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Recent Advances on Context-Awareness and Data/Information Fusion in ITS

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Abstract Intelligent transportation systems (ITS) involve various emerging technologies and applications. This paper presents a comprehensive review of recent advances on data/information fusion and context-awareness referring to ITS. Data/Information fusion is necessary to fuse the data from different sensors and thereby extract relevant information on the target sources. On the other hand, context-aware information processing provides awareness of the driving environments by deploying intelligent query processing and smart information dissemination. The fusion and context-awareness should help in improving ITS operations with better road-awareness service, traffic monitoring, vehicle detection as well as development of new methods. This paper is centered on data fusion and context aware methodologies developed recently in the areas of ITS rather than on their ITS applications. We found that the recent progresses in ITS fusion are devoted to the potential cooperative approaches providing real-time/dynamic vehicle sensing technologies, whereas the recent context awareness techniques are deploying service concepts (e.g. location aware service) and frameworks. It is believed that the newly developed advanced fusion/context-aware techniques are becoming more effective to tackle complex traffic scenarios (e.g. traffic intersection) as well as complex urban environments.

Keywords Intelligent Transportation Systems (ITS) · Data/Information Fusion · Context-Aware Processing

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1 Introduction

Intelligent transportation systems (ITS) deal with exploring emerging technologies and system engineering techniques to develop and enhance all types of transportation systems [1–3]. The research and development on ITS have various implications, such as improving transportation convenience and safety (e.g., autonomous driving), enhancing efficiency in transportation (e.g., traffic congestion reduction), and having transportation schemes for environmentally-friendly traffic (e.g. by minimizing the fuel consumption) since we are very much dependent on transportation systems in our day-to-day lives [4]. Intelligent Transportation Systems (ITS) focuss on integrating various technologies with vehicles and transportation infrastructure to make transportation safer, cheaper, and more efficient in applying various technologies. ITS could provide five key merits by: 1) enhancing traffic safety, 2) improving transportation network performance, especially through traffic jam reduction, 3) increasing traffic flow and comfort, 4) providing green environments, and 5) raising the production and lifting the growth in employment as well as economy [2, 4, 5].

It has been reported by the ministry of national highway traffic safety that traffic collisions in USA have been caused the death of more than 33,000 people and an estimated injury of 2.22 million people in 2009 [6, 7]. In order to minimize the number of accidents, numerous research and development works are initiated in the government and the private sectors to integrate different technologies that could improve transportation safety. Most fatal accidents, as reported in [6, 7] are occurred by the driver's fault. Therefore, technology supporting to automate the vehicular operation and release a person even partially from the control operation would presumably enhance the road safety significantly.

ITS has been primarily concerned about the problem of traffic congestion, which is rapidly increasing due to the increase of population, population density, and vehicles as well as urbanization [2]. Traffic congestion seriously affects the efficient operation of ITS due to increment of roadway travel time, fuel cost and environment pollution. According to the Urban Mobility Report for 2010 carried out by TTI (Texas Transportation Institute) in Texas A&M University, shows that Americans have spent extra 4.8 billion roadway hours because of the traffic jam. This results in additional fuel consumption of 1.9 billion gallons, that increases the overall transportation expenditure of about 115 billion dollars for waiting time and fuel consumption. This is much higher than the cost of fuel just needed to travel around without traffic congestion. Also the overall yearly wasted time of an automobile due to congestion has raised from 14 hours to 34 hours between 1982–2010 [8]. Thus, everyone including civil engineers, urban planners, administrators, and the common public are very much concerned on minimizing the traffic congestion as well as the relevant economic and environmental costs.

In order to increase transportation safety, efficient use of roads and fuels, automobiles are accomodated with smart sensing, computing and communicating technologies. In the long run, the perspective is to build intelligent vehicles which could operate without driver's interaction. A number of research institutions and companies around the world are therefore investing to deploy technology in autonomous vehicles. Sophisticated sensors (such as laser scanners, radar, video camera, GPS (Global Positioning System)) and powerful computing resources (such as AI (Artificial Intelligent) algorithms, control softwares, navigation systems) have been deploying for autonomous navigation. In USA, ITS America (Intelligent Transportation Society of America) [9] focuses on the research and development of ITS applications within USA. In Europe, several large scale ITS projects have been conducted focussing on ITS related problems [5]. The European IST project CarTalk2000 [10] had plan to develop cooperative assisted driving systems. The GST [11] project is also related to road safety. The integrated European project PReVENT [12] had been carried out for road safety improvement by developing and running collision prevention systems for safe traffic. The ESA [13] project had goal to decrease road accidents by 50 % within 2010. In Japan, large investments have been made towards the developments of driver information systems. The AHS (Automated Highway System) project conducted in Japan, the purpose is to assist in autonomous driving by developing an automatic highway system. In Canada, ITS Society of Canada [14] is actively working to find technological solutions for various ITS problems throughout the country for a variety of transport.

ITS technology plays a crucial role to prevent an accident and response fast in emergency situations. Therefore, the current in-vehicle safety technology already provides systems for accident avoidance, lane departure warning, and drowsy driver warning [15]. In case of any traffic event and emergency situation, ITS technology could assist to locate and getting response fast about vehicle accidents or other disaster places. For instance, an automatic crash notification (ACN) system deploys sensors to locate any crash and simultaneously contact to emergency call center from the event/vehicle location. Emergency vehicle preemption system gives the right-of-way to the emergency vehicles at traffic lights in order to take fast action to the crash. In this way, ITS is able to coordinate traffic management and emergency action by sharing the data/information between emergency personnel, traffic managers, and police. Standardization efforts are also being taking place to develop such cooperative systems enabling the interactions between technologies [16].

ITS technology also provides large facility in highway toll collection. Automated toll collection systems utilize transponders using RFID, license plate recognition (LPR) system, or barcode stickers, for detecting vehicles and collecting the toll fees without stop/slow down the vehicles. This assists to remove or reduce check points and toll booths along the roadway. In cities if there are restricted zones, additional road tax is collected through the electronic road pricing (ERP) system when vehicles are arriving at the congested zones. To control the congestion, in some cases where the high-traffic systems further engage high occupancy vehicle (HOV) lanes. Thus, for the cause of law enforcement, different automatic vehicle occupancy counting systems as mounted in the vehicle are designed [17, 18].

One of the main reasons for having congestion and pollution in the city specially in metropolitan areas is occurred due to extra driving around the city to search the parking spots. Therefore, important service of real-time dissemination of information about parking spots is provided by ITS. It can be done by a distributed sensors network which use to monitor whether the parking spots are available or not and this data is delivered instantly to the drivers. For example, in Los Angeles city, a ITS project known as ExpressPark has already started that guides the drivers to empty parking spots as well as display the current parking rates using demand based pricing principles and technology [19]. The parking rates are determined instantly based on several factors, such as the number of parking spaces available, parking time and parking duration. Further advancement in technology could even provide the reservation of parking space before arriving to minimize the waiting delays, frustrations, fuel cost, and the wear and tear of the vehicle due to the time spent to search for available parking spaces/open parking blocks around the city [20].

Using the distributed sensing technologies forming the ITS network, real-time data about current situations of the roadways, such as accidents, road construction, poor weather condition, could be acquired and warn the drivers by delivering instant messages through signs, highway advisory radio, in-vehicle navigation systems, or Smartphone apps. Drivers receive the relevant information before they decide to follow the same route or different route, or to change their travel time/mode of transportation. Various information on public transit including bus and train fares and their schedules are also provided by ITS.

To illustrate the impact of ITS, we can consider the collision warning for a complex intersection scenario[1] in Fig. 1. In this scenario, vehicles A_1 and B are heading to a traffic intersection with collision risk. In order to detect the mutual position and avoid the accident at the intersection, vehicles A_1 and B periodically exchange positioning information by means of CAMs (Cooperative Awareness Messages). The information exchange allows the ICW(Intersection Collision Warning) application to alert the drivers of a potential intersection collision before reaching the intersection. However, although vehicle A_1 might avoid the accident at the intersection through sudden deceleration, its action might result in a rear-end collision with its neighboring vehicles (vehicles A_2 and A_3 in Fig. 1). The rear-end collision could be avoided if vehicle A_1 is alerted of the potential intersection collision with sufficient time to avoid a sudden deceleration.

