Chapter 10
Multisensor Fault-Tolerant Automotive Control

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Abstract. This chapter deals with the problem of obtaining fault-tolerant guarantees of a multi-sensor switching strategy for automotive control. It is assumed that each sensor (or a family of sensors) has an associated observer that performs a good estimation under normal operation conditions. In presence of sensor failures the related observer provides an estimation that is biased by signals (that often depend of the references). Since the automotive vehicle is modeled as a linear parameter varying (LPV) system by taken the vehicle speed as a scheduling parameter, the main problem concerns the computation of robustly positively invariant-sets for the state trajectories of the controlled system during fault-free operation. These invariant-sets could be used as bounds and/or thresholds for the residuals (here the tracking error estimations for instance) allowing to detect a sensor failure even in presence of nominal disturbances. The invariant-sets provide a support for fast fault-detection avoiding selecting faulty-sensors. Then, these invariant-sets together with a sensor switching mechanism allows to obtain fault-tolerant guarantees of the controlled system. Here, the proposed approach is applied for a vehicle lateral dynamics control.

10.1 Introduction

Modern automotive control applications require multiple redundancy sensors to keep the driver safety. However, a sensor could fail or operate outside its specified operating conditions. In longitudinal or lateral dynamics vehicle control the sensors could be affected by traffic spray, fog, rain and/or a simple dirt on the cover. A laser scanners, for instance, can miss the object when the vehicle is pitching.

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In heavy rain, standard laser scanners lose measurements because of raindrops even though the laser beam hits objects behind the rain curtain. Sensors work well into certain regions and environmental conditions [23]. Using faulty sensors for feedback-control, even during a few seconds, could be dangerous and the stability of the faulty system is not guaranteed. Hence, during an abrupt sensor failure, it is then very important to perform a fast Fault Detection and Isolation (FDI) and control-reconfiguration actions. The concept of virtual actuators and virtual sensors (or fault-hiding approach) require a fast reconfiguration mechanism in such a way that the fault is hidden from the nominal controller and, the fault effects are compensated [20]. In [19] the concept of virtual actuators and virtual sensors is extended from linear to PWA systems on the basis of the fault-hiding principle. These approaches suggest that a multisensor switching mechanism, as proposed in [12, 21], could be more suitable for fault-tolerant control (FTC) schemes.

Most of works in the literature solve the FDI problem by considering additive faults. However, FTC problems require more accurate faults models. In these terms, severe faults such as component failure is better represented by multiplicative models. Additive faults, when considered as pure exogenous signals, can never destabilise a stable linear closed-loop system, whereas actuator or sensor failures can very well destabilise the control-loop. This consideration shows that additive fault models do not capture the entire nature of severe faults (see for instance [14] and [19] for more details).

Recent advances in sensor technology have generated substantial research interest in developing strategies for multisensor fusion, which aim at combining data supplied by different sensors to provide more accurate and reliable information. When compared with a system employing a single sensor, a multisensor system has enhanced properties such as improved reliability and robustness, extended coverage, increased confidence, faster responses and better resolution [24]. Numerous strategies for multisensor fusion have been proposed in the literature; see, e.g. [4, 8, 10, 11, 22, 24, 25].

The use of sensor fusion estimates in feedback control systems has largely relied on ad-hoc techniques, whereby a multisensor fusion system and a controller are designed independently prior to their assembling within a feedback loop. Recent examples of this type of assembly technique have been reported for automotive applications. For instance, [7] combine a mixture Kalman filter having fault detection capabilities with an arbitrarily designed stabilising controller in a multisensor strategy for vehicle lateral control. The resulting scheme does not have pre-checkable fault tolerance guarantees but it performs well in simulations. Because the vehicle model are often written in terms of the vehicle speed (this is the case when using the classical bicycle vehicle model), LPV modeling and switched systems theory seems to be well adapted to tackle the problem of fault-tolerant control under sensors failures for automotive control applications.

This chapter deals with the problem of obtaining fault-tolerant guarantees of a multi-sensor switching strategy for automotive control. It is assumed that each sensor (or a family of sensors) has an associated observer that performs a good