AA222 Final Project Proposal: Optimization of Bicycle Suspension Tuning

Jeffrey B. Robinson
Master's Degree Candidate, Aeronautics & Astronautics, Stanford University

I. Background

Bicycle suspension is critical to the ability of the rider to maintain control and comfort when traversing rough surfaces, particularly in the context of off-road, or "mountain" biking. The suspension system of a bicycle must be able to smooth the effects of large impulses due to trail obstacles or rider input, while also damping smaller, higher-frequency disturbances due to roughness of the trail surface. In the case of either input, the goals of the suspension system are to reduce the magnitude of the impulses transferred to the rider - improving comfort - and to maximize the amount of time during which the wheels of the bicycle are in contact with the ground - improving traction.

Although suspension components are often among the most expensive components required to assemble a bicycle, and passive observation of media regarding the mountain bike industry over several years has yielded a general impression that advancement in suspension development is a primary point of conversation and marketing, little exists in the way of publicly available information regarding the methodology of tuning bicycle suspension [1, 2]. In practice, the process of tuning bicycle suspension thus often appears to the cyclist as more of an art than a science, with adjustments made randomly, based on intuition, or based on communal wisdom.

The purpose of this project is to explore the applicability of direct, stochastic, and population based optimization methods to the problem of tuning bicycle suspension, with the goal of assessing the aptitude of different methods for the task in terms of the performance achievable with each algorithm with respect to the number of iterations required.

II. Related Work

Little concrete information is available about the engineering efforts made by companies involved in the development of mountain bike suspension components, making it difficult to ascertain what approaches have been explored for the optimization of suspension tuning for mountain bikes in particular. However, it is clear from marketing efforts by suspension component manufacturers that the issue of suspension tuning is of significant interest to the industry, with some companies offering paid tuning services, smartphone apps, and even aftermarket replacement components to simplify the tuning process [2–6].

In the more general scope of suspension tuning optimization as applied to motor vehicles, significant effort has been made to characterize and optimize suspension performance for cars, public transportation such as buses, road-going commercial cargo vehicles, and railway vehicles, with [7–10] being some examples of the breadth of the field. In these studies, the suspension systems of multi-wheeled vehicles are analyzed using kinematic models, laboratory testing, and field testing. The methods used to optimize the damping parameters of the suspension systems are in some cases left unclear beyond the definition of the optimization problem, as in [7]. In [8], a multiobjective optimization problem is solved using the `gamultiobj` genetic algorithm in Matlab. In many papers on the subject, such as [10], the object of optimization is an active rather than a passive suspension system, in which cases the optimization algorithm tunes not only the damping parameters of the system but also the control forces applied by the suspension system. There does not seem to be an industry consensus on an optimal method for tuning suspension.

III. Problem Formulation

A. Objectives

The objectives of this optimization problem are "ground following" and "ride comfort," which can be defined respectively as:

- ground following - the percentage of time during which the wheel of the bicycle is in contact with the ground with a normal force or proximity sufficient to reach a given cutoff, yet to be determined

- ride comfort (transmitted impulse) - the root mean square of impulses transferred through the suspension to the rest of the bicycle

In assessing the performance of suspension systems for other applications, sources [7, 10] use similar criteria. In the case of this project, the *ground following* objective will be maximized, and the *ride comfort (transmitted impulse)* objective will be minimized. While further work must be done to fully characterize the problem, the definition of Pareto Optimality for this problem will likely be skewed slightly to discount the importance of the *ride comfort* characteristic, since this is less important in practice than the traction advantage associated with improved ground following.

B. Design Space

The design space of this problem consists of the different tuning parameters commonly available on mountain bike suspension products:

- spring rate - spring constant of the suspension, adjusted in practice by air pressure or the exchange of one mechanical spring for another
- compression damping - damping coefficient applied only during the compression stroke of the suspension
- rebound damping - damping coefficient applied only during the rebound, or extension, stroke of the suspension

The *compression damping* and *rebound damping* parameters can be subdivided into "low-speed" and "high-speed" components, where each respectively applies only to compression or rebound events occurring above or below a specified crossover point, to better enable the suspension to differentiate its response to "high-speed" phenomena such as surface roughness and to "low-speed" phenomena such as larger obstacles or rider input. The crossover between these components can also be included as a parameter in the design space. Preliminary limiting values for these parameters will be estimated from simple kinematic analysis of the spring-mass-damper system.

IV. Approach

A. Modeling

The modeling of the suspension system for this project will follow the general method decribed by [10], with the tire and suspension being each modeled as a spring and damper in parallel, and the bicycle wheel and frame being modeled each as a mass. The "trail surface" used to assess the response of the system will be generated randomly from a Gaussian distribution, and a rolling average of "trail surface" height values will be used to avoid an unrealistically rough surface. The objective functions will be determined by running this simple physical model for a set number of time steps.

B. Optimization

The algorithms that seem best suited to a task such as this are direct, stochastic, or population based methods, given that the objective function is a numerical measurement derived from a physical simulation rather than an analytical function. The Cyclic Coordinate Search (CCS) method is of particular interest given the purpose of this project, as this algorithm is an intuitive choice when tuning suspension qualitatively, as must be done in practice, and assessing its performance relative to other, more sophisticated algorithms could prove interesting. Other algorithms which will be investigated include Hooke-Jeeves, Divided Rectangles, Cross-Entropy, and Particle Swarm. The latter selections are made for similar reasons to the above, being that broadly sampling the design space seems to be a logical strategy for a concealed, potentially non-continuous objective function.

These algorithms will be implemented using Julia, and the physical model described above will be called as an optimization function on which the algorithms operate. Depending on the time required for each iteration, several iterations will be run with the algorithms whose performance depends more strongly on the initial design point (CCS, Hooke-Jeeves), to ensure their aptitude for this task is appropriately assessed.

References

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