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Situation awareness within the context of connected cars: A comprehensive review and recent trends

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ABSTRACT

Driving safety is among the most important factors in the design of next generation vehicles as an integral component of Intelligent Transportation Systems. Crash avoidance and reduction of potential subsequent fatalities require timely delivery of sensitive and pertinent safety information for the drivers. Hence, the driver can become aware of the current driving situation, and can consequently, take appropriate decisions to avoid potentially imminent hazards. In this paper, we propose a comprehensive survey on situation awareness within the context of connected vehicles and Internet of Cars (also called here as connected cars). We provide context for the Internet of Cars and highlight its major features. Furthermore, situation awareness in the Internet of Cars is explored through presenting an in-depth discussion on its different components. Various aspects of high and low level information fusions are described within this context. Besides, major methods/models in situation awareness are linked to the main aspects of each component, and an overall comparison between them is reported. Moreover, on-the-road safety frameworks incorporating situation awareness are highlighted. Finally, the challenging issues and the emerging trends that shall be faced by the research community are addressed.

1. Introduction

Nowadays, our cities face new challenges such as spectacular population growth, massive pressure on city infrastructure (power, water, health care, transportation) and pollution. The advent of the smart city concept came in response to some of these modern era challenges. Intelligent infrastructure, innovative data process, smart grids and electric vehicles provide synergistic benefits for smart cities. One of the fundamental premises of smart cities is to improve quality of life by developing “smart mobility” [1]. The development of Intelligent Transportation Systems (ITS) has been a crucial element in the design of future smart/connected cities, with the objective of super-efficient navigation and safer travel journey. With more than a billion cars on the roads today and growing, road safety has quickly become a major challenging factor to deal with within the transportation industry. Alarming statistics indicate that traffic accidents produce on their own 1.3 millions of fatalities per year [2]. In light of these facts, it is becoming clear that novel alternatives within the transportation industry are deemed necessary. Connected cars are quickly becoming a major milestone of the next generation design of intelligent transportation systems. Indeed, Vehicular Ad-hoc Networks (VANETs), which represent communication platform for these systems, have witnessed a strong rise research activities in the last decades [3]. The purpose was to ensure transportation efficiency, improve safety and mitigate the impacts of traffic congestions. In VANETs, vehicles are deemed mobile sensor platforms [4] that are able to collect data from their surrounding envisioned, and then, transmit relevant information to the interested entities [5]. To model such connectivity, VANETs rely on wireless communication channels that connects the car to other nearby entities. In the transportation domain, these entities can be cars, Road-side Units (RSUs), public networks, humans, and/or physical sensors. The communication links for each of them are respectively called Vehicle-to-Vehicle (V2V), Vehicle-to-RSU (V2R), Vehicle-to-Infrastructure (V2I), Vehicle-to-Human (V2H), and Vehicle-to-Sensor (V2S). Fig. 1 illustrates the different types of communication in VANETs. These various communication channels are used for safety and traffic information flow and ensure an enlarged situational view of the environment beyond the limitation of the driver’s view. Thus, an early perception of potential risks could be attained and anticipated maneuvers could be taken by the car or the driver. The potential of VANETs has been acknowledged with the establishment of ambitious research programs such as WAVE, C2C-CC, CVIS, NoW, VSC [6]. Moreover, radio spectrum has been allocated in

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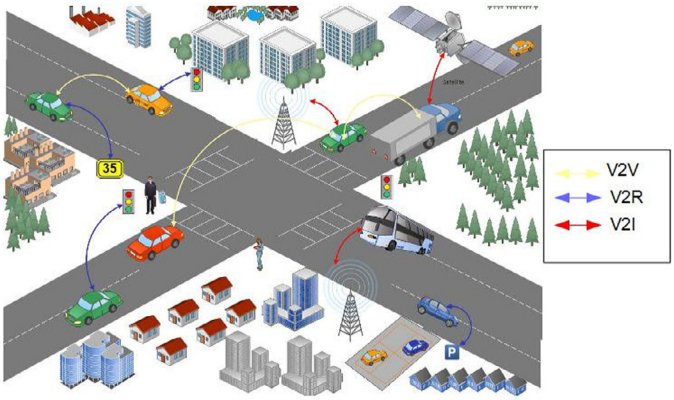

Fig. 1. Different types of communication in VANETs.

North America, Europe, and Japan for the dedicated short range communications (DSRC) to facilitate the widespread of ITS.

On the other hand, intelligent infrastructure is a main component of a smart city, and a key enabler for the development of intelligent infrastructure is the Internet of Things (IoT). It depicts the pervasive integration of sensors within physical infrastructures [7]. Already, billions of smart sensors are embedded today in our cars, bridges, streets, buildings, and within the environment of our living space. These devices are expected to autonomously discover their own environment, connect and interact with their surrounding space, and be able to send out streams of data for various objectives [8]. Recent statistics from Cisco [9] and Ericsson [10] predict that at least 50 billion of “things” will be connected to the Internet by 2020. Smart cars will represent a substantial portion of these connected things. This convergence of VANETs and IoT has given birth to a new paradigm called the Internet of Cars. Actually, cars become mobile devices while drivers are becoming connected drivers. We witness the birth of “computers on wheels”. However, such mobility comes at a cost.

