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Protocols and applications in vehicular sensor networks for driving safety, driving efficiency, and data services

Recently, vehicular sensor networks have been spotlighted for driving safety, driving efficiency, and data services in the road networks. The sensors in vehicles play a vital role in monitoring road surfaces to detect obstacles and road hazards, and the monitoring is performed by collection of various motion sensors (e.g. accelerometer, gyroscope, and magnetometer), obstacle detection sensors (e.g. ultrasonic and laser sensors), and camera (e.g. dashboard camera).

For the driving safety, precisely monitoring the road surface and identifying the road hazards are critically important, and this sensing information can be shared among the vehicles to avoid possible dangerous circumstances and situations. Additionally, it is important to support instantaneous response to dynamic road situations and neighboring vehicles through the efficient and delay-bounded data communications. This is possible through dedicated short-range communications (DSRC), such as IEEE 802.11p. The driving safety can be further improved by leveraging a cooperation with infrastructure nodes (e.g. road-side units (RSU) and relay nodes) and other nodes (e.g. smartphones and Internet of Things (IoT)). Therefore, the construction of the vehicular sensor networks in vehicles and stationary infrastructure nodes is vital for providing the overall safety. The vehicular sensor networks for driving safety can include media access control (MAC) protocols, data forwarding schemes, and routing protocols for unicast, multicast, and broadcast, transport layer protocols, and security services (e.g. message authentication, light-weight digital signature, user identification, and malicious vehicle detection). Using the protocols, one of the useful applications in the vehicular sensor networks is collision warning system for vehicles and pedestrians.

For the driving efficiency, sensors (e.g. loop detectors and road traffic cameras) can measure a road congestion level for the navigation purpose. Also, vehicles with a navigation system can measure the current congestion level and share their navigation paths with a Traffic Control Center (TCC) for the real-time coordination of the navigation service. As a result, TCC performs global optimized navigation and provides updated navigation information to the vehicles to relieve the congestion level. To perform driving efficiency features, applications in the vehicular sensor networks can include real-time coordination-based navigation, navigation-path-aware traffic signal scheduling, and the integration of navigation system and traffic signaling system.

For the data services, the effectiveness of communication cost and performance needs to be considered together according to application types. The delay tolerant data services for uploading and downloading the road sensing data can take an advantage of DSRC-based vehicular sensor networks with RSUs instead of relying on 3G/4G-long-term evolution (LTE) infrastructures. For this purpose, the vehicular sensor networks require efficient IP address auto-configuration, Domain Name System (DNS) naming services, service discovery, and vehicular network architecture using network functions virtualization (NFV) and software-defined networking (SDN). For this purpose, applications in the vehicular sensor networks can include DSRC-based cellular traffic offloading, multimedia streaming, and anonymous data delivery/retrieval.

This special issue focuses on protocols and applications in vehicular sensor networks related to the driving safety, driving efficiency, and data services. It includes the survey, designs, implementation, experiments, and analysis for the protocols and applications for the vehicular sensor networks. This special issue received 10 submissions from both academia and industry in the vehicular sensor networking field. Through a strict peer-review process, this special issue accepted four papers with high quality. At least two experts in this field reviewed each paper. The following summarizes each paper along with its main contribution.

The paper entitled "Survey on Protocols and Applications for Vehicular Sensor Networks," which is authored by JP Jeong and TT Oh,[1] surveys protocols and applications for the driving safety and efficiency in vehicular sensor networks. The vehicular sensor networks are feasible because of the following technology trends. The first trend is that the current vehicles are equipped with a Global Positioning System (GPS) navigation system in the form of a dedicated navigator (e.g. Garmin) or smartphone app (e.g. Waze). The second trend is that the government regulation requires vehicles to be equipped with a DSRC device for the communications among vehicles and infrastructure nodes for the road safety. Because of these trends, various applications in vehicular sensor networks are envisionable for not only the road safety of drivers and pedestrians but also the driving efficiency and fuel saving. To support these applications, computer networking protocols need to be designed and tailored for the optimal performance in physical, link, and network layers. This paper summarizes and analyzes the state-of-the-art articles in the protocols and applications for vehicular sensor networks in order to provide the guidance of research direction to the audience in vehicular sensor networks. For the protocols, the IEEE standards of wireless access in vehicular environments (WAVE) are explained as physical and link layer protocols. Also, broadcast schemes and data forwarding schemes are reviewed for the aspect of the data dissemination in vehicular sensor networks. Also, the applications in vehicular sensor networks are introduced, such as navigation system, pedestrian protection system, vehicle collision avoidance system, and green driving assistance system. Finally, security and privacy issues are discussed for vehicular sensing networks in terms of security threats, security requirements, vehicular ad hoc networks (VANET) security approaches, and security challenges.

