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Modeling and Implementation of a Reaction Wheel Stabilization System for Low Speed Balance of a Cargo Bicycle

Jason K. Moore [1,*], Jeswin Koshy Cherian [1], Björn Andersson [2], Oliver Lee [2], Anders Ranheim [2]

[1] Delft University of Technology, The Netherlands ; j.kmoore@tudelft.nl, ORCID 0000-0002-8698-6143; j.koshycherian@student.tudelft.nl, ORCID 0009-0002-2264-8097;
[2] Ictech AB, Sweden ; bjorn.andersson@ictech.se; oliver.lee@ictech.se; anders.ranheim@ictech.se
[*] corresponding author

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Abstract:

Cargo bicycle use has grown over the last decade with electrification contributing to a rapid growth in the recent years. With the growth of safer bicycle infrastructure in many countries, these vehicles can be a greener, more energy efficient replacement for cars for a variety of short and medium distance activities, e.g. "last mile" delivery or transportation for families. One particular problem cargo two-wheelers face is that the vehicles are hard to balance and handle at low and near zero speeds. Delivery people need to quickly park their vehicle without the need for a bicycle storage rack or cumbersome kickstands for quick door calls. Similarly, parents need to seat and remove their children from the vehicle without worrying that it would fall. Also, both vehicles come to a stop in traffic many times throughout a trip. At every instance near zero speed, balance assistance would simplify vehicle operation for the rider; even enabling it as a new transportation mode for those with limited motor skills and coordination. Our goal was to develop and test the feasibility of robotically stabilizing a single track cargo bicycle at zero and near zero forward speeds.

There is a long history of efforts to robotically stabilize single track vehicles beginning with inventions like Brennan's monorail in the early 1900's (Barr, 1907), to the motorcycle steer motor control of (Ruijs and Pacejka, 1985), and a too long list of models

(a) CAD rendering of the envisioned reaction wheel on a common delivery bicycle model.

(b) Prototype vehicle with a Bafung motor driven at 48 V with a maximum power of 1500 W and added rim mass to maximize the rotational inertia.

Figure 1: Vehicle images.

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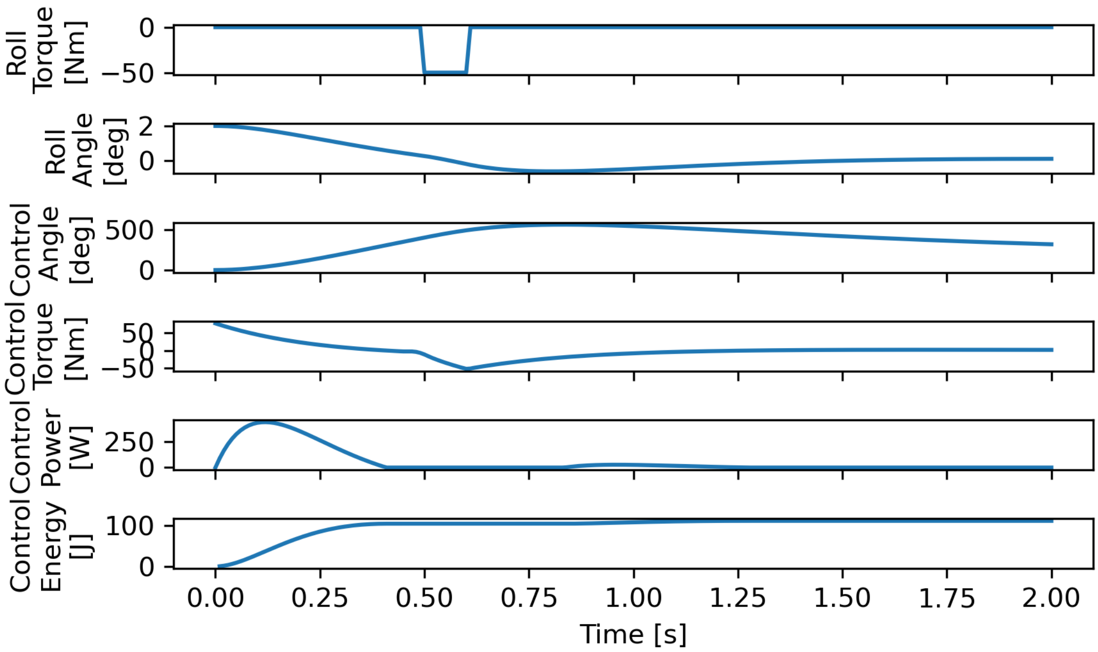

Figure 2: Roll stabilization results at zero speed from an initial roll angle of 2 ° and a pulse roll torque perturbation showing the reaction wheel controller behavior: angle, torque, power, and energy consumption.

and demonstrations of steer control, control moment gyroscopes, reaction wheels, inverted pendulums and the like. None of these solutions have become commercially viable, so our approach tries to focus on the narrow need of near zero speed stabilization. We chose a reaction wheel due to the low cost (<$500), ability to stabilize vehicle roll at any speed, and the possibility to fit the reaction wheel in a concealed manner in a small portion of the cargo space.

To that end, we have developed a compact reaction wheel that fits in the cargo space of a standard cargo bicycle. The reaction wheel is capable of applying roll torques up to 200 $\mathrm{N\,m}$ to the vehicle, see Figure 1a. This can stabilize the roll degree of freedom at zero speed for roll angles up to about 10 °. Figure 2 shows that the reaction wheel can stabilize the vehicle from a 2 ° and 50 $\mathrm{N\,m}$ disturbance within two seconds using about 100 J and 50 $\mathrm{N\,m}$ of peak torque. A modern e-bike battery has up to 4M joules of energy available for use so it is possible to dedicate a portion of the energy to stabilization during medium length trips. Minimizing the energy consumption from the reaction wheel while maximizing stability will be investigated further.

The reaction wheel has some disadvantages, including significantly increasing the mass of the vehicle as well as increasing the complexity and cost. The energy consumption can be large when the system is constantly managing large repeated disturbances, reducing the available range of an e-bike (possibly drastically and unexpectedly to the rider). The reaction wheel will generate pitching torques during rapid changes in heading (although we expect this to be negligible). These disadvantages can be overcome with system optimization.

In the paper and presentation, we will report on the model and simulation results that demonstrate the practicality of the design as well as its limits. We will also report on the performance of the prototype shown in Figure 1b in relation to the simulation results.

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References

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