Road Profile Estimation and Output-only Half-Car Model Identification and its Application to Smartphone Measurement

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1. INTRODUCTION

The road surface is subjected to the vehicle load directly and prone to damage; damaged road will reduce the drive comfort and pose the traffic safety issues. Omission of proper maintenance can further increase long-term maintenance costs [1]. Thus appropriate evaluation of the current condition of road and corresponding repair are important. Smartphone-based road profile measurement framework that combines GPS and IMU (inertial measurement unit) measurement is a promising alternative to conventional road profilers because of its low cost and objective evaluation capability as well as its potential wide-spread use taking advantage of commonly available devices. In this paper, a road profile estimation method using multiple vehicle body responses measured by a smartphone is presented. The vehicle is modelled as a half car model and the parameters are identified by an output-only algorithm. By including the front and rear tire excitations into the augmented state vector, road profiles are estimated by a combination of the augmented Kalman filter (AKF), the Robbins Monro (RM) algorithm, and the Rauch-Tung-Striebel (RTS) smoothing. The output-only algorithm optimizes the vehicle parameters by minimizing the difference between identified road profiles at the front and rear tire locations within a short road segment using Genetic Algorithm (GA) [2].

2. Road Profile Estimation

In the system of Fig. 1, m_H is the sprung mass, whereas m_f and m_r are the front and rear unsprung masses, respectively The corresponding vertical displacement of these masses are x_H, x_f and x_r, respectively. The damping and stiffness of the front and rear suspension are denoted as c_f, c_r, k_f and k_r, respectively. Similarly, k_{ft} and k_{rt} are the respective front and rear stiffness of the tires. To evaluate the road-excited vibration of this model, road profiles at the front and rear wheels are given by y_f and y_r, respectively. The model has a wheelbase of $L_f + L_r$ and has the center of gravity at distance L_f from the front tire. Also, I_y is the moment of inertia of the sprung mass and V is the speed of the vehicle model. The smartphone is installed at a distance d from the front tire.

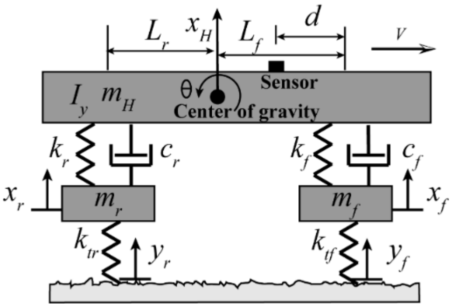

Figure 1. The HC model

By using the vehicle body acceleration and angular velocity responses as well as the vehicle speed measured by a single smartphone, the road profile is estimated. The profile estimation algorithm consists of an AKF, the RM algorithm, and the RTS smoothing. The RM algorithm automatically determines the process and observation noise covariance matrices, manual setting of which is time-consuming and error prone. Figure 2 is an overview of the road profile estimation method.

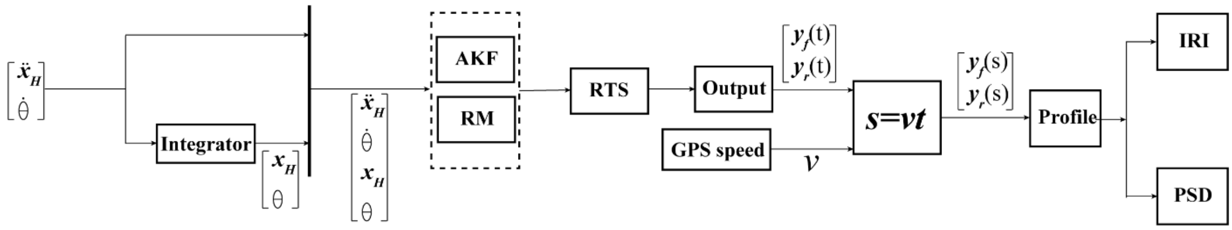

Figure 2. Diagram of the road profile estimation algorithm

3. Output-only half car model identification

Instead of identifying all the system parameters of Fig. 1 through laboratory tests, these parameters are estimated by analyzing responses of the vehicle when the vehicle is driving on a normal road at a constant speed. While the profiles at the front and rear tire locations are obtained as two independent state variables of the AKF, the profiles physically corresponds to one profile with distance axis differences of the wheelbase. The unknown parameters are estimated through the minimization of the difference between the PSDs of the estimated front and rear profiles using the Genetic Algorithm (GA). When the vehicle parameters are correct and the AKF is appropriately designed, the front and rear profile PSD should be the same. However, the converse is not guaranteed. Thus the performance of half-car model identification is experimentally studied.

