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On the importance of haptic feedback in the balance task of bicycling

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Abstract

Since the birth of the safety bicycle in the 1890s, their dynamics and self-stability have been subjects of numerous discussions and bodies of research. These issues can nowadays considered to be partly resolved [1] for a wide range of applications. Still, the question remains on how the rider stabilizes the lateral motions of the bicycle when it's driven at low (unstable) forward speeds or how the rider follows a desired path; e.g. the required control inputs and the rider learning process. These probably comprise of haptic, vestibular and visual cues; here we will focus on the haptic cues and the task of stabilization.

Haptic systems in vehicle control are usually connected with two types of realities. One current application of kinesthetic devices is focused on enabling the driver to feel feedback from the vehicle state when steer-by-wire systems come into play. Steer-by-wire vehicles often need a resistance torque to prevent excessive rotation of the steering wheel. This feedback torque is often defined by a simple relation, e.g. a function of wheel angle, wheel torque, or vehicle state, and aims to assist the driver in achieving the desired trajectory in real performance [2]. Similarly, haptics can also be used as a tool to improve first stages of task learning through fading guidance towards a goal [3]. On the other hand, computer simulations with virtual environments can be helpful in evaluating different strategies for steering control [4], as a previous stage to its implementation, and in development of control systems aimed to improve riding safety [5].

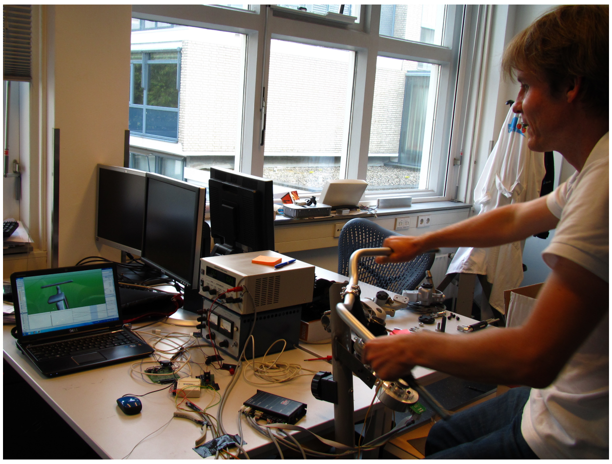

Figure 1: Experimental bicycle simulator setup with steering input device with haptic feedback and a computer screen for visual feedback

In this work we address the need for haptic feedback in the balancing task of bicycling. For that we use an experimental bicycle simulator setup which has been described in [6]. The system, which is shown in Fig 1, consists of a stationary bicycle on which one can pedal and steer. The lateral dynamics of the bicycle are governed by the linearized equations of motion for lean and steer [7] which are implemented in the computer model. The steering assembly has torque feedback driven by the model; it is computed using the measured handlebar state, steer angle and rate, and the estimated lean angle and rate. The steer dynamics are governed by the real handlebar system. Visual feedback is given by means of a real time animation on a computer screen, with either a first or third person view.

Stability of the haptic system for any kind of human contribution, e.g. tight grasp or sudden release, must be guaranteed. In so doing, one can resort to place a "virtual coupling" between the haptic device and the virtual environment that acts as a mechanical filter [8]. The bicycle haptic interface, as developed, shows a impedance casuality, i.e., forces are transmitted to the rider, whereas the input of the virtual environment is the handlebar state. Uncertainties in the measurement and sampling rate of steering angle and its rate, as well as actuation rates of the haptic feedback motor and update rate of the visual display are key factors in the haptic system. Low sampling and actuation rates may lead, depending on the physical model utilized, to unrealistic feedback torque or excessive phase lag [9] resulting in poor simulation and reproduction of a rider's behavior in a real environment.

Previous work [10] has shown the states necessary for control of a bicycle, but not how a rider obtains state information. While it has been determined that visual feedback is insufficient and handlebar feedback torque is necessary for stabilization of the bicycle [6], this work investigates the extent feedback torque is used by the rider to maintain balance and how it is that a rider performs this task. We utilize system identification techniques to isolate the proprioceptive feedback loop used to maintain balance and determine how it varies with the bicycle steer dynamics in the unstable speed range. By minimizing the usage of the vestibular and visual cues, and removing the maneuvering task, largely the system dynamics are only available to the rider through the handlebar feedback torque.

The rider is instructed to maintain balance of the bicycle at a constant forward speed in the uncontrolled unstable speed range. The lean angle and rate are presented to the rider via the computer display and handlebar torque is generated by the computer model. A torque perturbation is applied to the handlebars in addition to the computed handlebar torque from system dynamics. To obtain an accurate estimate of the rider's proprioceptive controller at a given speed, several periods of the rider response are recorded and the experiment is repeated at various unstable speeds and with multiple subjects.

Acknowledgments

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