9

Perspectives

Vehicle system dynamics and integrated control is a new subject that has emerged in recent years, and is a research hotspot in the field of vehicle engineering internationally. Over the past two decades, vehicle system dynamics and integrated control technologies have developed a relatively complete theoretical and technical foundation with the drive of various applications and techniques in relative fields. At present, this technology is leading towards the integration of dynamic system modeling, simulation, analysis, and control. The previous chapters of this book respectively describe the background on the modeling of vehicle system dynamics, tyre dynamics, full vehicle dynamics, longitudinal/lateral/vertical vehicle dynamics and control, centralized integrated control, and layered coordinated control. However, vehicles are complicated multivariable nonlinear dynamic systems, developed with an increasingly higher demand for their performance. Hence, when a complete analysis and integrated control to improve the overall vehicle performance is conducted, there are many key technical problems that require further in-depth studies.

9.1 Models of Full Vehicle Dynamics

Under the influence of complex operating conditions and various uncertain factors (due to the uncertainty of the environment and inaccuracy of design factors), the tyre load, road adhesion condition, and vertical/lateral/tangential forces change during vehicle travel. The uncertainty included in the vehicle ride comfort and handling stability are the functions of the dynamic models. Therefore, when performing the system's dynamical modeling and integrated control, the factors corresponding to the driver, vehicle, road, and environment

Integrated Vehicle Dynamics and Control, First Edition. Wuwei Chen, Hansong Xiao, Qidong Wang, Linfeng Zhao and Maofei Zhu.

lead to extremely complicated models and numerous parameters. In order to solve the controlling problems based on integrity and relevance, it is important to propose effective calculation models, simulation algorithms, and control strategies.

9.2 Multi-sensor Information Fusion

With the development of the fields of microelectronics, field bus control, computer measuring and control, information processing, wireless communication, and drive-by wire technologies, there are more and more types of sensors installed on vehicles. Also, it has become a new research direction to explore the applications of multisensor information fusion technology in condition detection, fault diagnosis, and integrated control for vehicle systems. Multisensor information fusion is actually a kind of functional simulation of complicated problem-solving by the human brain. In the multisensor system, the information provided by a variety of sensors is likely to have different characteristics, including time-varying/time-invariant, real-time/unreal-time, fuzzy/exact, accurate/ incomplete, and mutually supportive/complementary. By making the best use of multiple sensors and combining complementary and redundant information in both space and time based on some kinds of optimization criterions, a consistent interpretation or description of the observational environment can be created, which improves the performance and effectiveness of the whole sensor system and avoids the limit of a single or few sensors. Therefore, with the aid of multisensor information fusion and multisensor management, the optimum use of the limited sensor resources is achieved, as well as multiple goals and multiple scanning spaces of the vehicle system, and the values of each specific characteristic is also obtained. Information fusion technology refers to the theories and techniques in various aspects, such as signal processing, estimation theory, uncertainty theory, pattern recognition, optimization techniques, neural networks, and artificial intelligence; but each method developed according to the requirements of various applications is a subset of the fusion method. For the vehicle integrated control system, the research study is mainly focused on the comprehensive utilization of the fusion information provided by multiple sensors, the foundation of a more exact integrated control modeling, and the development of a desirable optimum control strategy, allowing the improvement of the comprehensive performance of a full vehicle[1].

9.3 Fault-tolerant Control

Fault-tolerant control is a practical interdisciplinary subject, and also a high-reliability technology. Starting in the 1980s, this technology has achieved great advances with numerous significant successes. Fault-tolerant control technology is especially applicable to a chassis integrated control system: a complicated system consisting of several subsystems including the braking/driving system, steering system, and suspension system. If the sensor or actuator in one of the subsystems fails while the vehicle is traveling, other subsystems or the whole integrated control system remain with a suboptimal performance, allowing a safe and stable motion. This is a novel way to improve the reliability of the complicated chassis integrated control system. As each system is inevitably broken down, fault-tolerant control can be regarded as the last defense to maintain the vehicle operating safety. Fault-tolerant control is classified as passive fault-tolerant control and active fault-tolerant control according to the design methodology. Passive tolerant control is able to make the system insensitive to failure, while the active one utilizes a fault accommodation or signal reconstruction to maintain the performance and stability of the system after failure. The design of the passive fault-tolerant control is always conservative, but the active fault-tolerant control, including measurement module, fault diagnosis module, execution module, and fault-tolerant processing module, is more appropriate to the complicated chassis integrated control.

