論文の内容の要旨

Vision System-based Multi-rate State Estimation and Control for Electric Vehicles

（ビジョンシステムを利用した電気自動車のマルチレート状態推定と制御）

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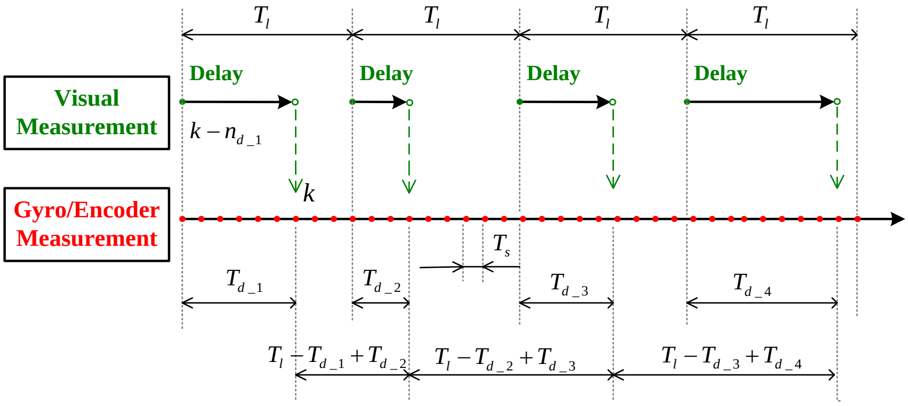
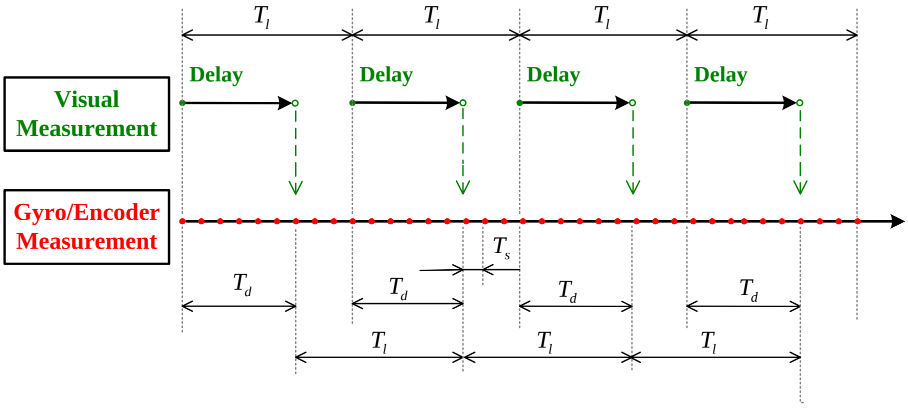
This work focuses on two objectives: 1) develop new and practical state estimation methodologies based on Kalman filter for systems with multi-rate and delayed measurements; 2) apply the multi-rate Kalman filter to vision-based control systems for electrical vehicles (EVs).

Vehicle electrification has become a world-widely recognized solution to the oil shortage and emission problems brought by engines-driven vehicles. Besides trying to build EVs that can be comparable with conventional vehicles, it should also be critical to have a deep understanding of the advantages and challenges brought by EVs. It is widely known that motors can response hundreds of times faster than engines and hydraulic systems. In fact, the inherent merits of EVs provide opportunities to realize advanced active safety control systems as have been already studied thoroughly during the last decade. However, motion control-related issues brought by EVs should also be emphasized for performance enhancement.

For motion control systems, real-time feedback of vehicle information is indispensible. While many vehicle states can be measured directly from cheap sensors, some of them are not readily available and therefore need to be estimated using information from the other sensors. However, different sensors may have different sampling rates and some of them are delayed. Therefore, direct fusion of different sensors may be problematic. Lots of conventional research simply down-sample the fast rate sensors to adapt slow-rate ones. On the other hand, from the viewpoint of EV control, fast feedback is preferable because the control periods of electric motors are short. Thus, unlike traditional vehicles with slower control input, multi-rate measurements can be a specific problem for EVs. Moreover, sensor measurement delays (constant or random) should also be considered in the estimator design. The sampling sequences of the measurement system that including random delay and constant delay are shown in Fig. 1.



(a) Multi-rate and uneven delay



(b) Multi-rate and constant delay

Fig.1 Measurement Sampling Sequence.

Regarding the multi-rate problem, two solutions can be employed: 1) down-sample fast-rate sensors to adapt slow-rate device; 2) design multi-rate estimation algorithm without changing sensor sampling times. Although method 1 is simple and straightforward, it has to reduce the sampling rate of the whole system. In contrast, method 2 allows better estimation accuracy by full utilization of sensor information and provides faster updating rate that can match with the control periods of electric motors. The system’s open-loop stability margin can thus be increased. Meanwhile, inter-sample residuals should be considered into the estimator design to guarantee the inter-sampling convergence. For constant or uneven delays, they can be included into the estimator using augmentation method or the proposed residual estimation method. The proposed approaches can be applied to a variety of multi-rate and delay-related applications such as chemical process estimation and control, vision-based estimation and control, GPS-based estimation and control, etc.

