博士論文（要約）

Road roughness evaluation based on the identification of vehicle rigid body motion models and inverse analysis of vehicle responses

(車両剛体運動モデルの同定と車両応答逆解析に基づく路面ラフネス評価)

趙博宇 (Zhao Bo Yu)

論文題目　Road roughness evaluation based on the identification of vehicle rigid body motion models and inverse analysis of vehicle responses

（車両剛体運動モデルの同定と車両応答逆解析に基づく路面ラフネス評価）

氏　名　趙博宇（Boyu Zhao）

Abstract

The maintenance of road infrastructure, whose surface pavement is subject to severe deterioration due to direct loading from passing vehicles, is important. Without appropriate maintenance, pavement damage can further deteriorate and seriously influence both drivers and neighborhoods. For example, accidents may happen due to large potholes; loud noise emission and poor driving comfort are also expected.

Dynamic Response Intelligent Monitoring System (DRIMS), which estimates international roughness index (IRI), has been used to evaluate road condition using ordinary vehicles. However, the previous DRIMS methods have limitations. First, vehicles are modeled by a QC model, which cannot reproduce the pitching or rolling motion of vehicle dynamics. As a result, IRI estimates are inaccurate and sensitive to sensor location. To account for both pitching and bouncing motion, as well as the effect of sensor location differences, the use of HC model and its calibration by Unscented Kalman filter (UKF) had been proposed. However, the parameter estimation oftentimes does not converge due to large system and observation noises. Furthermore, previous DRIMS methods cannot estimate road profile although it can calculate IRI.

This thesis addresses these shortcomings and further improves DRIMS with the following proposals: 1) robust vehicle parameter identification in the frequency domain and its application to IRI estimation; 2) road profile estimation method based on a half car (HC) model with multiple vehicle responses; and 3) improve the accuracy of road profile estimation based on the combination of HC and full car (FC) model which accounts for bouncing, pitching, and rolling motions of vehicle dynamics. The methodologies are shown below:

The vehicle parameters are identified through drive tests over a set of portable humps with a known size.

The vehicle model is firstly assumed as a HC model. As opposed to the previous approach of parameter identification in the time domain using UKF, the parameters are optimized to minimize the difference between simulation and measured hump responses in the frequency domain using genetic algorithm (GA). The robustness of the proposed vehicle model calibration method is validated by multiple hump passages. After HC model calibration, IRI is estimated by measuring vertical acceleration. Measured acceleration is converted to the acceleration RMS of the sprung mass of standard quarter car (QC) by multiplying a transfer function. The transfer function, estimated through the simulation of the identified HC model, reflects the vehicle pitching motions and sensor installation location. The RMS is further converted to IRI based on correlation between these values. Numerical simulation is conducted to investigate the IRI estimation performance in terms of various drive speeds and sensor locations. Experiment is carried out at a 13km ordinary road in Chiba prefecture, Japan. IRI estimation results are compared with a laser based road profiler.

With the HC model estimated by GA, a road profile estimation method is proposed. An augmented Kalman filter (AKF), whose state vector includes the road profile as random walk model, estimates the road profile. The type and locations of measurements are determined by an observability analysis. An RTS smoother further improves the state estimation by filtering the AKF results backward from the end and re-estimate the states. Though the combination of AKF and RTS smoother does not provide a real time estimation, the accuracy of the profile estimation is of more interests in this study. Numerical simulation is conducted to investigate the profile estimation performance in terms of various drive speeds and sensor locations. Experiment is carried out by comparing the estimated profile with a laser based road profiler.

In order to consider all of the vehicle rigid body motion dynamics, including bouncing, pitching, and rolling motions, a seven degree-of-freedom full car (FC) model is introduced and optimized by measuring vehicle body vertical acceleration, pitching angular velocity, and rolling angular velocity when vehicle passes on a hump on one side. Firstly, a numerical simulation is conducted to investigate that whether HC model is enough to represent the vehicle dynamics. In the simulation, real vehicle is simulated by a FC model while the profile estimation is processed by the calibrated HC model. The necessity of FC model is discussed by introducing different roughness between left and right profiles. As for profile estimation based on FC model, in order to satisfy the observability requirement of FC model using vehicle body responses, one of the four tires' profile is firstly estimated by HC model and set as a known input in FC model. In this manner, the FC model system becomes observable and thus is able to estimate the profiles corresponding to the other three tires. Numerical simulation is conducted to investigate the performance in terms of various roughness of left and right profile. Experiment is conducted at a 700m road where left and right path have clearly different roughness. The left and right profiles are measured by a road profiler cart. The estimated results are compared with true value in terms of both profile time history and IRI and showed improvement over the HC model.

A road roughness evaluation method based on the identification of vehicle rigid body motion models and inverse analysis of vehicle responses has thus been developed and validated. This method assuming simple implementation with smartphones is easily employed and achieves a high accuracy evaluation.