論文の内容の要旨

論文題目 Development of a Vehicle Static and Dynamic Load Estimation Method from Bridge Acceleration Response Measurement
（橋梁加速度応答計測を利用した走行車両の静的および動的荷重推定法の開発）

氏　名　王　浩祺

Overloaded vehicles have negative impacts on bridges by accelerating pavement degradation and fatigue of bridge structural members. Overloaded vehicles on bridges with inadequate design or degradation may result in local damage of bridge members or, in extreme cases, the collapse of bridges. Understanding the real loading condition of bridges, e.g., vehicle gross and axle weights, axle number, dynamic load, and the lane in which the vehicle is passing, is thus important.

Traditional methods to estimate the weight of a vehicle using bridge response measurement typically measure the strain responses of the bridge induced by the passing vehicle. By minimizing the difference between the measured strain and one predicted by the bridge influence line and vehicle weight, the vehicle weight is estimated. The solution is usually obtained as a least-square solution with reasonable computational cost. However, there are some drawbacks of this method. The installation of strain gauges is usually labor-intensive and time-consuming; the influence line needs to be calibrated in advance usually using a heavy truck of known-weight; while the vehicle weight is estimated, the dynamic load remains unknown.

In this thesis, a new method to estimate both static and dynamic vehicle loads from bridge acceleration response measurement is proposed. The load estimation process is an inverse problem to identify the input load using the output response measurement; two difficulties exist in the inverse problem. The first difficulty is that the system properties, i.e., the bridge properties, are unknown. Bridge modal mass and bridge pavement roughness are representative bridge properties, which are not known in advance. Chapter 3 and Chapter 4 propose techniques to easily estimate the modal mass and the pavement, respectively. These bridge properties are then used in the identification of vehicle static load in Chapter 5, and in the identification of dynamic load in Chapter 6. The second difficulty is that the inverse problem to be solved is a nonlinear problem due to the vehicle-bridge-interaction and the drive path uncertainty. A particle filter method, which can track both the time varying states and parameters, is employed to solve the inverse problem.

Chapter 3 explains a two-step method to estimate bridge modal mass. For this estimation, both the input which is large enough to excite bridge vibration and the output which is accurate enough to capture the bridge motion are needed. A vehicle is a convenient tool to excite the bridge while the tire force input to the bridge is difficult to measure. The tire force estimation method based on vehicle response measurement is first established by including the tire forces as augmented state variables of a Kalman filter. The force is then used together with the synchronously measured bridge acceleration responses to determine bridge modal masses. A genetic algorithm finds optimum bridge modal masses which reproduce the bridge responses well under the input force.

In Chapter 4, bridge pavement roughness is estimated from vehicle responses. To eliminate the influence of the bridge vibration on the pavement roughness estimation results, vehicle-bridge-interaction is taken into account. When the vehicle and bridge is considered as a coupled system, the equation of motion of the system becomes nonlinear. Therefore, the particle filter is adopted to estimate bridge pavement roughness as state variables, which serves as the only excitation source of the vehicle-bridge coupled system in the vertical direction and is used in the next chapter.

Chapter 5 proposes vehicle static load estimation from bridge acceleration measurement. The vehicle half-car model parameters, including the vehicle mass, are included in the state vector of the particle filter. The bridge pavement roughness estimated in Chapter 4 is used as the known input to the vehicle-bridge coupling system. The bridge displacement responses, which are double integration of acceleration, are used to improve the accuracy and to increase the speed of convergence. Experimental validation shows that the algorithm gives static weight estimation with the largest error of 11.9 %.

In Chapter 6, the problem of vehicle dynamic load identification is addressed. The properties of the modal model of the bridge are extracted from acceleration measurement. The dynamic tire forces are included in the state vector and their evolution are formulated by a random walk model. The estimation of vehicle dynamic tire forces is given at each time step. The entire time history of the force is compared with the time history obtained from the method explained in Chapter 3; these two signals show good agreement, validating the proposal.

The proposed algorithm to estimate the static and dynamic traffic load are thus realized upon the understanding on the vehicle-bridge interaction system and adequate combination of inverse problem solution techniques, i.e., Kalman filter, particle filter, and genetic algorithm. By taking advantage of recent advance in monitoring techniques, the proposed approach addresses problems of the conventional strain-based algorithm. The proposed approach is expected to contribute toward the realization of rational bridge management taking into account the actual traffic loading conditions.