The application and development of fault-tolerant control technology in vehicle electronic control systems is scarce compared to its wide application in the fields of aeronautics, astronautics, computer sciences, and nuclear energy. For example, the current electronic control units (ECU) in vehicle systems are in dual machine structure, and the actuators and sensors use hardware redundancy methods, which results in extremely redundant hardware, high-cost fault tolerance, and a complex system structure if a second-order system is applied to compensate the failure of the first subsystem. Hence, it is essential to explore novel fault diagnosis and fault-tolerant control methods applicable to chassis integrated control systems because they can improve the fault tolerance performance and avoid the high cost of hardware redundancy.

For the application of fault-tolerant control technology in chassis integrated control systems, the main research involves fault-tolerant control structure, control mode, control scheme, and controller design[2]. By utilizing fault-tolerant control technology of integration, networking, and intelligence, the resource-sharing of a complicated chassis control system is accomplished, along with the synthetic diagnosis and fault-tolerant control of multiple methods. Also, based on the properties of smart materials and smart structures, the mentioned method can develop smart fault-tolerant control structures of self-healing and self-compensating that meet the requirements of vehicle operation, and the fault-tolerant control of nonlinear systems and time-delay multivariable dynamic systems. The theoretical level and practical application values of the aforementioned studies are obviously of great importance.

9.4 Active and Passive Safety Integrated Control Based on the Function Allocation Method

Recently, the rapid development of electronic control technologies has played an essential role in promoting advances in vehicle technology, especially in security technology. The progression of vehicle security technology is moving in several directions, by using radar technology and vehicle-mounted photography technology to develop: lane departure warning systems, automatic collision avoidance systems, high-performance tyre comprehensive monitoring systems, adaptive cruise control (ACC) systems, ABS/ASR/VSC systems, driver identity recognition systems, seat belts, and airbags. With the wide applications of advanced intelligent sensors, fast-response actuators, high-performance electronic