We can further illustrate the major aspect of ITS in terms of autonomous driving such as cooperative platooning [23] which is basically a vehicle platoons (usually trucks) where the first/leading vehicle alone has a human driver and other vehicles are electronically controlled to follow the leading vehicle closely but safely enough. This advanced system makes the transportation system more efficient and more reliable through in-vehicle information exchange. This ITS application deals with controlling the exact position, speed and acceleration of the vehicles in a platoon and benefits to traffic utilization and pollution reduction. For example, we can illustrate Volvo's cooperative platoon and the self-driving car in [24]. Various service-oriented ITS applications using vehicular communications have been outlined in [25].

Regarding hardware, there are already some products available in the market, for example, forward collision warning in Nissan, lane-passing alarm in Mercedes Benz, blind-spot detection in BMW (see Table 1).

It is worth mentioning that in this paper, we are moving from a very broad topic to a specific type of solution. The remainder of the paper is as follows. In Section 2, we discuss the major components of ITS to highlight the various technologies involved in ITS. A review on recent work on data/information fusion in ITS is presented in Section 3. The current state-of-the art approaches for context-awareness issues related to ITS are described in Section 4. Some concluding remarks are drawn in Section 5.

2 Major Components of ITS

As illustrated in Fig. 2, ITS can be categorized into two major areas: ITS Technologies and ITS Applications. ITS Technologies can be primarily grouped into: Sensing Technology, Communication Technology, Computational Technology, Actor-Network Technology. In contrary, ITS applications can be grouped into five primary categories: Traveler Information Systems (TIS), Transportation Management Systems (TMS), Transportation Pricing Systems, Public Transportation Systems (PTS), and V2V/V2I-based ITS System [4].

2.1 ITS Technologies

2.1.1 Sensing Technologies

The sensors which are used here to detect the surrounding traffic environment of the vehicle can be grouped into two types - *active* sensors and *passive* sensors [26]. Active sensors such as radar, laser, and infrared sensors, detect an object based on the reflection of emitted electromagnetic energy. Passive sensors, such as camera/optical sensors detect the naturally reflected/radiated energy to capture the information in a non-intrusive way. The main benefit for using active sensors is that they are able to acquire data in any time or any weather conditions as well as directly measure the parameters like distance, velocity. However, the scanning speed and spatial resolution of active sensors are low, while their size and cost are high. In contrast, by means of this optical sensor, the moving vehicles can be efficiently tracked and the visual information captured can be useful for vehicle recognition/identification [27]. However, passive sensors are sensitive to complex environments and illumination variations. The general requirement about sensor can be found in [28, 29].

1. `Video Image Processor (VIP)` – VIP typically consists of one or more cameras/optical sensors, a digitizing and image processing module together with image interpreting and converting the image into traffic flow data software [30]. A VIP has lower maintenance

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[1] Intersections are the most complex driving environments and often cause injury/fatal traffic accidents.

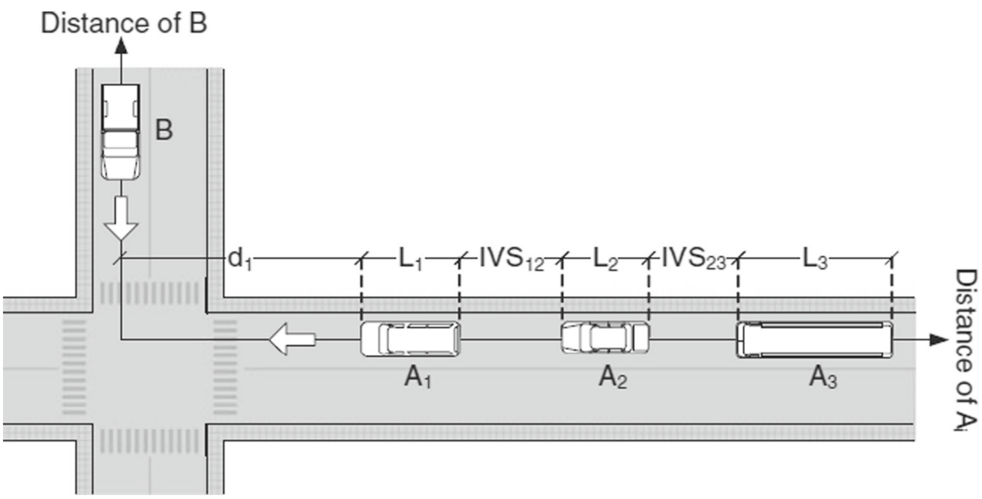

Fig. 1 Intersection scenario [82]

costs and is widely used to detect vehicles across several lanes, estimate the traffic flow rate, location, and speed of the vehicles, classify vehicles. For example, roadside camera recognition systems are used for collecting tolls on specific roads and use roadside cameras at the entrance and exit of the congestion zones [31]. Similarly traffic sign recognition using visual sensors and real-time image processing is reported in [32]. The collision detection problem in city intersections is addressed in [33, 34]. Multiple cameras are employed to identify 3D ground plane locations of vehicles by calibrating as in [35] with road primitives followed by projecting the foreground masks to the road plane. 85 % of 273 vehicles is correctly detected based on the data used. The graph correspondence is used in [36] for vehicle tracking and classification. In [37] the problem of vehicle and pedestrian tracking is addressed using the CLEAR data set [38] and applying the greedy graph correspondence tracking introduced in [39]. A Bayesian approach for vehicle detection is introduced in [40] using MCMC (Markov Chain Monte Carlo) sampling. First, a foreground map is calculated using background subtraction followed by computing a proposal map from foreground map, indicating possible vehicles centroids. The distance of the centroids from the foreground map boundary represents the likelihood in the proposed map. Then using a proposed Bayesian framework for the vehicle positions, the overlapping vehicles in 3D plane are eliminated. A MCMC algorithm is used to generate new states with respect to the changes in number of vehicles, the positions, and the orientations. Viterbi algorithm [41] is applied here for tracking between frames, in order to find an optimal path for each frame. Probabilistic frameworks are also used in other works [42, 43] for vehicle detection and tracking. The video technology is also used for drowsy driver warning system by tracking the eye movements and detecting when there is any sign of fatigue from a driver [44].

Table 1 Driver assistance systems available in the market [21, 22]

System	Maker
Forward collision warning	Nissan
Adaptive Cruise Control (ACC)	Mitsubishi
Lane-keeping support	Nissan
Collision mitigation brakes	Honda
Low-speed ACC	Nissan
Night visions	Honda
Lane-passing alarm	Mercedes Benz
Tire sensors	Fiat
Brake Assist with Navigation Link	Toyota
Blind-spot detection	BMW

2. `Inductive Loop Detector (ILD)`–ILD sensor is often used in transportation management. It detects the conductive metal object by the inductive currents passing through it. A wire loop is excited by passing through electrical current having frequencies between 10kHz to 50kHz and above to generate a magnetic field. It induces current in the metallic object as it passes over the loop. The induced current decreases the loop inductance, which is sensed by the attached electronics unit as a vehicle detection. The information of the vehicle presence, count and occupancy can be retrieved from conventional ILD. Although conventional loop cannot directly measure the speed, a two-loop speed trap could provide such information.
3. `Magnetic Sensor` – Magnetic sensor is a passive type of sensor which works by detecting the generated

perturbation by the metal object in Earth's magnetic field to sense the presence of the vehicle for traffic flow measurement. Among two types of magnetic sensors, the two- and three-axis fluxgate magnetometers detect the variations of the vertical and horizontal components of the Earth's magnetic field generated by ferrous metal of the vehicle and able to identify any vehicles. The other search coil magnetometer sensor usually detects the vehicles moving more than nearly 50km/hour by measuring the changes of magnetic flux lines produced by the ferrous metal.

