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CORNERING IN BICYCLING: COMPUTER MODEL SIMULATIONS

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SUMMARY

An advanced multi-body bicycle-rider computer model is developed to assess the stability and behavior of older cyclists. The final goal of the project is to improve and prolong their mobility on the bicycle. Cornering is one of the critical situations wherein stability and controllability is important. Therefore, in this study, cornering movements are assessed using computer simulations. With model simulations the principle of counter steering and the effect of leaning and lateral knee movements are shown. Additionally, it is shown, how the model parameters influence the behavior of the system. This will give ideas which parameters need to be controlled to improve controllability and stability during cornering.

INTRODUCTION

For elderly people, cycling is important to remain socially and physically active; they use the bicycle mainly for social activities, like shopping and visits, but also for recreation. However, cycling entails some risks for the elderly; after the age of 65, they experience a significantly higher injury risk than younger people. Reasons could be an increased physical vulnerability and a higher risk of falling.
The exact nature of problems of elderly cyclists is not yet well understood, but is believed to be related to a reduced motion feedback ability of elderly, health issues that reduce power or force and insecurity due to slower information processing in heavy traffic or situations where multiple tasks are required.

The goal of the SOFIE-project (Smart Assistive Bicycle) is to develop an Intelligent Assisted Bicycle for the elderly, to improve and prolong their mobility. More generally, we would like to improve our knowledge about bicycle and rider stability and handling. Within this project, an advanced computer model of the complex system of the bicycle dynamics, the biomechanics and control of the rider, environmental influences and their complex interactions, f.e. the tire-road contact is used to assess the stability [1].

In this paper the particular case of cornering is assessed, using computer simulations. It is assumed that the bicycle rider uses three control mechanisms to control the bicycle: steering, upper-body lean and lateral knee movements. With the computer model simulations it is shown how these control mechanisms can be used and what the effect is of changing model parameters. As a next step, experiment data will be used to validate the model and identify unknown model parameters.

METHODS

The model of the bicycle and rider is fully parameterized, to allow for adjustment to any bicycle and any rider. Also, it allows for testing the influence of various design variables of the bicycle and parameters of the rider on the behavior of the system.

The multi-body model contains 8 rigid bodies and 3 controllable degrees of freedom (Figure 1). The 8 rigid bodies are: (m1) the upper-body (including the mass of the head and arms), (m2) the pelvis (which is rigidly attached to the bicycle frame), (m3) the left and (m4) right leg, (m5) the rear frame of the bicycle, (m6) the front fork of the bicycle, (m7) the front wheel and (m8) the rear wheel. The deformation of the tires is accounted for in the tire-road contact model [2]. The arms are modeled as spring-dampers, that can simulate the amount of co-contraction of the arms and therefor the tightness of the grip on the handlebars.

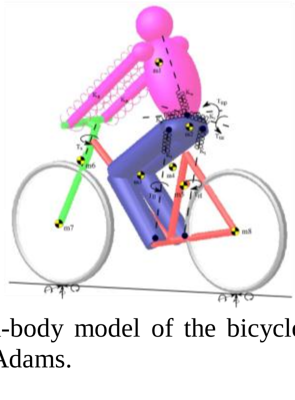

Figure 1: Multi-body model of the bicycle, rider and tire-road contact in Adams.

The three controllable degrees of freedom of the computer model correspond to the assumed control actions of the bicycle rider to maintain balance and to change the direction of heading (i.e. stability and controllability).
Balance control is needed when cycling below the stable speed range. This can be accomplished solely by steering actions. These steering actions are modeled by a steering torque around the steering axis of the bicycle.

A PD-controller is chosen to represent the CNS (central neural system) control action of the bicycle rider. The PD-controller generates a steering torque around the steering axis, in the direction of the fall. The system is stable when maintaining a constant roll angle (zero roll velocity). This applies for both a straight riding situation as for a cornering situation.
To initiate a corner, three input motions are used: a short steer motion, a short upper-body lean movement and a short lateral knee movement. Subsequently, a PD-controller on the steering torque is activated attempting zero roll velocity, to stay in a constant corner. Finally, the PD-controller is set to maintain a zero roll angle, to go out of the corner in a straight direction again.

Next to the simulations, experiments were set-up to measure the kinematics of the bicycle and rider during cornering in a real life situation. 2 healthy, young subjects performed cornering tasks at 3 different forward speeds (slow-normal-fast) in a sports hall. As a next step, this data will be used to validate the presented model and identify model parameters.

