A dynamic friction model with normal force and coefficients of friction as parameters of transition range

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Abstract

This work presents a simple continuous dynamic friction model, with dependence on normal contact force, slip velocity, and static and dynamic coefficients of friction. The model doesn't require the dependence on additional parameter such as transition velocity as in Brown and McPhee's model, instead it utilizes a combination of an iterative methodology and an empirical parameterization to adjust the variation of transition velocity region, which may vary with the magnitude of normal reaction forces and the difference between the static and dynamic coefficients of friction. The model, along with Brown and McPhee's model and regularized Coulomb's model, to be applied on a case study with spring-mass system kept on a moving belt with a defined speed v_0, as shown in Figure 1. The results to be compared and reported.

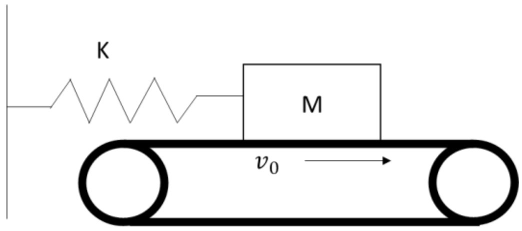

Figure 1: Spring-mass system on a moving belt

Peter Brown and John McPhee proposed a simple velocity-based model [1]. In this model, friction has been characterized as a continuous function of sliding velocity. To reduce model complexity, only the main velocity-dependent characteristics of friction i.e., the Stribeck effect and viscous friction were included. What makes this friction model especially promising for dynamic systems is its ability to simulate stiction without any discontinuities in the stick-slip transition regime. Such a model is represented in Equation (1)

$$F_f(\mu_s, \mu_d, v_s, v_t) = F_n \left(\mu_d \tanh\left(\frac{v_s}{v_t}\right) + \frac{(\mu_s - \mu_d)\left(\frac{v_s}{v_t}\right)}{\left(\left(\frac{v_s}{2v_t}\right)^2 + \frac{3}{4}\right)^2} \right) \quad (1)$$

where μ_s is the static coefficient of friction, μ_d is the dynamic coefficient of friction, v_s is the slip velocity, and v_t is the transition velocity. The transition velocity v_t is a difficult parameter to estimate in this model. Haug [2] recommends v_t to be between 10h and 20h, where h is the timestep size.

Yet another static friction model by Wang and Rui [3] is revisited as represented in Equation (2)

$$\mu = \mu_s \sin\left(C.tan^{-1}\left(Bv_s - E\left(Bv_s - tan^{-1} Bv_s\right)\right)\right) \quad (2)$$

where μ_s is the static coefficient of friction v_s is the slip velocity. The constants C, B and E are manually adjusted to suit the requirements of the system. The main problem with this model is that it does not include dynamic coefficient of friction as a functional parameter, and it depends only on slip velocity.

With experiments we find that the coefficient B and C together decide the transition range from stiction to slipping. Typical time step being close to 0.001, the v_t from Equation (1) can lie between 0.01 and 0.02. Further, we propose that for a system, v_t may depend on the magnitude of normal reaction F_n and the difference between the given coefficients of static and kinetic friction. Considering this, the model in Equation (2) is modified as presented in Equation (3)

$$F_{friction}(\mu_s, \mu_d, v_s, F_n) = \mu_s F_n \sin\left(C_{corrected}.\,tan^{-1}\left(B_m v_s + 2\left(B_m v_s - tan^{-1} B_m v_s\right)\right)\right) \tag{3}$$

where B_m is empirically evaluated as per Equation (4)

$$B_m = \min\left(100, 50\left(e^{(\mu_s - \mu_d)F_n}\right)^{0.2}\right) \tag{4}$$

and the numerical limit of 100 is decided as per experimentations in comparison to Brown and McFee's model. The value of B_m = 100 corresponds to v_t =0.015. Further the parameter $C_{corrected}$ is iteratively evavaluated as per the algorithm in Figure 2.

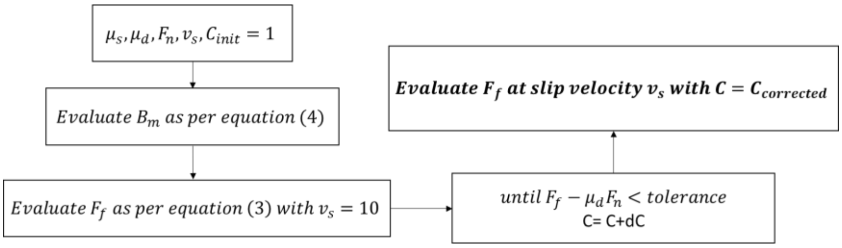

Figure 2: Algorithm to implement the model framework

The Figure 3 represents preliminary computational results in comparison to Brown and McPhee's model. The variation of transition range can be observed with change in F_n.

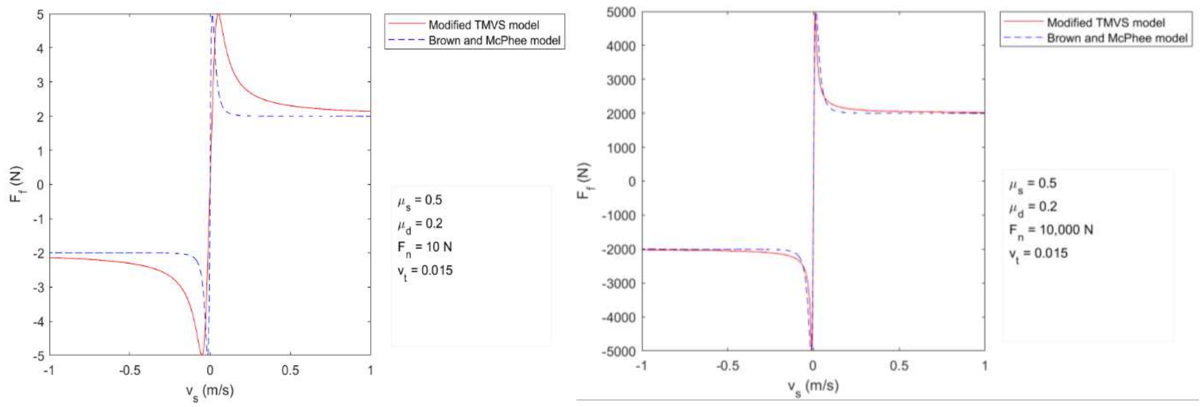

Figure 3: Preliminary comparison with Brown and McPhee model

The further work to be included is the application of this model on planar and spatial multibody systems, and comparison of results with those of Brown and McPhee model, Gonthier's model and LuGre model.

References

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