4. `Piezoelectric Sensor` – It utilizes the piezoelectric material that generates a voltage due to any mechanical impact or vibration. A voltage which is proportional to the force/weight of the vehicle, is measured and then used to determine the vehicle's speed and weight (using multiple sensors).
5. `Pneumatic Road Tube Sensor` – This sensor works by sending an air burst through a rubber tube when a vehicle's tires are passed over the tube, which is set as perpendicular to traffic flow direction. As the pressure pulses close the electrical switch, it is sensed by a counter. This type of sensor is used for short-term vehicle counting, vehicle classification by axel count and spacing. The gathered information is further used to measure various parameters, such as spacing between the vehicles, delays due to intersection and stop sign, saturation flow rate, instant speed in terms of vehicle type.
6. `Microwave Radar Sensor` – Microwave radar sensor uses radio waves within the microwave frequency band (1 GHz to 30 GHz) to detect vehicle and measure distance and speed. This sensor sends radio waves from an overhead antenna toward an area around the roadway. Emitted energy is partly reflected back to the antenna when a vehicle is passing through the antenna beam. The receiver of the detection scheme then calculates the information of the vehicle, e.g. volume, speed, occupancy, length. There are two types of microwave radar sensors based on their use in traffic management: 1) CW(continuous wave) Doppler radar, 2) FMCW(frequency modulated continuous wave) radar. The CW Doppler radar detects the moving vehicles and measures their speed, while FMCW radar is able to detect stationary vehicles. One of the important features with radar sensors is its use in adaptive cruise control (ACC) by measuring the distance and speed of the vehicle ahead. If the leading vehicle reduces the speed, the sensor transmits a signal to the speed control to reduce the speed of the following vehicles. However, ACC retains to its original speed when the road is clear [45]. In [46], radar sensors are used together with the cameras for blind spot monitoring providing collision avoidance warning.
7. `Passive Acoustic Array Sensor` – Passive acoustic array sensor detects vehicles from the vehicular traffic using 2D microphone array by receiving the acoustic energy generated from different parts of the vehicles and interaction of the vehicles tires to the road. When vehicles pass through the detection zone, signal processing algorithm detects the presence of the vehicles based on the increment of their sound energy. Both the presence of the vehicles and their speed can be measured by this type of sensor.
8. `Ultrasonic Sensor` – This type of sensor transmits ultrasound energy with frequencies between 25 kHz and 50 kHz. These sensors work by measuring the distance between the road surface and vehicles using pulse waves by estimating the time of arrival for the reflected waves received by the sensor from an area within transmitter's beam width. The information of vehicle count and vehicle presence can be obtained using this sensor. Moreover, using two sensors placed by a known distance, it can also be possible to measure the vehicle speed.
9. `Infrared Sensor` – Infrared (IR) sensors of both active and passive types are used in traffic monitoring. Active IR sensors illuminate the detection zones by sending low infrared energy beam from the laser diodes operating near infrared spectrum at 0.85 μm. The reflected energy beam from passing vehicles is generated by an optical system of an IR-sensitive receiver unit and the laser radars detect the vehicle entering the detection zone by using two or more beams. Information such as the presence of the vehicle at the traffic light, vehicle speed, volume and length of traffic queue are provided by active IR sensors. On the other hand, passive infrared sensors work based on emitted energy detection from vehicles, road surfaces, etc without sending any signal/energy. This type of passive sensor is used in vehicle counting, lane position estimation, and queue detection.

2.1.2 Communication Technologies

Some of the key communication technologies used in ITS are as follows:

1. `Dedicated-Short Range Communications (DSRC)` – DSRC is a short-range to medium-range wireless communication channel, operating in the 5.8 or 5.9 GHz spectrum, specially designed for automotive uses and is suitable for safety applications (such as post-crash notification) due to its low latency [47].

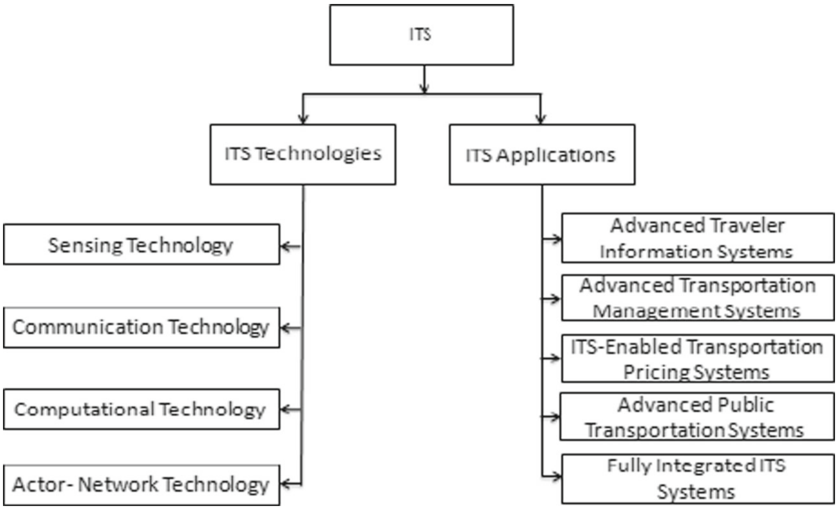

Fig. 2 Major components of ITS

2. `Wireless Sensor Networks` – Wireless sensor networks, such as WiMAX [48], is a communication technology commonly used for wireless Internet access and allows rapid vehicular communications.
3. `Mobile Telephony` – Although mobile telephony [49] is popular specially for urban areas and major roads, it may not be suitable for some safety-critical ITS applications, since it could be too slow.
4. `Radio Wave` – Radio wave or infrared beacons are used as in Japan to transfer real-time traffic information arterial roadways, a moderate capacity roadways just below highways in level of service.
5. `Probe-Vehicle` – In some countries, taxis/government owned vehicles equipped with DSRC or other wireless technology are often used as probe-vehicles to send the probe data such as their locations and speed, to a centrally operated traffic management center (TMC). The TMC then aggregates the received data to get an impression about the traffic flow and congested locations of an area.

2.1.3 Computational Technologies

In this section, we focus on floating car data (FCD). This so-called "Floating car" or "probe" data collection is a set of comparatively low-cost method to measure the travel time and speed for the vehicles traveling along the roads, highways, freeways, and other transportation routes. The benefits of this technology to measure traffic data are that it is less expensive and provides more coverage including nearly all locations and roadways, requires less maintenance, and is workable in all weather conditions. The three methods which have been used to collect the probe data are as follows [50].

1. `Triangulation Method` – In the mid 2000s, in-vehicle mobile phones have tried to use as anonymous traffic probes to receive instant traffic data as the vehicle moves. The traffic data can be transformed into traffic flow measurement by measuring and analyzing traffic data using triangulation and pattern matching or cell-sector statistics. The more congestion the more probes due to more cars and more phones. Ideally the method should work better in case the distance between the antennas is shorter, such as in urban areas. The advantage of this method is that it does not require the road-side units other than using only the mobile phones. However since early 2010s, the usage of the triangulation method has been decreasing.
2. `Vehicle Re-identification` – This method requires a number of detectors placed along the road. In this approach, a unique serial number of a device (e.g., MAC (Machine Access Control) addresses from Bluetooth devices, or RFID (Radio-frequency identification) serial numbers/tags from Electronic Toll Collection (ETC) transponders) in the vehicle is detected once in one location followed by detected again (re-identified) in another location of the road. Travel time and speed can be thereby estimated by measuring the time at which the specific device is detected by a pair of sensors.
3. `GPS Based Method` – Global Positioning System (GPS) is an increasingly popular method. Vehicles as equipped with in-vehicle GPS (satellite navigation) system having 2-way communication link to the traffic data provider. Here position data of the vehicles are obtained which are used to compute their speeds.

2.1.4 Actor-Network Technology

It is evident that recently the interest of actors in ITS has paid a large attention. It is found that the actor-network technology can play an important role in ITS to improve the vehicle safety. An insecure, distributed, wireless vehicular safety system could be easily accessible resulting in poorer vehicular safety. Therefore, VANET safety messages need to be secured to mitigate falsified reports received from malicious vehicles and to detect erroneous information generated by untrusted vehicles. Precisely, safety messages should be authenticated to a vehicle, and revoke the credentials (i.e., the certificate(s)) of a malicious/untrusted vehicle (i.e., one that generates the falsified or erroneous messages). Three types of actors are considered for safety applications providing security and privacy in VANETs as described below.

1. Vehicles or On-Board Units (OBUs) - Vehicles can be treated as intelligent actors. In safety applications, each vehicle can be assumed to be equipped with a temper-proof security device responsible for ensuring privacy of the sensitive and personal information of the ego vehicle, such as private key, and to execute all the cryptographic operations that the vehicles needs to operate, in order to participate to the secure vehicular network.
2. Certification Authorities (CAs) - These entities represent the trust establishments. They are responsible for providing for each vehicle and RSU's personal certificate allowing it to prove its identity when communicating with other participants. A CA is also in charge of revoking certificates of untrusted and malicious nodes. It is responsible for establishing the security requirements within its region. Moreover, CAs cooperate to ensure in- ter-regions security (when vehicles move between regions managed by different CAs).
3. Road-Side Units (RSUs) - The RSU entities participate to the security architecture of the VANET; they are delegated by the corresponding CA to carry out some security functionalities, such as generation of pseudo-certificates based on pseudonym pair of keys (i.e., public and private keys).