Keywords: Kalman Filter, Robins Monro algorithm, Profile Estimation, Model Identificatoin
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4. Experimental validation

Field test was conducted on a 13km ordinary road in Chiba city, Japan. Three different cars shown in Fig. 3 were tested to verify the applicability and the accuracy of the proposed road estimation and vehicle identification algorithm. Fig. 4 shows the estimated profiles at the front and rear tire locations after the parameter identification. The profiles in the frequency domain are close with each other. Using these optimized vehicle parameter sets, the profile estimation is evaluated in terms of IRI. The IRI comparison between the three vehicles and the laser profiler are provide in Fig. 5. The difference between the three different types of vehicles are compensated and the estimated IRIs are consistent with each other. In addition, the speed differences are compensated. At the distance of 2.5 km, only Pixis stopped twice while the other two vehicles did not stop. The estimated IRI are almost the same.

(a) Collora (b) Pixis Epoch (c) Landcruiser (d) Profiler

Fig. 3. Experimental vehicles and profiler

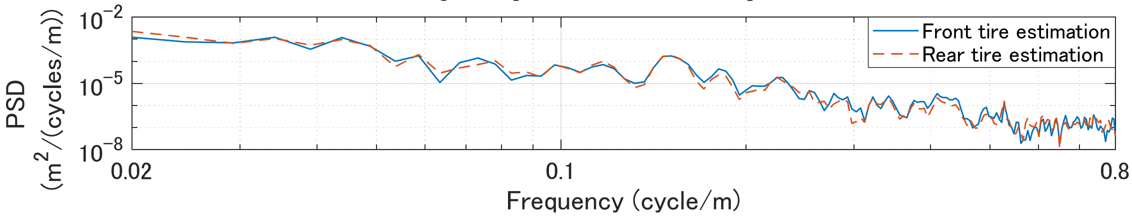

Fig. 4. Road profile estimation at the front and rear tire (Collora).

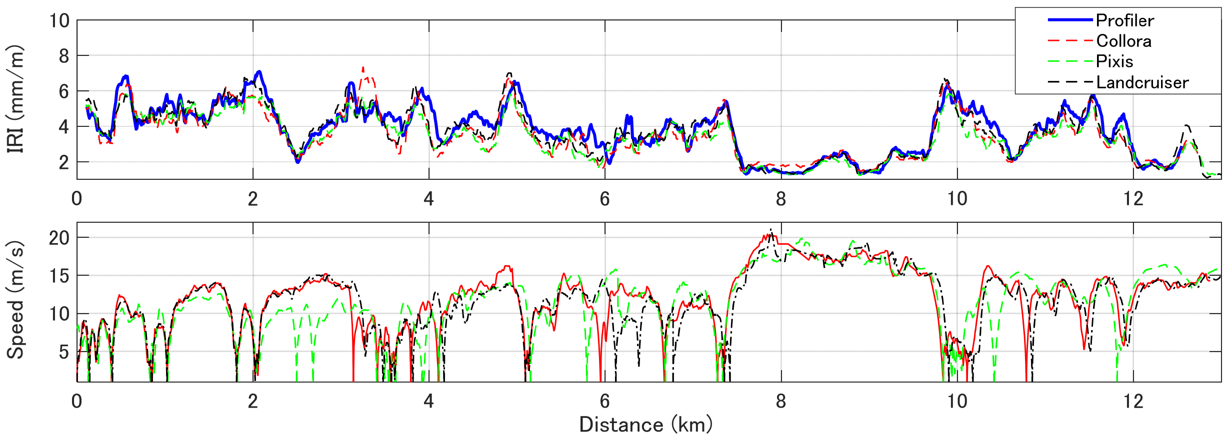

Fig. 5. Comparison of the estimated IRI of three vehicles with the profiler

5. Conclusions

A road profile estimation method and an output-only HC model identification method were proposed to automatically process smartphone data to evaluate the road profile accurately. The profile estimation algorithm consists of an AKF, the RM algorithm, and the RTS smoothing. For the model parameter identification, differences between two profiles at the front and rear tires obtained as two independent variables are set as the objective function of the parameter identification problem. Through the minimization of the difference using GA the vehicle parameters are obtained. The experiments with three different types of vehicles and the laser profiler show that the proposed algorithm can accurately estimate the IRI by compensating the vehicle type difference and drive speed differences.

ACKNOWLEDGEMENT

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