Balance-assist bicycle weave mode experiments

Marten Haitjema

June 21, 2023

1 Introduction

Research into the balance-assist bicycle is done with a model of a bicycle. The parameters of this model are for a different bicycle than the balance-assist bicycle. It is unknown how well the model represents the balance-assist bicycle. It is important for the balance-assist bicycle to be properly modelled, because the controller is designed based on the (thus far inaccurate) model. If the model is not representative of the balance-assist bicycle, the designed controller may be invalid.

The goal of this experiment is to identify the actual weave mode of the balance-assist bicycle for different controller gains.

2 Methods

The weave mode will be identified by manually perturbing the bicycle at the seat post, and measuring the consequent roll rate. The weave mode can be found be fitting a decaying oscillation to this data. The following equation, defined by Kooijman et al. [1], is used to fit to the roll rate data:

$$c_1 + e^{dt}(c_2 \cos(\omega t) + c_3 \sin(\omega t)) \tag{1}$$

The imaginary part of the eigenvalue is given by the frequency ω. The real part is given by the damping d. An example of the function fitted to roll rate

data can be seen in figure 1. Eigenvalues were measured with the balance-assist system on with a gain of -6, -8 and -8 at speeds of 6, 8, 10, 12, 14, 16 and 18 km/h. For each velocity, the real and imaginary part of the eigenvalues were averaged over three perturbations.

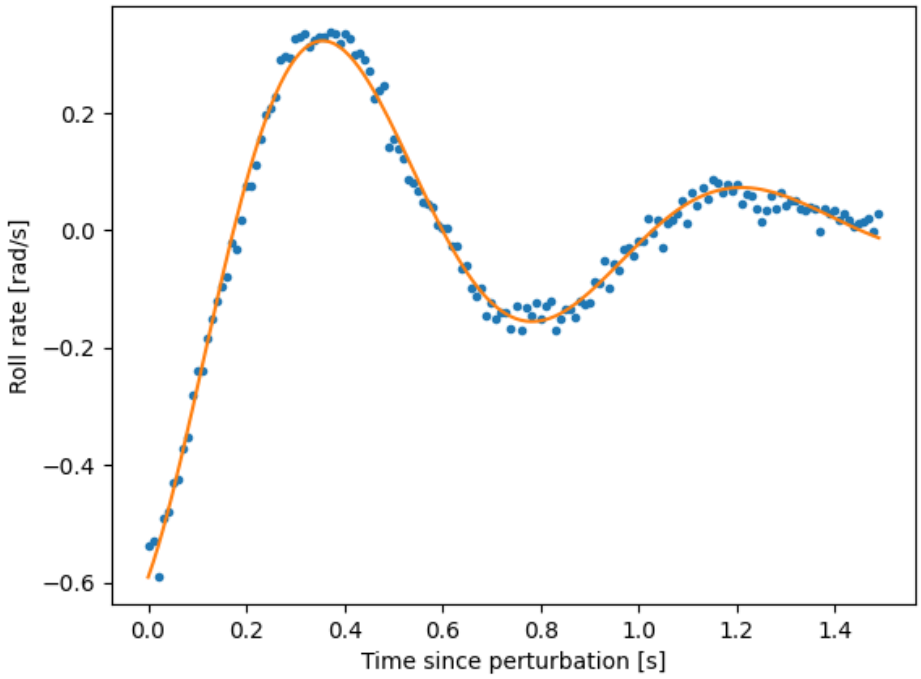

Figure 1: Example of a fit of a decaying oscillation to roll rate data.

3 Results

Measured eigenvalues for a gain of -6 can be seen in figure 2 and table 1. The results for a gain of -8 can be seen in figure 3 and table 2. The results for a gain of -10 can be seen in figure 4 and table 3.

Table 1: Real and imaginary parts of the measured eigenvalues for a gain of -6.

Velocity (m/s)	**Real part**	**Imaginary part**
1.66	-3.10437	6.90899
2.22	-1.73230	7.47695
2.78	-1.07677	7.81142
3.33	-0.64501	7.79933
3.89	-0.57419	6.93977
4.44	-0.73719	7.33274
5.00	-0.82591	4.65962

