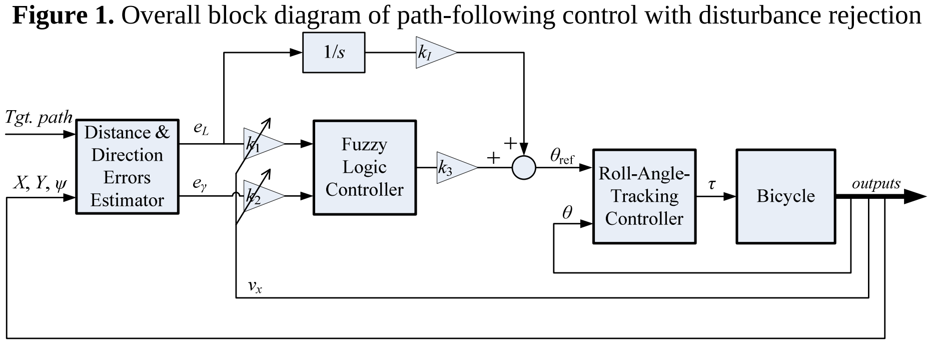
Abstract

In this study, a genetic-fuzzy control system is used to control a riderless bicycle where control parameters can adapt to the speed change of the bicycle, with the control structure shown in Figure 1. This controller consists of two loops: the inner is a roll-angle-tracking controller which generates steering torque, and the outer is a path-following controller which generates the reference roll angle for the inner loop. The equations of motion of a bicycle with constraints of rolling-without-slipping contact condition between wheels and ground are developed. The inner loop is controlled by a sliding-mode controller (SMC) on the basis of a linear model obtained from the non-linear one via system identification. By defining a stable sliding surface of error dynamics and an approriate Lyapunov function, the bicycle can reach the roll-angle reference in a finite time and follow that reference without chattering. Three control parameters for SMC can be tuned to adjust the performance of this controller.

Figure 1. Overall block diagram of path-following control with disturbance rejection



The outer loop determines the proper roll-angle reference by using a fuzzy-logic controller (FLC). For path-following control, the preview distance error e_L and the preview direction error e_γ are considered simultaneously. The preview errors are determined following the scheme in Figure 2. First, the preview point P is determined at a preview distance ahead from the reference point of the bicycle, where the preview distance is given by $L_{\text{pre}} = v_x \times T_{\text{pre}}$, with v_x is the forward speed and T_{pre} is a constant preview time. Once the preview point is determined, the preview distance error e_L will be the signed shortest distance from the preview point to the defined path. The preview direction error e_γ is the angle between the axis of the bicycle and the direction vector (or tangent vector) of the path at the nearest point H on the path to the preview point. This scheme is adopted from a study of Sharp [1] with a slightly difference in determining the target point, to avoid the situation in which the target point might be undefined.

From the preview distance and direction errors, the FLC generates the reference roll angle. To make the controller speed-adaptive, the controller parameters including the scaling factors and the deforming coefficients of the fuzzy membership functions are tuned by using genetic algorithms [2] for different speeds in the operational speed range, and the gain scheduling technique is used. Figure 3 shows the results of a simulation in which the bicycle is controlled to follow a sinusoidal path defined by the equation $Y = 2.5\sin(2\pi X / 50)$ from an initial lateral error of 2m. At the same time, the speed is controlled to increase from 5 at the initial position to 30km/h at a longitudinal position of 50m, then decrease back to 5km/h at the longitudinal position of 100m. It can be observed that the bicycle approaches the target path in the first 10m. After that, the absolute value of the tracking error is kept under 0.07m in this simulation.

From the riding experience, lateral wind force and disturbance usually affect the maneuverability of the bicycle and cause stability problems. This problem can be solved by adding an integrator and an adjustable gain k_I between the preview distance error e_L and the reference roll angle. A simulation with this controller at a speed of 10km/h is shown in Figure 4, where the value of k_I is 15. As soon as the disturbance is applied, the tracking error increases. However, by the effect of the integrator, an additional term is added to the reference roll angle. This can help the bicycle be pulled back to the direction making the tracking error reduced. When the disturbance releases and the equilibrium point changes, a similar process also happens, but in the inverse direction. The overshoot is about 0.3m, and the transient longitudinal distance is about 7m. The tracking error the simulation without the integrator is also plotted for comparison, showing that it approaches a steady-stead error of nearly 0.8m during the appearance of the disturbance.

Figure 2. Error estimation for path-tracking control with preview

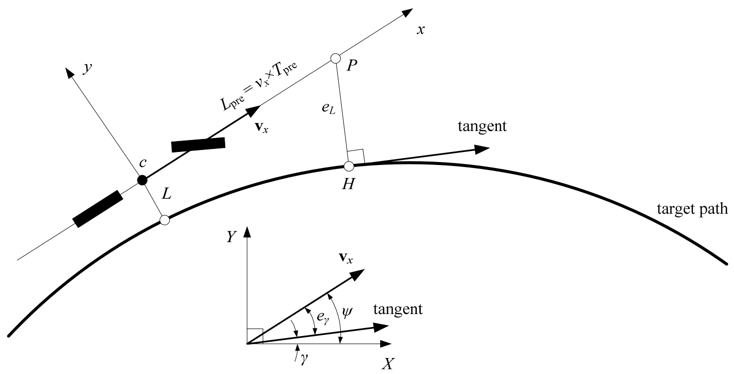


Figure 3. Path-tracking control at varying speed

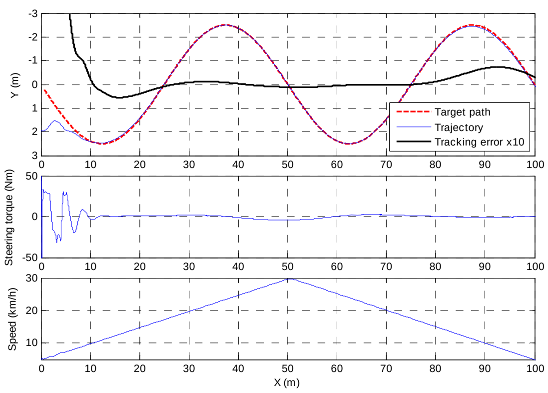
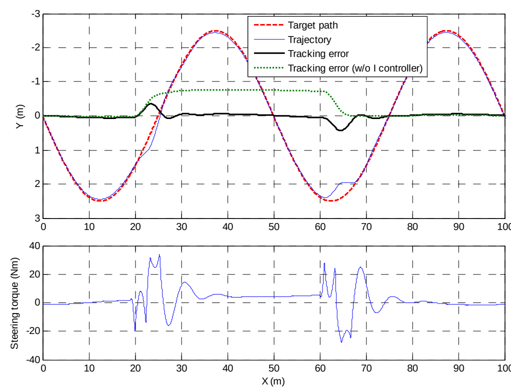


Figure 4. Path-tracking control with disturbance rejection at a speed of 10km/h



References

[1] R. S. Sharp, "Motorcycle steering control by road preview", *J. of Dynamic Systems, Measurement, and Control*, **129** (2007), 129, pp. 373-381.

[2] C. K. Chen and T. S. Dao, "Genetic fuzzy control for path-tracking of an autonomous robotic bicycle", *J. of System Design and Dynamics*, **1** (2007), pp. 536-547.