2.2 ITS Applications

2.2.1 Traveler Information Systems

Traveler Information Systems (TIS) are used to guide the driver by sending various real-time information related to travel and traffic, such as bus/train routes and their time schedules as well as information regarding any delays caused by traffic jam/accidents/bad weather/road construction. This category also includes in-car navigation systems and telematics-based services, which offer a range of safety, route navigation, accidents notification, and concierge services, e.g. services regarding location, mobile calling, or in-vehicle entertainment with various options including access of Internet, downloads of music or movie, etc.

2.2.2 Transportation Management Systems

Transportation Management Systems (TMS) mainly provide ITS applications that concerns with traffic control devices for traffic signals, ramp metering, and dynamic message signs on highways for the purpose of real-time messaging about traffic or the status of the highway. It depends on centralized traffic management centers, called as Traffic Operations Centers (TOCs) run by cities and countries worldwide, to connect sensors and roadside equipments, probe vehicles, message signs, and other devices together to get an integrated overview of traffic flow and to detect vehicle crashes or any unexpected events occurred due to bad weather, or hazards on the road.

2.2.3 Transportation Pricing Systems

Transportation pricing systems play a major role in developing countries' ITS system. They have been commonly used in electronic toll collection (ETC), where the drivers could pay tolls automatically through DSRC (Dedicated-Short Range Communications)-enabled on-board device or ID placed on the windshield. Also, such systems can be used in High-Occupancy Toll (HOT) lanes reserved for buses and other high occupancy vehicles where they only allow single occupant vehicles upon tool payment in case of traffic jam. In these reserved lanes, the transportation pricing systems could help to control the traffic flow (i.e. the number of vehicles) by deploying variable pricing (through electronic toll collection) to maintain a smooth traffic flow, even during rush hours.

2.2.4 Public Transportation Systems

Public Transportation Systems (PTS) provide the automatic vehicle location (AVL) application for transit vehicles, i.e. bus or rail, to provide information about their current locations which make it possible for the traffic operations managers to get a real-time impression about the status of transit vehicles. PTS further make transit system more attractive by displaying the arrival and departure times of buses and trains providing particularly useful 'next bus' or 'next train' information to the passengers. PTS is also concerned with the electronic fare payment for public transport.

2.2.5 V2V/V2I-Based Integrated ITS Systems

V2V/V2I-based ITS systems combine both V2V (Vehicle-to-Vehicle) and V2I (Vehicle-to-Infrastructure) integration into a consolidated platform, would enable a number of driving assistance safety and non-safety ITS applications, including dynamic lane departure warnings, curve speed warnings, re-routing of traffic through variable message signs, or notify weather-related conditions, such as icing.

3 Recent Advances on Data/Sensor Fusion in ITS

Data/Information fusion adaptively gathers and fuses data to process meaningful information for a particular task [51]. Data/Information fusion is integration of technologies where information from multiple sources/sensors are combined for better inference and becomes a compulsory tool in ITS. A thorough review on its applications in ITS can be found in [52, 53]. Our aim here is to provide a review of the recent progress on data/information fusion in the areas of ITS.

3.1 Data/Sensor Fusion Based on Fuzzy Technique

In Bauzav et al. [54], a fuzzy-based cooperative technique (CoTEC) has been proposed to efficiently detect the road traffic congestion (RTC), such as traffic intensity and length, using V2V communications for real-time traffic monitoring. In CoTEC, fuzzy logic has been used to accurately detect the road traffic congestion by sharing the individual estimations made at different vehicles within a zone. CoTEC thus introduces a fuzzy based traffic congestion quantification system considering traffic density and vehicle speed as inputs and measures the level of traffic congestion as output. The continuous value of the output within [0, 1] interval shows the intensity of traffic jam, where ′0′ and ′1′ indicate free flow and severe traffic congestion, respectively.

In Chiang et al. [55], a multisensor driver-assistance system is developed using V2V communications for safe driving maneuvers including lane positioning/changing, vehicle overtaking. The system consists of a fuzzy controller to perform steering and speed automation during driving. There are two types of fuzzy controllers used here that consist of four main modules: a rule base, a decision-making logic, fuzzification/defuzzification interfaces. IF-THEN rules are used to quantify the drivers knowledge in the rule base. The output of the rule base module is used as input for the successive decision-making logic to make current decisions on traffic situations. The fuzzification interface converts the crisp (non-fuzzy) inputs into fuzzy values for the input of the following decision-making logic. Note that membership function is used to incorporate fuzzy property or fuzzy operation to induce fuzziness for a certain fuzzy set. Finally, defuzzification interface converts the decisions from decision-making logic into non-fuzzy control actions.

This is a low-cost scheme embedded in real-time and implemented on a testbed vehicle. Although it provides promising results in line keeping, line change, double overtaking in 3-car scenario, the presented method has some limitations, such as restricted image resolution beyond 10m distance, reaction delay of the system, which makes the preferable speed limit of the vehicle not more than 80km/h.

The paper in [56] describes a driving assistance system based on fuzzy logic and V2I communications. The fuzzy based control algorithm developed here is maintained a safe distance and adjust the speed of the vehicle for collision avoidance and smooth traffic flow. A good performance is demonstrated based on computer simulations scenarios similar to those used in real vehicles.

3.2 Data/Sensor Fusion Based on Ranging Technique

In Yao et al. [57], a cooperative positioning (CP) method is proposed that fuses kinematics information as obtained from GPS or other kinematic sensors, with distance measurements calculated based on radio-ranging techniques such as Time Of Arrival (TOA) and Time Difference Of Arrival (TDOA). Moreover, the accuracy of vehicles positions is improved within each vehicle cluster[2] by employing a routing algorithm presented in [58]. Also, the effect of exchanging large amount of information between vehicles on positioning accuracy is studied. The accuracy bounds of cooperative positioning (ABCP) in VANET[3]. are proposed as the inverse of the Fisher Information Matrix (FIM):

$$F = -E\left[\frac{\partial^2 \ln(f(Z|W))}{\partial W^2}\right] \tag{1}$$

where $E(\cdot)$ is the expectation operator and $f(Z|W)$ is the conditional joint probability density function (pdf) of the measurement vector Z with size N_Z, $W = \{x_1, y_1, \cdots, x_n, y_n\}$ as the vector of true 2-D positions of vehicles and

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[2] Vehicle cluster consists of vehicles where all pairwise distance measurements between the vehicle are known.

[3] VANET is a special type of Ad-hoc network, which is structure-free as well as it has fixed and mobile nodes. VANET can be viewed as an intelligent component of ITS as the vehicles communicate with each other as well as with the roadside base stations/roadside units (RSU) located at critical points of the road, such as intersections or construction sites. A comprehensive well-organized VANET is responsible for extracting, managing and interpreting the information to achieve knowledge, and making it available for travelers. VANET differs notably from other types of ad-hoc networks, such as wireless sensor networks (WSN) or mobile ad-hoc networks (MANET) [59] in terms of node dynamics and heterogeneity. The detailed description of the properties, features and applications of VANET can be found in [60, 67]

$Z = \{\hat{x}_1, \hat{y}_1, \ldots, \hat{x}_n, \hat{y}_n, \hat{D}_{1,1}, \cdots, \hat{D}_{1,n}, \cdots, \hat{D}_{n,n}\}$ as the vector consisting of measured GPS positions and range information. The CTLB (Cramer-Rao Lower Bound) C_r is inverse of the FIM, i.e. $C_r = F^{-1}$, since the localization error variances of CP, σ_P, of each vehicle within the cluster lies along the diagonal of C_r. Then positioning accuracy gain (PAG)(%), a performance metric, is introduced to evaluate efficiency of the proposed CP scheme over the unassisted GPS positioning.

$$PAG = \left(\frac{\sigma_P - E_P}{\sigma_P}\right) \times 100 \qquad (2)$$

where the positioning error E_P of the entire cluster is given by

$$E_P = \sqrt{1/(2n) \times trace(C_r)} \qquad (3)$$

By receiving range vectors (RVs) from neighboring vehicles, a range matrix is constructed by each vehicle to operate the CP algorithm. Since a vehicle may simultaneously belong to multiple clusters, therefore in this approach, a vehicle first needs to identify the cluster to which it belongs. It can be done by using a simple algorithm/pseudocode provided in [57]. It is based on by comparing the positioning performances of all the identified candidate clusters as the positioning accuracies vary with the number of vehicles and their relative positions within the cluster. Finally, a cluster with maximum positioning accuracy is selected.