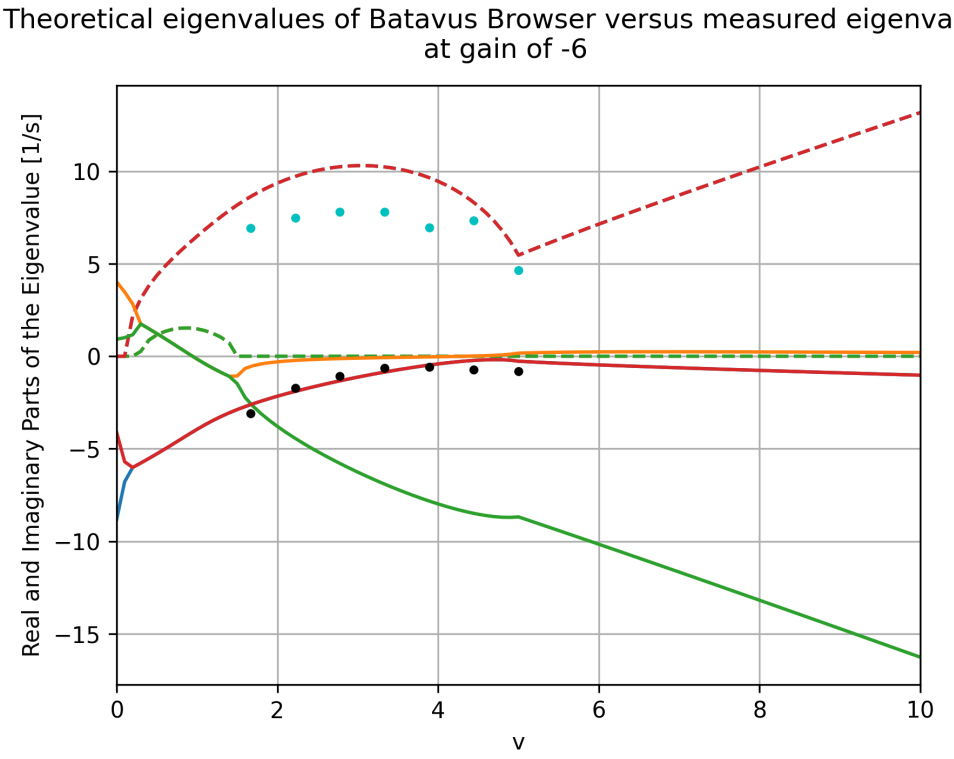

Figure 2: Theoretical eigenvalues of Batavus Browser with balance-assist controller and the measured eigenvalues at gain of -6. The real part of the measured eigenvalues is displayed in black, the imaginary part is displayed in cyan.

Table 2: Real and imaginary parts of the measured eigenvalues for a gain of -8.

Velocity (m/s)	**Real part**	**Imaginary part**
1.66	-1.96625	8.97518
2.22	-1.67178	9.59152
2.78	-1.08789	9.82538
3.33	-0.82441	9.27701
3.89	-0.56166	8.26214
4.44	-0.70618	5.97152
5.00	-0.90672	5.32524