As it is highlighted in various review papers, the challenges of the Internet of Cars area are highly concentrated on topics such as: routing and communication protocols [11–14], security and privacy [15,16], data dissemination [17–19], simulation [11,20,21], information management [22,23], and information fusion [16,24–26]. The last two were motivated by the fact that connected cars operate in a data-rich environment. In fact, various sensors are installed on cars, which makes them a swarm of mobile sensors and information sources that consistently generate and receive huge amount of data and information. The external driver’s environment presents a variety of data such as weather, road conditions, traffic and social networks streams. The levels of abstraction of this information range from lower-level physical sensors data to higher-level human-generated soft information.[1] Consequently, connected cars should use this big pool of data and information to provide drivers with required situational awareness.

In most of the Internet of Cars applications, cars need to be aware of the current situation (dependent on the type of application) to consequently achieve the goals of those applications. Indeed, the applications envisioned for the Internet of Cars can be roughly organized into three main classes: safety, convenience, and comfort [27]. This paper will mainly focus on the safety applications. Safety applications allow vehicles to consistently perceive the surrounding environment (specifically the state of other cars or road conditions), and if necessary, avoid incidents by taking proper actions on time. Based on their level of interference, safety applications are either passive or active [28]. Passive applications automatically take physical actions (often at critical moments), and active applications only provide driving assistance to drivers using proper Human–Computer Interaction (HCI) units. Collision (Avoidance) Warning Systems [29–32], Intersection Safety Management [33–35], Object Detection [36–39], Lane Departure Warning Systems, and Blind Spot Mitigation [40–42] are deemed the major safety applications of the Internet of Cars [25].

However, the diversity and the huge size of the available data/information are the main challenges that the Internet of Cars faces. In fact, a vehicle has to efficiently manage and interpret a huge amount of diverse data/information to achieve *Situation AWareness (SAW)* and alert drivers to traffic conditions, closed roads and accidents among other critical driving information. Accordingly, the importance of SAW on the road is highlighted by Salmon et al. [43]: *“SAW has received far less attention in a road transport context. This is despite the fact that failures related to poor SAW, such as inattention, have been identified as key casual factors in road traffic crashes.”* The authors also study the application of SAW in the road and transportation area from three different perspectives: individual, computational, and socio-technical.

While the individual, and the social perspectives are well-studied in the literature [44–46], just a few attempts that exploit computational side of SAW in VANET, can be found in the literature. For instance, Markis et al. [26] propose a survey on context-aware mobile and wireless networking by mainly discussing context uncertainty handling, acquisition, modeling, exchange, and evaluation. Specifically, Markis et al. [26] introduce an abstract classification that while clarifies the main aspects of a context aware mobile network, avoids giving sufficient knowledge about the available methods that aim to model those aspects. In fact, the analysis given in this paper is more abstract and technology-centric (rather than being specific and methodology-centric).

As another example, Kakkasageri and Manvi [22] propose a general taxonomy for information management protocols in safety applications. The presented taxonomy structures information management protocols into four main branches: information gathering, aggregation, validation, and dissemination. Furthermore, the authors introduce different classes of approaches per branch, and introduce the major protocols assigned to them, accordingly. While the proposed classification is very useful in information dissemination problems in VANET, it does not provide any information about how to achieve situation awareness.

Besides the above review perspectives, classification of secure information aggregation methods [16], and categorization of lower-level data-driven models in ITS [24,25] are among the other topics in structural analysis of information processing-related problems. In fact, what makes this paper different from the similar attempts in the literature is its fully SAW-inspired comprehensive approach in studying the necessary steps towards constructing a reliable SAW-based framework from both technology-centric and methodology-centric standpoints.

In this paper, we propose a series of taxonomies that are designed in a way to assist the interested researchers identifying their own requirements within the Internet of cars context, and then, select the adequate methods and techniques, with rich mathematical basis, to produce a fitting SAW model. Besides, various SAW models are compared according to different criteria related to their features and applicability. To the best of our knowledge, this is a novel approach in structuring various leading SAW-related methods in the Internet of Cars area.

The rest of the paper is organized as follows. In Section 2, the paradigm of SAW in the Internet of Cars is introduced, and a structural analysis on SAW is briefly explained. Sections 3–6 provide detailed aspects of the existing SAW taxonomies. Comparative aspects on different SAW methods and models are presented in

[1] Throughout this paper, *Data* is deemed to be any low-level fact that specifies the features of a certain entity, whereas *information* encloses the facts about an already recognized entity and/or its relationships with other entities.