By sharing the ranging data among the vehicles within a cluster, the positioning accuracy can be increased over 40 %, even at low traffic density, while accuracy gain PAG becomes more than 70 % in the heavy traffic density. However, the performance significantly deteriorates due to packet collisions in real-world communication condition. Note that in [57], it is assumed σ_P to be constant in the CP CRLB model in order to see the effect of DSRC channels on CP performance without considering vulnerabilities by the GPS receiver in urban condition. As a future work, the current CRLB model could be extended by proposing more realistic GPS error model suitable for urban situation.

Ou [68] presents a localization method for vehicular network by using a pair of Road-Side Units (RSUs) placed at both sides of the road and communicating with the passing vehicles continuously. The vehicles are assumed to move along 2-way straight road separated into two carriageways, i.e., one for each direction where length and width of the road are Ln and Wd, respectively. Two RSUs, R_l and R_r, are mounted on either side of the road having position coordinates of (x_l, y_l) and (x_r, y_r) in terms of their middle position. The radio range of the RSU is supposed to entire road, i.e. $Range >> \sqrt{(Ln/2)^2 + Wd^2}$, and the direction and the position of the vehicle can be found by a pair of RSUs. Although in reality, this presumption cannot be always satisfied to estimate both the positions and travel directions for all vehicles. So, two or more pairs of RSUs might be required to have more robust RSU deployment scheme to cover a vehicle and determine its position information.

Further studies on the effect of RSU deployment, beacon collision and failure is discussed, and enhancements are done to handle such issues. For example, the beacon collision risks can be reduced by jittered scheduling and the number of beacon messages received by the vehicle from different RSUs are thereby maximized. The corresponding jittered beacon interval is defined as

$$\begin{aligned}\text{JitteredBeaconInterval} = {} & \text{BeaconInterval} + \\ & \text{JitterofBeaconInterval}\end{aligned} \qquad (4)$$

However, the proposed beacon scheduling scheme may introduce some errors during the localization process. In another way, the two beacons from the RSU pairs might not be received by a vehicle at the same time.

The solution to this temporary RSU outage problem is further suggested in [68], since once one of the RSUs fails/becomes faulty for a short interval due to its fault occurred, the localization process would be temporarily disrupted. The corresponding performance evaluation is presented in terms of Root Mean Squared Error (RMSE) of the localization results and found to be robust against the traffic density (varying from 1 to 5 vehicles/km/lane) and the vehicle speed (increased from 70 to 110 km/h) in both faulty and fault-free RSU conditions. Also, the proposed RSU-based localization method outperforms the common V2V-based localization methods [69–71] in fault-free case.

In Ahammed et al. [72], the idea of using distance measurements to improve the location estimation accuracy by GPS is introduced. In this proposed framework (VLOCI), the authors assume that all vehicles are equipped with GPS, and therefore have an estimation of their current location. Further the vehicles are assumed to be traveled in one lane and in the same direction, and do not communicate with the vehicles of other lanes. Continuously, and after measuring the distance to their neighbors, each vehicle collects estimated location of its neighbors (found by GPS) and estimates its own location in their coordinate frames, using the measured distance. Lastly, the improved estimated location is obtained by calculating a weighted sum over the obtained estimated locations, where weights are proportional to the distance to the neighbors. Two techniques are used in [72] to measure the distance based on time-of-arrival (TOA) and intensity of the received signal. The accuracy of these techniques can be modeled in a way as distance increases, the accuracy of the measurements taken also decreases. Thus measuring the distance to vehicles within a close range becomes more accurate than measuring the distance to those further away. To tackle the variance in erroneous distance measurements, multiple measurements can be taken for which the average can be used as final distance measurement. If vehicles n_i and n_j are neighbors, then n_i can obtain n_j's estimated position $\hat{p_j}$ and the measured distance $\hat{d}_{i,j}$. Using these information, vehicle n_i calculates its position assuming that n_j's estimated position is correct, i.e.

$$\hat{p_i}^j = \left(\hat{x_i}^j, \hat{y_i}^j\right) = \left(\hat{x_j} \pm \hat{d}_{i,j}, \hat{y}_j\right) \tag{5}$$

Given a set of neighbors of n_i, $nbrs(n_i)$, vehicle n_i can construct the set $\left\{\hat{p}_i^j | n_j \in \{n_i\} \cup nbrs(n_i)\right\}$. With this set of co-ordinates, an average can be taken to calculate a new estimate for $\hat{p}_i$. A weighted average function w is used here to estimate $\hat{x_i}'$ as follows:

$$\hat{x_i}' = \frac{\sum_{\{n_i\} \cup nbrs(n_i)} w(n_j).\hat{x_i}^j}{\sum_{\{n_i\} \cup nbrs(n_i)} w(n_j)} \tag{6}$$

This value becomes the new estimated x co-ordinate for vehicle n_i. This weighted average position becomes the new estimated position for vehicle n_i, and this new coordinate is transmitted to its neighbors in the next iteration. The weight function of $w(x) = Ae^{-x^2/B}$ with $x = \hat{d}_{i,j}$, A=100, B=550 is used as it is inversely proportional to the measured distance $\hat{d}_{i,j}$.

The effect of skewness is further studied here to estimate the initial positions based on the following concept: A vehicle n_i is said to be skewed to the left, if $\hat{x_i} < x_i$ and skewed to the right when $\hat{x_i} > x_i$. Based on this, if the number of vehicles initially skewed to the left is γ (e.g. γ=0,1,2,3,4,5), then the remaining $N-\gamma$ vehicles are positioned skewed to the right. The metric used for measuring the performance of VLOCI is the location error, which is the average distance between a vehicle's computed position and its actual position at the current point in time. The vehicles have been simulated to receive GPS measurements only once at the beginning. Afterwards, only VLOCI is used to further improve the position estimates. In fact, the location error varies depends on how the vehicles are skewed over time. The best performance can be achieved when approximately half of the vehicles are skewed to one side and the other half skewed to the other side. The future works include a generic definition and description of a geometrical Dilution Precision (DOP) metric [73] for this proposed scheme by considering the vehicles constellations and topology parameters.

In Golestan et al. [74], a statistical cooperative method is proposed to solve the localization problem in VANET using V2V communication. It provides improved localization information of the individual vehicles by using motion model along with the sensory information (e.g. obtained from gas and brake pedal sensors, and GPS). In Golestan et al. [74], individual vehicles use data fusion techniques to combine the data gathered from different sensors installed on the vehicle to estimate its current location. Furthermore, the vehicle communicates with its neighboring vehicles to enhance the estimation by calculating a weighted sum over their estimations about its current location. Radio-ranging techniques of Time-Of-Arrival (TOA) and Angle-Of-Arrival (AOA) are used here for measuring the location of neighbors in polar coordinate. The weights used here are proportional to the belief of each vehicle regarding its current position.

The results in [74] for the simulated environments show significant achievement in terms of localization information improvement. Specifically, in the absence of GPS sensor of a vehicle for a period of time, there has been only negligible declination in the performance which makes this method robust to failures or blockages under urban scenarios. Comparing to another cooperative localization method in [72] based on distance measurements, the method in [74] removes the restriction of all vehicles having GPS, and deploying the data fusion technique such as using EKF or PF to estimate the vehicles locations by predicting the location using predefined dynamic motion model followed by refining using sensor model and the information received from other vehicles. The basic idea of this dynamic fusion model using V2V communications can be further found in [75].

3.3 Data/Sensor Fusion Based on Integrated Technique

Cooperative vehicle localization using V2V communication is addressed in [76, 77] which are involved with an European project called CoVeL. Here, the authors propose a comprehensive framework that incorporates a variety of localization methods of different types, as discussed in [78], in order to extract different types of available information. In this framework, the lane position is estimated by combining the outputs of Absolute Positioning, Relative Positioning, and Group Map Matching using various data obtained from a data access system called EDAS, odometry, GNSS(Global Navigation Satellite System), V2V communication, and a digital map.