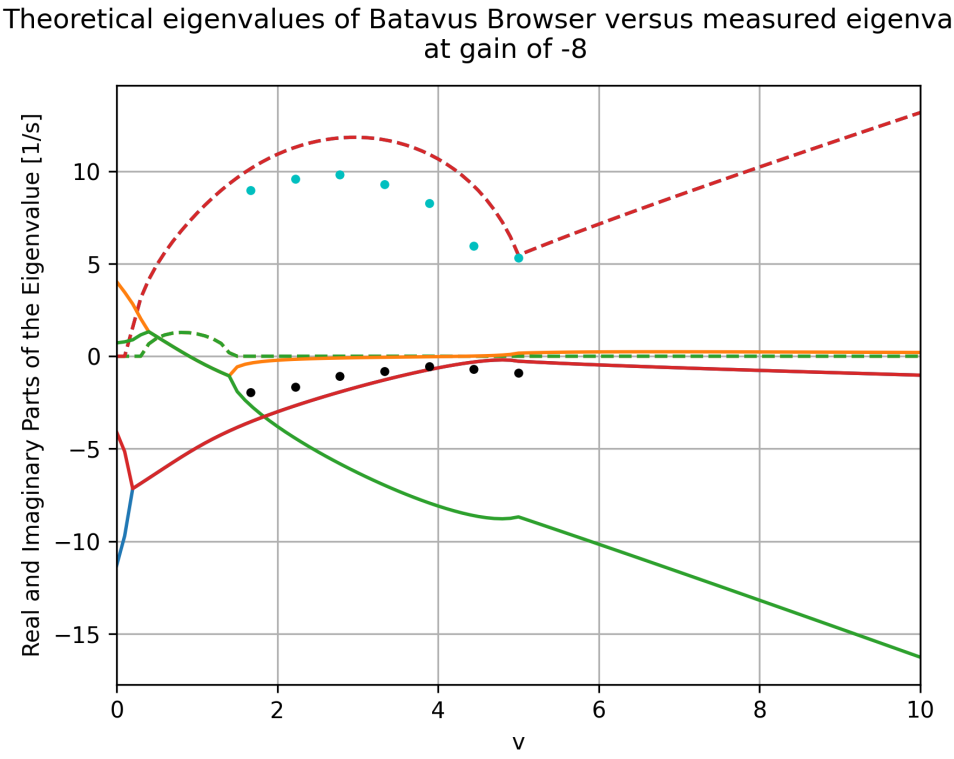

Figure 3: Theoretical eigenvalues of Batavus Browser with balance-assist controller and the measured eigenvalues at gain of -8. The real part of the measured eigenvalues is displayed in black, the imaginary part is displayed in cyan.

Table 3: Real and imaginary parts of the measured eigenvalues for a gain of -10.

Velocity (m/s)	**Real part**	**Imaginary part**
1.66	-3.73303	11.03922
2.22	-1.83437	10.90979
2.78	-1.08183	10.84567
3.33	-0.78383	10.49930
3.89	-0.59061	9.07418
4.44	-0.53405	6.87337
5.00	-0.02263	4.16736

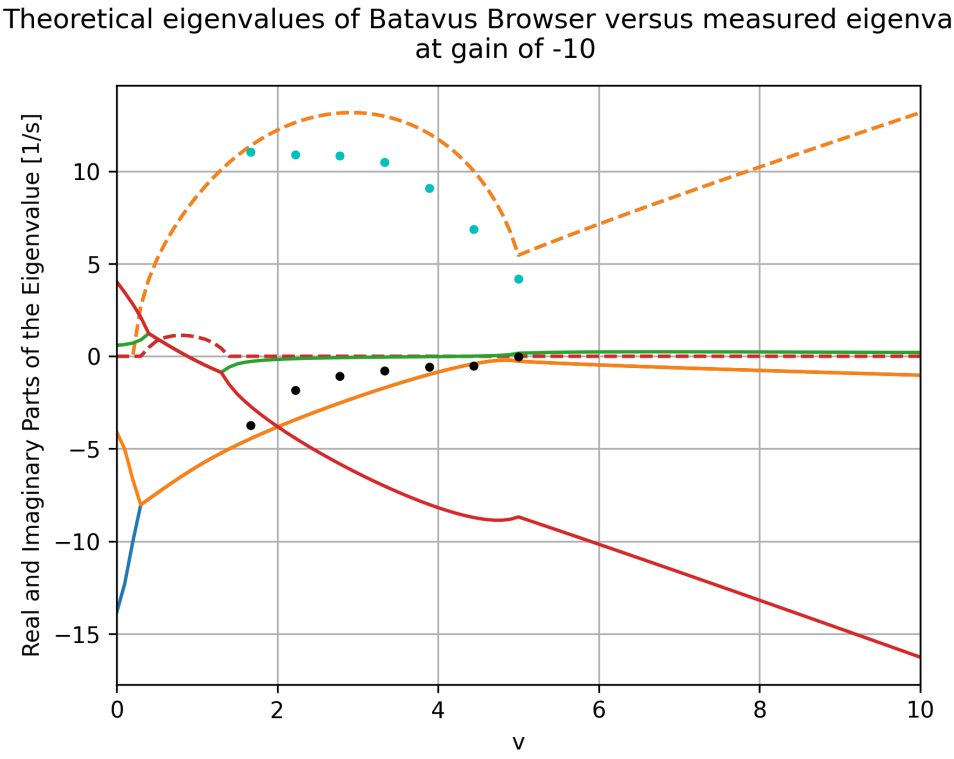

Figure 4: Theoretical eigenvalues of Batavus Browser with balance-assist controller and the measured eigenvalues at gain of -10. The real part of the measured eigenvalues is displayed in black, the imaginary part is displayed in cyan.

4 Discussion

For the gain of -6, the theoretical weave mode of the Batavus Browser bicycle with a model of the balance-assist system is close the measured eigenvalues. For the gain of -8 and -10, the measured real part of the eigenvalues is less damped than the Batavus Browser. For all gains, the imaginary part of the eigenvalues is substantially lower than the theoretical eigenvalues.

5 Adjusting model parameters

References

[1] J.D.G. Kooijman, A.L. Schwab, and J.P. Meijaard. Experimental validation of a model of an uncontrolled bicycle. *Multibody Syst Dyn*, 19:115–132, 2008.