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Critique of Assumptions Underlying Bicycle Handling Research

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Abstract

Stabilization / maneuvering may be harder to understand for bicycles than for other vehicles with roll freedom, such as airplanes or motorcycles. Since rider mass far exceeds bicycle mass, difficult-to-model corporeal flexibility dramatically reduces inertial reactions; and lagging postural control becomes an important part of the dynamics. The added degrees of freedom of rider deformations, and associated internal-variable postural control systems, not only increase the complexity of the system, but provide multiple avenues by which a skilled rider can control a bicycle (or an unskilled rider may disturb it). Furthermore, powerful pedaling efforts impose large forces on the steering mechanism. All the additional systems and qualities involved in bicycle control are inevitably subject to human inconsistency, adaptation, and fatigue.

The purpose of this paper is to call attention to some important ways in which ridden bicycles may differ from the models so far used to understand them. It is primarily ‘philosophical’, involving consideration of what makes an appropriate model, and what are meaningful questions to pose, rather than matching an assumed model to data. Unfortunately, some of the tentative conclusions offered here are quantitatively based on a simple rigid model [1] already known to be inadequate, so these will have to be revisited in future.

The perspective of this author is that bicycling is widely accepted only because it is normally a very low-bandwidth task. This could be in part because the steering adjustments necessary to keep the bicycle upright largely occur “instantaneously” through the intrinsic dynamics of the front assembly, rather than through rider sensing of roll and responsive control of steer angle (which are delayed by sensing and actuation lags.) To benefit from those intrinsic dynamics, the steer angle must be made a degree of freedom (the well-known “torque control” rather than “angle control”); and the uncontrolled (open loop) bicycle must possess near-stability. There may also be some involvement of upper-body leaning.

For a *rigid-rider model* in hands-free operation, at all but the lowest speeds, the system typically has several stable eigenvalues that rapidly damp any steering transients; plus a near-zero eigenvalue that allows the roll to maintain a (slowly changing) value with no steering input. Those hands-free eigenvalues mean that any open-loop steer torque (or impulse) quickly produces a ‘settled’ roll rate (or angle), absolving the rider of any need to monitor or control the roll angle in detail. And most cycling takes place on wide paths, requiring adjustments only occasionally (i.e., every few seconds). Then, typical path-following or stabilization actions are only needed at frequencies well below any estimate of maximum human-controller bandwidth [2, 3].

To convince oneself of this perspective, it may be helpful to explore an atypically *difficult* riding task – staying on a narrow (0.1 m) painted line – where monitoring / reacting must be both precise and rapid. This is fatiguing and quickly leads to a degradation of performance. It is suspected that similar difficulty will be experienced when riding a bicycle lacking helpful front-assembly dynamics (reduced mass, trail, and spin momentum, plus Coulomb friction), because it too will demand constant rider sensing and input to prevent falling.

Within the above context, the paper attempts to discuss the following issues:

1. Is precision of path following [4] a useful metric for evaluating the bicycle/rider system? We argue that it exercises a skill that is only rarely needed in the real world, and involves a riding regime that most would find intolerably wearying.

2. Is it appropriate to model a rider as an immediately-reacting (apart from known neuromuscular delays) continuous feedback control system? We hypothesize that ordinary tolerable riding might involve sensing roll angle error in relation to desired path curvature only *every few seconds*, followed by minimal *open loop* impulsive or steady steering inputs to keep the vehicle within the roadway edges – in essence a discrete control process, that relies on the rapid damping of roll transients after any steer torque input. We also explore a philosophy and possible method of approximate trajectory planning and following, based on the principle of minimizing rider sensing and control actions. In this scheme, continuous feedback control would be practiced only rarely, when path precision requirements become unusually demanding.

3. Bicycle + rider models are closely critiqued. (a) Appropriate rider flexibilities (roll, yaw, and lateral displacement of torso; lateral knee motion [5]) coupled with their internal-variable postural control dynamics (needed to stabilize rider configuration [6]) are clearly essential to the actual mechanics, and maybe also to the ease of riding, *but* appear prohibitive in complexity. We argue that rigid-rider models should be used exclusively until ideas about rider control are solidified; related experiments must rigidify the rider with a support frame. [7] (b) Models should also be upgraded to incorporate passive arm loadings on the steering assembly (inertia, geometric stiffness, and muscular impedance), and appropriate tire properties (pneumatic trail, camber thrust, spin torque) [8].

4. What benchmark maneuvers best reveal the roll authority afforded by a given bicycle, or the rider's limitations in high-frequency tracking? We propose that pure roll maneuvers in an open space eliminate subsequent data-obscuring roll moves (i.e., the heading and path-position corrections needed to stay on a path or treadmill). One test option could be tracking a commanded roll angle; another could be the response to a sudden step in roll torque.

5. The relation of steering impedance to "stability" will be discussed. High impedance does not directly imply greater dynamic stability, but it could have a role in reducing 'jitter' from muscular tremors or postural disturbances.

We outline methods for evaluating the foregoing hypotheses, and suggest what consequences to expect if they are validated.

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