For relative positioning, each vehicle determines the relative vector to other vehicles, using location information provided by absolute positioning. This data is then used for group map matching (GMM) using a digital map to refine the location estimation. Unlike conventional map matching, this new cooperative GMM matching considers the local and remote vehicles positions at once. A scheme to transmit EDAS data from RSU to the vehicles is further studied under CoVeL.

It is found that in urban situation under safety application, CoVel decreases the position error by 74 % by reducing the rough GPS outliers. It is further observed that the performance of the method strongly varies with vehicle constellation as well as road topology networks.

Therefore, the position error can be further lowered by 85 % compared to standard GPS measure for a good vehicle constellation. Time synchronization is another important factor since it directly relates to the error due to relative positioning.

3.4 Data/Sensor Fusion Based on Clustering Technique

In Ding and Zeng [79], a clustering-based multi-channel scheme is proposed to provide vehicle accident avoidance mechanism (VAAM) to enhance traffic safety. The multichannel used for the vehicular ad-hoc network, consists of five control channels and a single data channel. A self-cluster-organizing algorithm is proposed to coordinate the cluster head (CH) and cluster configuration. In this scheme, every vehicle belongs to either of three possible status, namely Cluster Head (CH), Cluster Member (CM) or Free Node (FN). Initially, vehicles broadcast various information consisting of their current locations, speeds and IDs via control channels. Then CH is selected based on the highest probability value, which sends its moving status, member's IDs via control channels to the CMs and coordinate joining of new CMs. After cluster formation, all the communications between CMs and CH within a cluster are established using the data channel. The proposed scheme improves the transportation safety by providing low access delay and high throughput. Here, throughput refers to the percentage of total time spend to successfully transmit the packets compared to simulation time. While the access delay consists of the time required for generating the packets plus their propagation delay.

When a driver intends to do lane change or increases the speed, VAAM sends warning message if there is any possible danger during the lane change due to trace of any vehicle in the blind spot or any violation to speed limit. Similarly, in any emergency situations, such as due to vehicle crash, traffic congestion, or bad roadways, VAAM works as follows: First, the CH nearest to the affected area sends emergency message to its neighboring CHs through the control channels. Each CH then broadcasts it to all CMs through data channels. In this way, all vehicles coming towards the emergency area are pre-informed about the emergency situation so that the drivers could take necessary actions such as slow down the vehicle, lane change or even detouring.

In this scheme, IEEE 802.11CSMA/CA protocol is used for control channel and TDMA/CDMA technique is adopted for the data channel. It is observed that the more the traffic density, the larger the cluster size. The proposed scheme is found to be effective at high traffic density or traffic load due to its low access delay and high throughput.

An overview of the recent progress on data/sensor fusion in ITS is presented in Table 2.

Table 2 Overview of the recent progress on Data/Information Fusion in ITS

Techniques used	Ref	Application
Fuzzy technique	[54]	Road traffic congestion
	[55]	Road traffic safety and comfort
	[56]	Road traffic congestion and comfort
Ranging technique	[57]	Road traffic positioning
	[68, 72, 74]	Vehicle localization
Integrated technique	[76, 77]	Road traffic positioning
Clustering technique	[79]	Road traffic safety

4 Recent Advances on Context-Awareness in ITS

In the following, we give an overview on the recent advances of context-awareness in ITS. Context-awareness is a main component for enhancing vehicular network in ITS [80, 81]. Contexts/contextual information could be physical/logical, system/user specific, explicit/implicit, with object entities embedded in a communication and computation domain [83]. The main issues on context-awareness include context modeling as well as its representation, acquisition, interpretation, together with managing context-aware applications in ITS. The information flow between the highly dynamic nodes (i.e. vehicles) can be optimized using context-aware processing in a large scale network like VANET (Vehicular Adhoc Network) [84, 85]. The middleware[4] part of the context-aware system plays the most important role [86]. As it gathers context information, processes it and derives appropriate actions from it by reasoning about it using different rules and then adapt themselves to the changing contexts [87–89].

4.1 Context-Awareness Based on Ontology Modeling

In Santa et al., Santa and Gomez-Skarmeta [90, 91], a context-aware system is proposed adapting ontology modeling to generate contextual information in a dynamic vehicular environment. The work presented here exploits a contextual model based on ontologies, using OWL (Ontology Web Language), to represent interesting information regarding zone services and user's (driver's) profile. For instance, different user's preferences (e.g., price and quality rates) about restaurants, hotels, museums, etc are contained in the profile ontology. A set of context rules model the

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[4] The task of the middleware in VANETs is to collect, aggregate and store the data from different sources (such as sensors (e.g. radar, camera) data inside a car as well as information from other vehicles or RSUs) while working as the main data repository in a vehicle. The fused (aggregated) stored data are then utilized by control algorithms for ITS applications. It has the other important task for cross-layer information exchange to provide access-control (privacy and security).

users' preferences which has been formed by ontological elements [92, 93]. By integrating the profile ontology with specific server ontology of each RSU, the inference process is performed. The rule, for example, infers the restaurants menu price using the highest price and the lowest price as recommended by the user. If this condition is satisfied for any restaurant, it would be included to the user's profile list displaying the matched results. The reason behind the use of context rules is their compatibility to any user's profile or any ontology applied to specific instance of service. An ontology-based reasoning module thus adapts the contextual information by performing reasoning on the stored data about interesting places and user's (driver's) profiles. A discrete relevance is used for matching which is calculated as the ratio between the number of user preferences the service satisfies and the total number of user preferences.

The system works as follows. First a vehicle is detected by the RFID (Radio Frequency IDentification) module at a specific location and sending a *Reader-Notification* message. This message contains the vehicle identifier, so that ES (Environmental Server[5]) searches user's profile using this information based on *User-Profile-Query* message. Then GS (Group Server) looks for the user's profile in its database and, replies with a *User-Profile-Not-Found* if there is no profile in the database; Otherwise, GS sends a *User-Profile-Response* containing user's OWL profile. Finally, ES processes the information of a zone as well as the user's profile, to infer the point-of-interests (POI) and deliver it to the vehicle through a *Specific-Environment-Event* message.

The system in [91] has been tested using a prototype vehicle set up with the necessary on-board hardware and software. The cellular network and P2P protocols provided by JXTA [94] are used here for the sophisticated V2V and V2I communications. For the implementation of ES module, Linux-based PCs using a Java environment and Jena framework have been used. In order to verify the link between an ES and all other RSUs, an RFID reader has been employed to detect the vehicles. The GS and Internet Traffic Operation Server are first implemented in Java, followed by install it over a high-performance server in order to facilitate high rate queries. The drawback of this method is its highly centralized processing since all user profiles are stored at the server side where inferences[6] of relevant services are taking place.

In Yasar et al. [95], a context-based grouping scheme is proposed to optimize information dissemination between vehicles using relevance backpropagation, which is basically a feedback based filtering mechanism to identify useful information for information sharing. Ontology is used here to design the exchanged preference messages among the nodes(i.e. vehicles), although it is not represented in OWL (Web Ontology Language [97]). The user preferences are represented by a basic triple containing user's location, main interest and sub-interest, without providing any detailed user's profile. The criteria used in group formation is: $G_D =< C_D, I_D, SD_D >$, where G_D is the group, C_D is the set of criteria e.g. location for group formation, I_D is the set of desirable contextual information (e.g. traffic/parking information) and SI_D is the set of sub-interests (e.g. traffic congestion/accident). Then a binary decision is made whether the vehicle belongs to the interest group or not (vehicles in the interest group have common interests), so that only relevant information can be disseminated between the vehicles within a group. Note that this vehicle grouping mechanism essentially works as a middleware [98] of the proposed context-aware system.