Considering the multi-rate and delay issues, two vision-based estimation and control systems for EVs are studied with the proposed estimation algorithm: 1) body slip angle estimation and control, 2) vehicle position estimation for integrated vehicle lateral control. Vehicle body slip angle is considered as one of the key enablers for vehicle safety control. However, due to the high cost of direct measurement, estimation approach needs to be investigated. In this dissertation, a combined vehicle-vision model is proposed for body slip angle estimation using multi-rate Kalman filter, and the estimation result is more robust against vehicle parameter uncertainties compared to the traditional bicycle model-based method. With the multi-rate estimator, a two-degree-of-freedom controller is designed for body slip angle control. In the second application, using the same vehicle-vision model, vehicle lateral position to the lane marker is estimated using the proposed observer, and it is then utilized together with yaw rate for integrated vehicle lateral control. Moreover, the two applications are implemented in simulation and experiments to verify the effectiveness of the proposed approaches.

This dissertation is mainly organized into three parts: backgrounds are given from Chapter 1 to Chapter 3; the multi-rate Kalman filter theories are explained in Chapter 4; in Chapter 5 and Chapter 6, vision-based vehicle state estimation and control applications are discussed. In the appendices, the experimental vehicle and image processing techniques for lane detection are introduced. The overall structure of this dissertation can be found in Fig. 2.

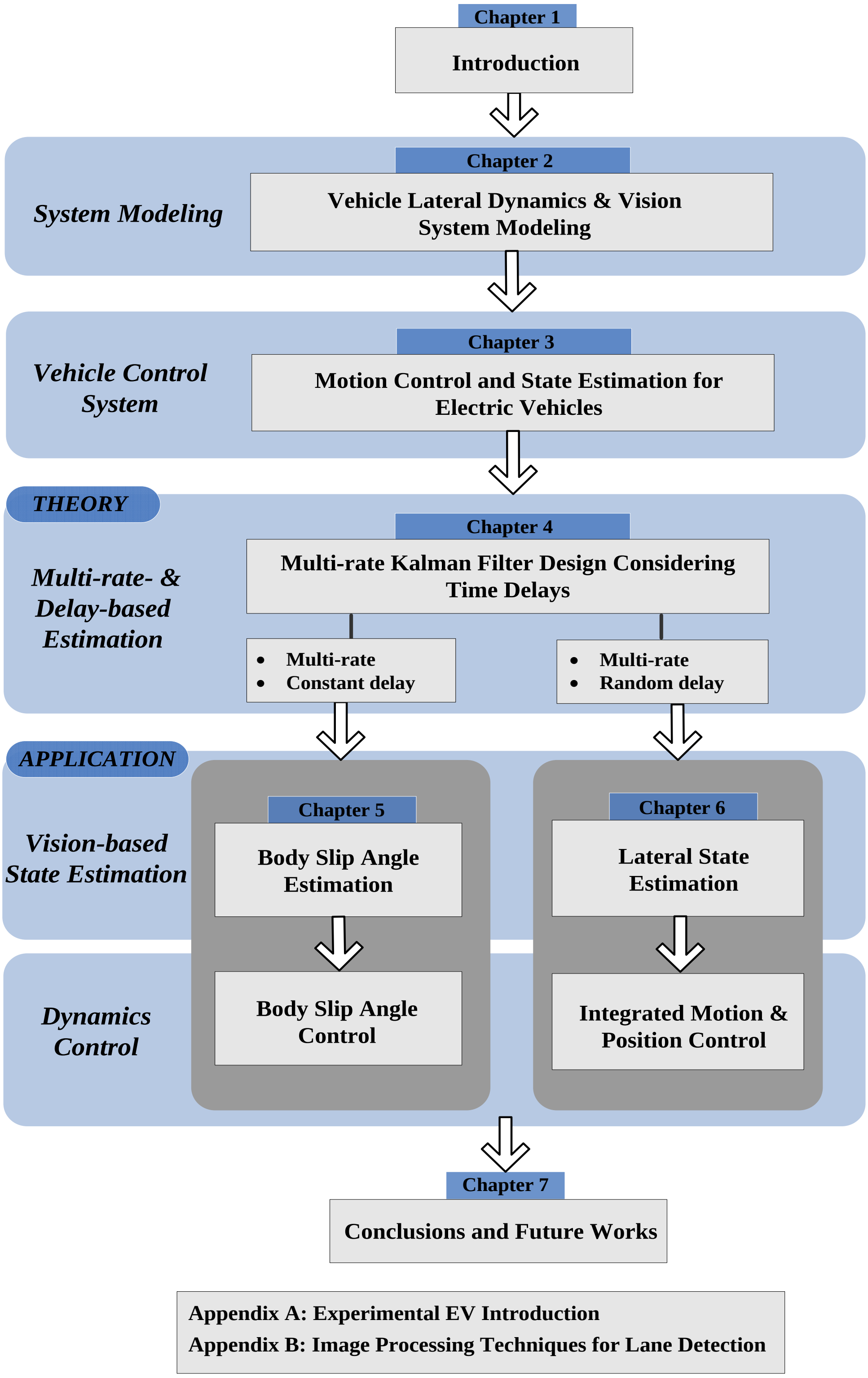


Fig.2 Dissertation Structure.