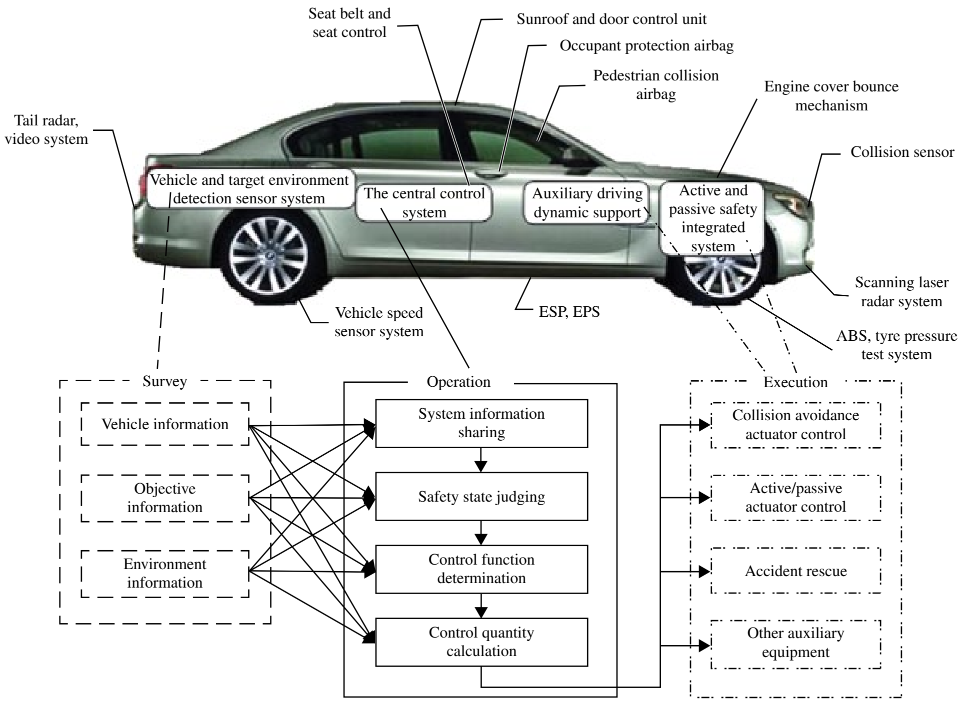

Figure 9.1 Arrangement and structure of an active and passive integrated safety system.

control units, advanced control strategies, vehicle networking technology and radar technology, modern vehicles will be developed towards the electromechanical integration of high intelligentization, automation, and informationalization for the purpose of maximizing driver and passenger safety with the effects of driving assistance systems, active and passive integrated control systems, combined occupant protection in all driving and traffic situations (Figure 9.1).

In different road conditions and driving cycles, it is the combined effect of the driver, driving assistance system, and integrated control system that improve the full vehicle ride comfort, handling stability, and driving safety. Generally speaking, drivers have great capacities of forecasting, solving non-programmed problems, and handling burst interference (i.e., lateral wind, bumpy shock); however, an integrated control system is capable of handling complex tasks and responding rapidly, something that is unmatched by drivers. Hence, in the design of an active and passive integrated control system, if the respective advantages of the driver and the integrated control system are analyzed, and

the functionalities are allocated to both based on a certain criterion and requirements after taking the overall performance of the vehicle into account, both the driver and the integrated control system can make full use of each advantage, improving the overall vehicle performances to the maximum. That is the man–machine function allocation problem at the decision-making level—the upper layer of the integrated control system. Moreover, due to the restrictions of the functionalities of each lower-level control execution subsystem and dynamic properties of tyres, each individual subsystem has its own active zone which enables it to mostly affect the vehicle performance in a specific direction or effective zone. If the system functions are allocated reasonably to each subsystem in its effective working zone, and the functional overlapping between the subsystems occurring during the integrated control is avoided, the overall performance of the overall integrated control system will certainly be improved. Thus, the function allocation matters between the low-level subsystems of the integrated control system[3]. Therefore, in the design of an active and passive safety integration control system, the "driver-vehicle-road" closed-loop system should be focused on, and each effective working zone and objective function difference of the driver, up-level decision-making system, and low-level control execution subsystems analyzed. In addition, by the advisable optimum allocation of the overall vehicle performance to the driver and the decision-making system, as well as the objective function of the decision-making level to each low-level subsystem, the respective advantages of the driver, up-level decision-making system, and each low-level control execution subsystem can be brought into full play, allowing the enhancement of the comprehensive performances of the integrated control system in different road and driving conditions.

In order to better accomplish an integrated control, more attention must be paid to some key issues, as discussed below.

1. *Real-time estimation algorithm of the vehicle driving situation and road parameters*
   The obtained vehicle driving situation and road parameters are the basis for designing an integrated control system. During the actual motion of a vehicle, it is hard to directly obtain many key parameters indicating the vehicle driving status from the vehicle-mounted sensors due to the influence of external disturbances and measuring conditions, such as the vehicle centroid sideslip angle, front and rear tyre sideslip angle, road adhesion coefficient, and tyre longitudinal/lateral/vertical forces; so it is necessary to consider how to know the vehicle motion status and road conditions via necessary information sharing and fusion technologies[4].
2. *Identification of the operating intention of the driver in different road and driving situations*
   In a "driver-vehicle-road" closed-loop system, the driver determines the actual operation intention by applying in a timely manner the steering angle, throttle, brake pedal displacement, and other physical parameters based on the vehicle dynamic performance and road information, such as the desired yaw rate, centroid sideslip angle, and traveling trajectory. Therefore, it is necessary to analyze the variation of such parameters as the driver's forward-viewing time, action lag time, system-following orders with respect to road conditions, and vehicle performance. It is also necessary to assess the operating behaviors of the driver, i.e., straight driving, curve steering, emergency steering, and fatigue. Thus the models of the driver operating intentions in different driving situations are built, hence the driving assistance system can better understand the driver operating behaviors, maintaining the vehicle motion as the driver expects.
3. *Analysis of the stability of the integrated control system consisting of multiple cooperative subsystems*