RESULTS AND DISCUSSION

First, the responses of the three control mechanisms are shown. Then the effect of changing model parameters is discussed.

Figure 2 shows the control input to the bicycle-rider model to go into a left corner, for the following three cases: initial steer (green), initial upper-body lean (red) and initial lateral knee movement (blue), applied at t=3 s. For all three simulations the same steering torque controller is used during and after the corner; the steering angle is shown in the graph as well. The forward speed was 10 km/h during all simulations.

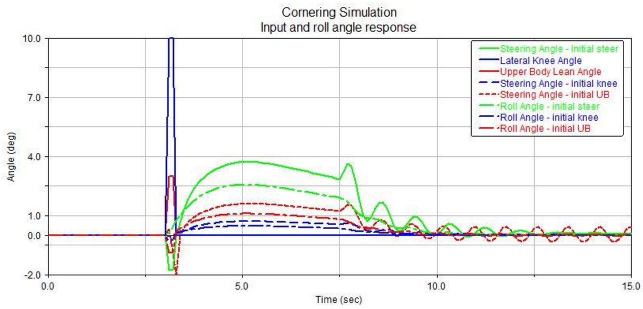

Figure 2: Control inputs to initiate a corner, steering angle to stay in and go out of the corner again and roll angle response.

Figure 2 also shows the roll angle response of the three simulations and figure 3 the yaw angle response (representing the direction of heading of the bicycle). From figure 2 it can be seen that an initial steering action to the right is needed to go into a left corner. This is called counter steering and is caused by the lean-steer coupling of the bicycle: steering to the right will cause the bicycle to lean to the left, subsequently; leaning to the left causes the steering assembly to fall to the left as well. This steer-lean coupling is the main mechanism that keeps a bicycle stable at certain forward speeds [3] and is used when controlling the bicycle.
The other two movements, where the center of mass is moved laterally, result also in an initial counter steer (see figure 2).

All three initial motions result in a similar left corner, but in different corner angles. Upper body lean and knee movements are much less effective, compared to steering.

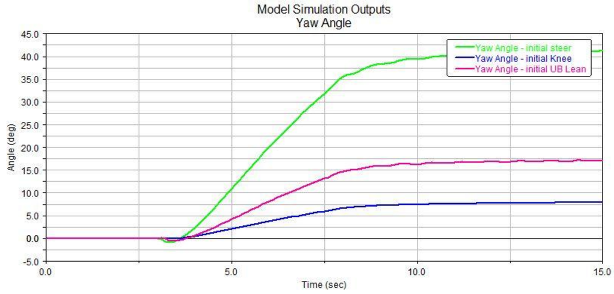

Figure 3: Output of the simulations with control inputs shown in figure 2, showing the yaw angle response.

Several model parameters influence the cornering movement, when simulating with the above described model. Forward speed is one of the parameters influencing the behavior of the system the most (therefor it is taken as an example here); hence the stability is speed-dependent [4]. Figure 4 shows the roll and yaw angle responses for a forward speed varying from 1 to 9 m/s.

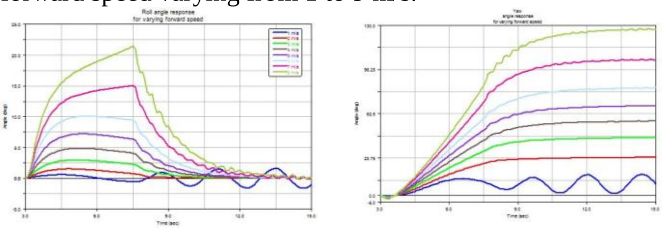

Figure 4: Roll and yaw angle responses of cornering movements with varying forward speeds.

Other parameters influencing the corner movement are: the initial angle amplitude and length, the controller gains and the arm stiffness and damping. These will be identified from experiment data.

CONCLUSIONS

Cornering movements in bicycling have been simulated using an advanced multi-body model, together with a simple control model. The corner movement depends on variables like the forward speed, the used control mechanism (steering, upper-body lean, lateral knee movements), controller gains and the stiffness of the rider's grip on the handlebars. To improve the balance and controllability during cornering, these variables should be controlled.
Experiment data is obtained and will be used for model validation and identification of model parameters.
As a next step a more complex control model can be developed, combining the three control mechanisms.

ACKNOWLEDGEMENTS

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