One of the key features in [95] is the relevance backpropagation algorithm [96]. It depends on the feedback received from the surrounding vehicles to select the peers to which the information only needs to be forwarded. The feedback technique uses contextual information such as position, velocity, direction, point of interest to decide whether the received data are relevant or not, and whether they have been used or not. Therefore, feedback to the delivering node is performed based on the condition whether context information is relevant/irrelevant/unused/duplicate to make the exchange of information between the nodes (vehicles) accordingly. For instance, if a vehicle receives a message from another vehicle within a vehicular network and the content of the message matches with the interests of the vehicle, message will be relevant and forwarded the message. That is why higher relevancy ratio is certainly desired since the vehicles will then receive lesser information by filtering out the information they are not interested in. In this way, this context-aware group based communication mechanism improves the information dissemination by filtering out the irrelevant/redundant information based on a relevancy measure R, given by

$$R = \frac{\sum_{i=0}^{N}(m_{ur}(i) + m_d(i))}{\sum_{i=0}^{n}(m_{ur}(i) + m_d(i) + m_{irr}(i))} \tag{7}$$

with $m_{ur(i)}$ represents the total amount of relevant messages received by the ith node for the first time, $m_d(i)$ is the number of duplicate message (i.e. the messages which are received at least once before) received by the ith node, whereas $m_{irr}(i)$ is for the number of irrelevant message received by the ith node for the first time.

The iConAwa system described in [97] is a context aware multi-agent system where the ontology is used to save user

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[5] It contains the Environment Ontology representing the points of interests (POI) consists of service areas like restaurants/hotels, gas stations, or attractive places for tourists including museums, shopping mall, etc.

[6] Inference is a process when context rules are applied over each of the drivers' profiles to match them with the relevant POIs using the Environmental ontology. of relevant services are taking place. Moreover, the user has to subscribe the provided services.

context and point of interest (POI)/service context. The user is then presented with the attraction points (e.g. museum, movie theater, park) relevant to his/her profile by submitting his/her location. The context agent has the key role of providing the context-aware information by using Jena framework to manipulate ontologies with rule-based reasoning. Most importantly, context agent reduces the network communication overhead by selecting the context information to be sent to the client agent. To realize this, consider a situation when the user has moved and same POI/service should be sent to the client agent. Then the context agent only send the updated distance value to the client agent rather than all of the information about POI. Although the solution has a high level of abstraction since it uses OWL, it is a fully centralized system since all the calculations are performed at the server side. This system has low privacy as the user profiles are kept at the server agent and used by the context agents to provide the context-aware information. Also, the relevance which is calculated as the number of matching keywords between the user preferences and the points of interest, is a discrete value. In addition, the user's preferences are only represented by a limited number of keywords.

4.2 Context-Awareness Based on Hybrid Context Modeling

In this context-aware system different context modeling approaches are combined to a hybrid scheme. The key idea is the combined use of different context models and contextual ontologies in order to take advantages of all the modeling approaches. The general concepts regarding hybrid context modeling approaches can be found in [99–101].

In Nassar et al. [102], an efficient and secure context aware system architecture utilizing information retrieval(IR) techniques and hybrid context models is proposed and tested based on information retrieval and decentralization effectiveness measures. To serve all different models used the context is divided into three types: 1) Basic Context (BC) such as location, time, spatial and temporal range attributes plus a short keywords list, 2) Detailed High Level Context (DHLC), which lists the high level attributes describing the context. For example the service DHLC is described by the attribute set (Name, Highest Price, Lowest Price, Contact, Type, Items, and Description), 3) Detailed Low Level Context (DLLC) for physical context. BC is mainly used for spatial filtering whereas DLLC is used as cues for emergency and convenience service situations. DHLC represent the user profile and detailed service description. For example, the context processing between vehicle and RSU is performing by using IR techniques such as filtering the commercial services at the RSU followed by structured retrieval and adhoc querying inside the vehicle. The services submit their XML file to the RSU. At the RSU end, the ontology is populated with the service BC (Basic context), consistency is checked, deduction of new context facts are achieved and service index is updated. When a leading vehicle submits its BC context, the relevant XML service documents, the subindex and BC relevance are disseminate to the vehicle. The disseminated services are then matched with the user profile and ranked according to their relevance in descending order.

So, the IR-CAS system developed in [102] can be realized as an IR model for context aware processing in VANET. Since no simulation program is readily available to test the effectiveness of the IR models used, an evaluation method needs to be designed and implemented to evaluate the effectiveness of the proposed IR models as well as the performance of the IR-CAS system. A test platform needs to be created for both commercial as well as safety and convenience applications and the results can be evaluated against user's perception for commercial services, real records for safety services and expert opinions for convenience services. The assessment model could also use IR efficiency measures such as average response time and latency in addition to user satisfaction.

4.3 Context-Awareness Based on Beaconing

The purpose of beaconing is continuously update of information among all neighboring nodes or vehicles, for example, to dispatch them with latest status data (beacon messages) such as the position, speed to allow for context awareness of the vehicles. In Sommer et al. [103], an adaptive traffic beacon (ATB) scheme is proposed ensuring good information dissemination using 1-hop local broadcast where the beacon interval is adapted based on the capacity of the channel and the dispatched message relevance/priority. The beacon interval, $\Delta I_b \in [0, 1]$ is obtained as:

$$\Delta I_b = (1 - w_b) \times M^2 + w_b \times C^2 \tag{8}$$

where C is the channel capacity and M refers to message priority with smaller values of C and M representing higher channel quality and higher priority, respectively. The weighting factor w_b, trading off C and M, is chosen here as 0.75. The result shows that ΔI_b becomes 1 only for the lowest message priority and the worst channel quality, whereas it falls below 0.5 for all other cases. The ATB scheme shows an improved performance in terms of number of collision messages for synthetic and realistic urban scenarios in comparison to the static beaconing scheme. Future work includes modification of the beacon interval ΔI_b imposing constraint on the vehicles near to the sender of a beacon by repeating information less often.

In Lasowski et al. [104], a context-aware multichannel beaconing scheme, i.e. beaconing as a service (BaaS) is proposed to transmit/receive beacons between vehicles by adopting a request-response framework requesting beacon transmission by vehicles if context-aware information is needed. Two service-oriented beaconing schemes, named as Beacon Forwarding Service (BFS) and Beacon Rate Control Service (BRCS) have been proposed. BFS is used for the collision detection phase to determine the optimal awareness level where the awareness level of each vehicle relates to the knowledge about the neighboring vehicles within a preset radius of interest (up to 300 m), since it is used to find the vehicles which are being the potential collision partners (CPs). The lost beacons can be further requested on demand and retransmitted by the neighbor vehicles using BFS.

For evaluation, a metric of awareness quality is calculated as in Eq. 9, which basically compares between the number of actual existing vehicles $|\mathcal{V}|$ and the number of effectively known vehicles $|\mathcal{N}|$ for each jth node within corresponding vehicles awareness radius r at time instance t as

$$Awareness_{\beta,r,t}(j) = \begin{cases} 1, & \frac{|\mathcal{N}_j^r(t)|}{|\mathcal{V}_j^r(t)|} > \beta \\ 0, & \text{else} \end{cases} \tag{9}$$

In Eq. 9, the parameter β is used to specify the percentage of surrounding vehicles that the jth vehicle node is needed to be aware with $\alpha = 100\%$ implies that BFS is applied to all vehicle nodes. It is found that the awareness value for the static beaconing scheme varies from $\approx$ 85 % to 30 % for 300 vehicles with the awareness distance r=200 m when the number of vehicles increases from 100 to 300. This would even deteriorate for middle and high vehicle density giving highly unreliable results in safety-critical situations. On the other hand, the proposed method achieves a high awareness value of 95 % for a vehicle density up to 200 and remains even as high as 85 % for vehicle density up to 300. In case of r=300 m, the awareness value is further reduced in static beaconing case at even low traffic density condition. In contrast, the presented method gives up to 60 % improvement, particularly at high vehicle density. Moreover, this approach seems to be very useful in shadowing situations when there would be communication disruption between two vehicles by another vehicle/truck for a short duration which is a common situation in urban environment. Here, a vehicle is asking for BFS from its neighboring vehicles. The BRCS, on the other hand, is used in collision avoidance phase to provide very recent information about CPs within an awareness distance of 100 m. For BRCS evaluation, a safety risk metric SR for the jth vehicle at time t is employed, defined in terms of average life of the beacons from all collision partners $\mathcal{S}$ as:

$$SR_t(j) = \frac{\sum_{s \in \mathcal{S}} BeaconAge_{j,t}(s)}{|\mathcal{S}|} \tag{10}$$

The lower the SR value, the higher the accuracy of the information about CPs.