If the coupling between subsystems is strong, it is necessary to analyze the effect of the subsystems' coupling on stability by conducting the analysis of the interconnected stability between them; thus, it is necessary to consider whether the extended subsystems are stable, and whether the integrated control system after extension is still stable. It is the analysis of the interconnected stability between the subsystems and the stability of the integrated control system that plays an important role in the study of the vehicle instability mechanism in critical conditions.

4. *Study of the coordinated decisions based on objective function allocation*
   In a wide range of driving situations, there is a great difference between the driver's operating intention and the objective function accomplished, where an effective work zone of each subsystem is limited. In order to ensure active and passive safety, ride comfort, handling stability of the vehicle in normal traveling and critical conditions, it is important to analyze the respective objective functions familiar to the driver, up-level coordinators, and low-level control execution subsystems in the design at the system decision-making level. Then, by the coordinated decision at the decision-making level, the man–machine function sharing and the function allocation for the low-level control execution subsystems, all the driver, driving assistance, coordinated and control execution subsystems can implement their respective functions in the effective working zones. Hence, the comprehensive performance of the vehicle is enhanced, especially for objectives under the critical conditions.

9.5 Design of System Integration for a Vehicle

In the design of the mechanical, control, information perception, and actuator units of a vehicle system, it is necessary to consider such factors as hardware integration, information integration, function integration, and driving situation of the system as a whole. Fault-tolerance and redundancy design are also important in the system design. Furthermore, attention should be paid to other matters, including topology expression of multiscale parameters and various domain parameters, objective optimization of singular modes and evolution indication, coupling of multiple active and passive control systems in the work process, coordinated design of multi-unit techniques, and so on[5].

The main purposes of advanced vehicle control technology, intelligent driving assistance, real-time collision early-warning, and avoidance systems are to reduce the mistakes and operations made by the driver, and enhance effective and active measures for the vehicle safety[6,7]. To view the system's integrated safety as a whole, sensors can provide additional condition monitoring and situation awareness; then, based on the data obtained from sensors, security algorithms can conduct evaluation, estimation, calculation, perception, and judgment using various determined and random methods. Moreover, this algorithm can provide optimal and safe corrective actions, which are similar to the judgment of proficient drivers in emergencies. The judgment can serve as an intelligent co-driver, and finally transfer to particular control processes (i.e., driving, braking, steering, etc.). The actual functionality of interaction/interference/drive is also a part of system integrated design.

As there is not yet any applicable uniform performance standard, the further development and popularization of active and passive safety integrated design technologies has been hindered. Note that it is complicated to set appropriate criteria for active safety systems,