The paper entitled "Application of Vehicle Mounted Accelerometers to Measure Pavement Roughness," which is authored by Y Du et al.,[2] proposes a crowdsensing scheme for pavement roughness measurement that uses vehicles as mobile sensors in road networks. To enhance the efficiency of pavement roughness measurement with minimum cost, this paper proposes an integrated and wireless transfer system for such road pavement measurement. The proposed system can obtain each vehicle's status and location data from wireless acceleration sensors and GPS, and provide periodically the reports for the road measurement data to a cloud server. This cloud server calculates the international roughness index (IRI) for the road pavement by power spectral density analysis. The architecture of the proposed system consists of data collector, car mounted terminal, and processing system. Two wireless communication systems, such as ZigBee and 3G modules, are utilized in the system. ZigBee is used so that the data collector can transfer accelerometer sensing data to the car-mounted terminal. 3G is used so that the car-mounted terminal can transfer the accelerometer sensing data and GPS positioning information to the processing system in the cloud server. The processing system uses an acceleration-IRI model to calculate IRI, and a GPS-based distance algorithm is used to segment the measured road per 1 km. Various results are saved in an Oracle database in the cloud server, displayed on the digital map, and made available to a mobile terminal. For the proof of concept, multiple field tests of the prototype system were conducted in Huzhou, Zhejiang province in China. The experiment results indicate that the relative error of this proposed system is less than 10% for the laser roughness testing method that is a legacy approach using expensive hardware. Therefore, the proposed system can measure the road pavement roughness with the accuracy, effectiveness, and reliability for the deployment in a large-scale road network.

The paper entitled "A Location-Dependent Tasks Assignment Mechanism in Vehicular Crowdsensing," which is authored by L Rui et al.,[3] proposes a location-dependent task assignment scheme for vehicular crowdsensing in road networks. Since the current vehicles are equipped with various sensors and wireless communication devices (e.g. 3G/4G-LTE and WiFi), it became possible to use the vehicles as mobile sensors to perform large-scale and complex social sensing tasks, such as road roughness measurement and road hazard detection. A key observation for this paper is that most of the sensing tasks are tightly coupled with specific locations, so the measurement needs to be performed in certain areas. This paper at first proves that a location-based optimal task assignment is a non-deterministic polynomial-time hard (called NP-hard) problem. To solve this challenging problem, this paper suggests a heuristic algorithm for a mathematical model of multi-vehicle collaborative task assignment problem. This algorithm considers each vehicle's time budget constraint and location, and also the requirements of sensing tasks. The heuristic algorithm performs an approximation location-based task assignment in two steps. The first step determines the allocation order among the engaged vehicles. The second step schedules an optimal sensing path for each individual vehicle. With Lingo software and simulations, this paper shows the efficiency of the proposed optimal sensing path scheduling algorithm for the crowdsensing task assignment.

The paper entitled "Internet of Vehicles: From Intelligent Grid to Autonomous Cars and Vehicular Fogs," which is authored by EK Lee et al.,[4] proposes a framework for Internet of Vehicles and use cases, such as intelligent grid, autonomous cars, and vehicular fogs in road networks. The enhancement in communications, controls, and embedded systems has made the formation of Internet of Vehicles. A vehicle is an important device for rapid human maneuver according to a driver's commands. It can be regarded as a moving sensor platform, collecting sensing data from the road environment and providing them to drivers and infrastructure to assist in safe navigation, pollution control, and traffic management. Furthermore, the evolution is the appearance of autonomous vehicles, which mean self-driving cars. Google self-driving car project envisions that the Internet of Vehicles will be an autonomous transport fabric, which can make its own decisions about delivering customers to their destinations without human intervention. For the autonomous platooning, vehicles need to continuously share their positioning information with their neighboring vehicles in a timely manner through VANET. As a branch of the IoT, the Internet of Vehicles will have communications, storage, and processing capability with intelligence, and learning capability to proactively serve the customers' intentions. This Internet of Vehicles can be realized through the vehicular fog, that is, an instantaneous Internet cloud for vehicles, which provides all the required services to the autonomous vehicles. This paper discusses the evolution from intelligent vehicle grid to autonomous, Internet-connected vehicles, and vehicular fog.

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Jaehoon Paul Jeong[1], Tae Tom Oh[2], Sangheon Pack[3] and Alexandre Petrescu[4]
[1]Department of Interaction Science, Sungkyunkwan University, Suwon, Republic of Korea
[2]Department of Information Sciences and Technologies, Rochester Institute of Technology, Rochester, NY, USA
[3]School of Electrical Engineering, Korea University, Seoul, Republic of Korea
[4]Division of Technological Research, CEA, Gif-sur-Yvette, France

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