With the development of sensing patterns, communication technologies, and computing paradigms, traditional vehicles are rapidly evolving towards intelligence, networking, and collaboration. With intelligent connected vehicles as the starting point, the intelligent transportation system (ITS) driven by the vehicle-to-everything (V2X) communications is expected to achieve safer, more efficient, and sustainable transportation. The vehicular cyber-physical system (VCPS) is the foundation and key to implementing ITS applications. However, the high heterogeneity, high dynamics, and distributed features of the vehicular networks, as well as the diverse demands of ITS applications, pose great challenges to the implementation of VCPS. First, the design of innovative service architecture and the establishment of efficient data sensing and quality evaluation models towards the highly heterogeneous and dynamic physical environment of the vehicular networks are the architecture foundation and driving force of VCPS. Second, the proposal of advanced task scheduling and resource allocation towards dynamically distributed nodes in vehicular networks is the technical support for further optimizing the quality of VCPS services. Third, the design of an equilibrium strategy for system quality and cost towards the diversified application demands of ITS is the theoretical guarantee for achieving high-quality, low-cost, and scalable VCPS. Finally, the design and implementation of a prototype system towards the real complexity of the vehicular communication environment is a necessary verification method for VCPS. Therefore, this thesis focuses on the theoretical and systematic innovations of the VCPS from four aspects: architecture integration and metric design, collaborative resource optimization, quality-cost tradeoff, and prototype system implementation. The main innovative contributions are as follows:

\circled{1} Design and optimization of quality metric for vehicular cyber-physical fusion based on vehicular hierarchical architecture. First, this thesis designs a hierarchical service architecture that integrates software defined network and mobile edge computing paradigms to maximize their synergistic effects. Based on this, distributed sensing and heterogeneous information fusion scenarios are proposed, where edge nodes fuse sensing information and construct logical views. Second, this thesis establishes an information queuing model based on multi-class M/G/1 priority queues and models the quality of VCPS for various requirements of heterogeneous information. Specifically, the Age of View metric is designed to quantitatively evaluate the quality of views, and the VCPS quality maximization problem is formulated. Third, a multi-agent difference-reward-based deep reinforcement learning (MADR) algorithm is proposed to achieve VCPS quality maximization. The system state includes vehicle sensing information, edge cached information, and view requirements. The action space of the vehicle includes information sensing frequencies and uploading priorities, while the edge node allocates vehicle-to-infrastructure (V2I) bandwidth according to vehicular predicted trajectories and view requirements. Finally, this thesis constructs a simulation model and gives a comprehensive performance evaluation, which conclusively demonstrates the superiority of the MADR algorithm.

\circled{2} Key technologies for communication and computing resource cooperative optimization for vehicular cyber-physical fusion. First, this thesis proposes a collaborative communication and computing offloading scenario, where edge nodes collaborate to schedule communication and computing resources to achieve real-time task processing for VCPS. Second, this thesis considers intra-edge and inter-edge interferences in non-orthogonal multiple access (NOMA)-based vehicular networks, and establishes a V2I transmission model. The cooperative resource optimization (CRO) problem is formulated to maximize the service ratio for VCPS tasks. Third, a multi-agent game-theoretic deep reinforcement learning (MAGT) algorithm is proposed to achieve cooperative optimization for heterogeneous resources. Specifically, the CRO problem is decomposed into two subproblems, i.e., task offloading and resource allocation. The task offloading subproblem is modeled as an exact potential game and the Nash equilibrium is achieve by the MAGT algorithm. The resource allocation subproblem is decomposed into two independent convex optimization problems and solved by gradient-based iteration methods and KKT conditions, respectively. Finally, this thesis builds the simulation model and gives a comprehensive performance evaluation, which conclusively demonstrates the superiority of the MAGT algorithm.

\circled{3} Key technologies for quality-cost tradeoff optimization for vehicular cyber-physical fusion. First, this thesis proposes a collaborative sensing and V2I uploading scenario, where edge nodes construct high-quality and low-cost views based on collaborative vehicle sensing and uploading. Second, this thesis considers the timeliness and consistency of heterogeneous information in logical views and establishes a VCPS quality model. Meanwhile, considering the redundancy of view information, sensing cost, and transmission cost, a VCPS cost model is established. On this basis, a bi-objective optimization problem is formulated to maximize VCPS quality and minimize VCPS cost. Third, a multi-agent multi-objective deep reinforcement learning (MAMO) algorithm is proposed to achieve quality-cost tradeoff. Specifically, the system reward is a one-dimensional vector containing VCPS quality and VCPS profit. The thesis also proposes a dueling critics network to evaluate agent actions based on state-value and action-advantage. Finally, this thesis constructs a simulation model and gives a comprehensive performance evaluation, demonstrating the superiority of the MAMO algorithm.

\circled{4} Design and implementation of a non-line-of-sight collision warning prototype system based on vehicular cyber-physical fusion. First, this thesis introduces a none-line-of-sight (NLOS) collision warning scenario, where vehicles at a crossroads have potential collision risks due to line-of-sight obstructions, and traditional line-of-sight collision warning is no longer applicable. Second, this thesis proposes an application-layer vehicular-to-infrastructure (V2I) communication delay fitting model and a packet loss detection mechanism, and proposes a view-calibration-based collision warning (VCCW) algorithm that achieves real-time and accurate logical view construction via packet loss detection and delay compensation to further improve system performance. Third, this thesis constructs a simulation model and performs performance evaluation to prove the superiority of the VCCW algorithm. Finally, this paper builds a hardware-in-the-loop test platform based on onboard units and roadside units and further implements a prototype system for NLOS collision warning in a real vehicle network environment, verifying the feasibility and effectiveness of the proposed system.