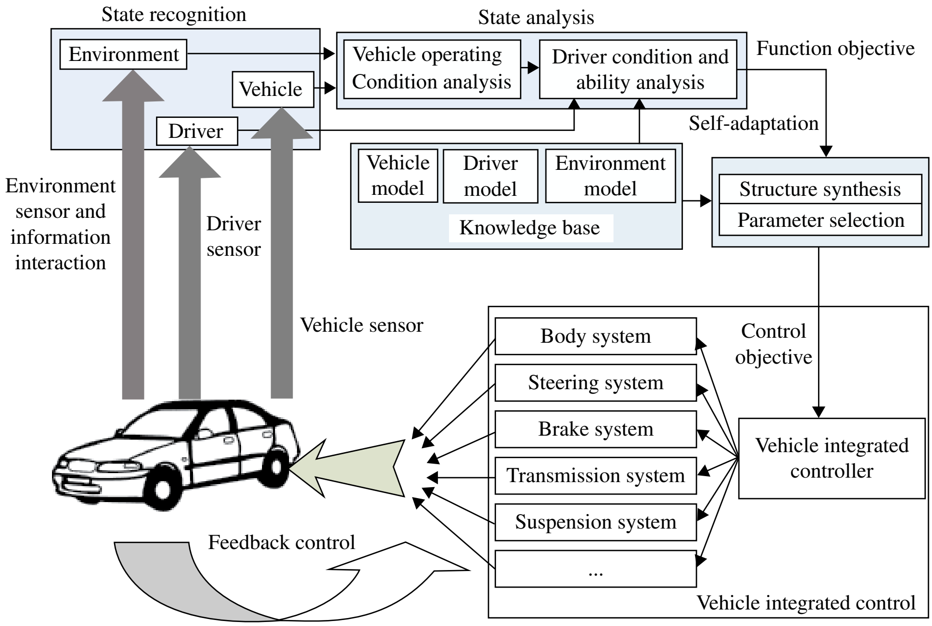

Figure 9.2 The adaptive intelligent vehicle.

due to great differencse between whole systems and the absence of uniform criteria between manufacturers; also, it is much harder to solve the problems of driver adaptability because the driver interactive system is quite complicated. Novel and effective criteria for the aforementioned technologies only can be set up by further studies and evaluations.

9.6 Assumption about the Vehicle of the Future

The assumption of vehicle development in the future is that the size of the vehicle body will vary according to different types of environment and available space, making passengers feel at ease and comfortable. The future vehicle will not have wheels, and will travel by suspending itself over the road, flying in a low level as a vertical take-off or landing aircraft. The vehicle velocity will reach up to 600km/h. The color of the vehicle body will be able to change to fit with different environments. Driving by wire will be used instead of current mechanical devices, and the drivers will not need to manipulate the car themselves, but will only have to send electronic signals and input destinations to the computer before departure. The vehicle will not only recognize people's voices, but also correctly determinate the relative position and driving situation of adjacent vehicles on the road, so that the parameters of the vehicle in control can be adjusted. Before a collision accident, the vehicle will be able to momentarily start the safety equipment by an electronic detection and sensor systems, ensuring the driving safety and rightness.

The future vehicle will be an adaptive intelligent vehicle as shown in Figure 9.2. This type of vehicle can be divided into two main modules: the action control module consisting of the steering, braking and driving subsystems, and the integrated control module which adapts to external environment and the driver's instructions. The future vehicle system utilizes a three-level structure: an adaptation layer for the driving situation, an optimization and coordination layer for the subsystems, and an adjustment layer for the execution subsystems. The driver module can form expected motion states of the vehicle according to all the information obtained by the drivers, and then conduct integrated control by sending instructions to each control subsystem via on-off control.

The ultimate goal of the vehicle is to be super intelligent and have zero emissions, which can greatly promote technological innovation and finally achieve the ideal goal—harmonious coexistence between man and nature.

References

[1] Jiang W, Yu Z P, Zhang L J. A review on integrated chassis control. Automotive Engineering, 2007, 29(5):420–425.
[2] Yang L Q, Chen W W, Wang H B. Optimal robust fault tolerant control for vehicle active suspension systems based on $H_2/H\infty$ approach. China Mechanical Engineering, 2012, 23(24): 3013–3019.
[3] Wang H B, Chen W W, Yang L Q, Xia G. Coordinated control of vehicle chassis system based on game theory and function distribution. Journal of Mechanical Engineering, 2012, 48(22): 105–112.
[4] Chen W W, Liu X Y, Huang H, Yu H J. Research on side slip angle dynamic boundary control for vehicle stability control considering the impact of road surface. Journal of Mechanical Engineering, 2012, 48(14): 112–118.
[5] Zhong J, et al. Coupling Design Theory and Methods of Complex Electromechanical Systems. Beijing: China Machine Press, 2007.
[6] Wang J E, Chen W W, et al. Vision guided intelligent vehicle lateral control based on desired yaw rate. Journal of Mechanical Engineering, 2012, 48(4): 108–115.
[7] Rajamani R. Vehicle Dynamics and Control. New York: Springer US, 2006.