Bai et al. [105] proposes a context-aware beacon scheduling (CABS) approach for vehicle safety application in order to deliver beacons within a predictable delay and high reliability. In this distributed beacon scheduling approach, a channel access method like TDMA is utilized to dynamically allocate the time slot for sending beacon messages based on the context aware information and communication channel reservation status. Based on local measurements of channel load and knowledge of context information (position,speed,heading, etc.) included in the beacon, each node dynamically schedules the beacon transmission at the assigned time slot in a decentralized way. The key feature of this scheme is formation of virtual time frame (VTF) based on position vectors of those received beacon messages and TI (Topology Information). A VTF table is thereby used to manage the real-time context-aware information of its neighbor nodes by updating it for each receiving beacons. In this VTF table, the identifier of the neighbor nodes, road segment, channel status bit, and flag bit are included; For example, the road segment contains the information of relative location and the distance of two neighbor nodes. When an event is triggered for beacon message transfer, the node checks its VTF table to see if there is any reserved time slot first. If there is a reserved time slot, the node generates a beacon message and sends it to the lower layer. Otherwise, the node reserves one of the available time slots to itself and uses it for its next beacon transfer. If there is no reserved time slot, then the node waits until its VTF table get an available time slot.

A performance comparison of the proposed CABS scheme is performed using a realistic channel model and suitable vehicular scenarios. The results verifies that the presented CABS scheme performs better compared to the periodic beacon scheduling scheme in terms of packet reception ratio and the channel access delay. Future work includes enhancement of the proposed CABS scheme by (1) interworking the MAC layer to support time-slot based transmission; (2) developing a theoretical analysis of beacon scheduling in this TDMA-like approach.

In Knorr et al. [106], a simple context-aware scheme is proposed to reduce congestion and improve traffic flow using beacon messages. The method uses periodic beacon messages and estimates the traffic state using velocity and position parameters as inputs. Thus the proposed method gives simplicity from implementation point of view. In contrast to other methods, this approach seems effective before a traffic jam actually occurs providing recommendations to the driver. For this reason, this approach relies on a traffic state analysis based on vehicle density together with vehicles' position and velocity so that drivers are able to make decision about the time and direction to divert their vehicles. The results are shown in terms of averaged travel time (sec) versus penetration rate (%) of communicating vehicles, e.g. with 40 % penetration rate (i.e. 40 % of the vehicles are involved in messaging) the overall travel time is reduced to become 3.6 % compared to actual travel time.

In Vinel et al. [107], a joint overtaking assistance system is suggested for automotive safety application in rural areas based on real-time video transmission between the vehicles and the following considerations: 1) two platoons are driving in opposite directions in a 2-lane straight rural road where the first vehicle in each platoon is leading vehicle and exchange beacons as well as transmit videos to the other vehicle of the M vehicles in the platoons; 2) Deterministic model and stochastic Nakagami-m model are used for propagation. To evaluate the performance of the method, a theoretical framework is further developed by finding the pdfs of contact and warning events in terms of inter-platoon distance. The probability of the contact events is obtained as $Pr_{contact}(d) = 1 - \prod_{k=0}^{m_b(d)-1}(1 - Pr(l_k))$, where d is the distance and m_b is the number of dispatched beacons by the leading vehicle which is computed as $m_b(d) = [((d_{max} - d)/2v)r_b]$ and $l_k = d_{max} - (k/r_b)2v$, r_b is the frequency of the beacon, v is the velocity of the vehicle. The leading vehicle should know about the approaching of oncoming vehicles through the contact event and then begins to dispatch warning message to all other vehicles in the platoon. Through warning message, information about the approaching traffic is thus sent to the other vehicles. On the other hand, warning events occurs upon the condition that all vehicles in the platoon are aware of the contact event. The probability that a warning event occurs with respect to distance d is derived as $P_{warning}(d) = \sum_{k=0}^{n_b(d)-1} \hat{P}_{contact}(l_k)\hat{P}_{warning}(m_b(d) - k)$ where $\hat{P}_{contact}(l_k) = P(l_k)\prod_{i=0}^{k-1}(1 - P(l_i))$ and $\hat{P}_{warning}(i) = 1 - (1 - P(M\Delta))^i$, Δ is the intervehicle distance, i is the number of times the leading vehicle attempts to transmit the message and l_k is the distance where the contact exactly occurs.

The advantage of the proposed scheme is demonstrated using H.264 advanced video coding and IEEE 802.11p WAVE communication standards. This joint beaconing and real-time video based scheme seems more reliable than the solely beaconing-based scheme, which has limitation to deliver information/warning message about the upcoming traffic to the driver. Also when two platoons of vehicles are approaching each other, this solely beaconing-based scheme is affected by significant degradation of the video quality due to the use of a common multiple-access communication channel. In contrast, this suggested joint scheme gives assurance of low latency and acceptable visual quality (with up to 25 dB PSNR improvement) by exploiting the additional information received by beaconing.

Table 3 Overview of the recent works on context-awareness in ITS

Ref	Main features	Benefits
[90, 91]	Integrates a knowledge management model based on ontologies using OWL and the driver's profile	provides location-based information
[95]	Integrates V2V/V2I communication paradigm to enrich information management system	provides safety, traffic, points of interests (POI) information
[102]	Integrates a highly abstract hybrid context model and IR based processing	provides safety, traffic, and points of interests (POI) information
[103]	Deploys context-aware adaptive beaconing for efficient distribution of contextual information	provides Points of Interest (POI) information
[104]	Introduces multichannel context-aware beaconing as a service (BaaS)	provides beaconing request/response service
[105]	Develops a context aware distributed beaconing	provides vehicle safety application
[106]	Develops an adaptive context-aware traffic warning system based on beacon messaging	provides improved traffic flow information
[107]	Proposes a context aware driving assistance system based on joint beaconing and real-time video transmission	provides advance warning of overtaking traffic

In Table 3, the main features and the benefits of the context-aware infrastructures discussed above are listed.

5 Conclusion & Outlook

Data/Inofrmation fusion techniques fuse the data from multiple sensors providing outputs with improved accuracy and more specific inferences than that could be obtained by using a single sensor. Based on our discussion, the recently developed techniques for data/information fusion in ITS can be categorized into fuzzy, ranging, integrated, and clustering techniques. The fuzzy technique is based on fuzzy theory where each input is fuzzified by a membership function followed by an inference using fuzzy rules. The resulting fuzzy outputs are finally defuzzified by a set of output rules. The ranging technique is based on the estimation of distance between the nodes (i.e. vehicles) by finding TOA and signal strength or AOA where the distances continuously over time. On the other hand, data fusion based on integrated method can be considered as a high-level data fusion where the decisions from different systems are combined to get a new decision. In case of cluster based fusion approach the cluster consists of a central node (vehicle) and the neighboring nodes (vehicles), where the central node sends the required information to the neighboring nodes and assign jobs for each node.

Multisensor data fusion has been found a great deal of attention recently in ITS with growing interests and promising results. It is realized that the current trend in data/information fusion techniques is to improve ITS performance by deploying the potential cooperative systems [108] using V2V/V2I communications. Using V2V/V2I communication, the cooperative systems are able to collect data/information that are difficult or impossible to measure directly using in-vehicle sensors/technologies. Therefore, a great deal of attention has been paid to improve ITS safety and efficiency by exchanging the information between vehicles, or between vehicles and the road-side infrastructure despite some challenges exist with excess time delay and accumulated uncertainty due to the use of large number of heterogenous sensors and communication devices [109, 110]. Another critical issue is that performance of many methods are evaluated in simulated environment. It is vital to do real-world simulation by performing real test run and evaluating the performance under realistic conditions. Real-world scenarios consist of potentially large vehicular network with hundreds of vehicles in large geographical areas need to be simulated to find the true performance, for instance jamming, and/or other type of congestions. Therefore, real-life situations should be integrated in the simulations for truely assess the existing techniques. As in [57], nearly optimal performance is obtained in cooperative positioning under ideal condition. However, one wants to know about the performances in realistic situation, such as under urban scenarios with blockage and multipath fading. Moreover, representation and exploitation of high-level and contextual information in data fusion would be beneficial. For example, the context would be represented as knowledge-bases described in ontologies and would form a powerful tool to gain adaptability and improved performance in the designed fusion systems.

Another critical issue is the necessity to deploy anomaly detection system for the security of current advanced fusion systems. In V2V communication, for instance both the network and client (vehicle) sides could have content integrity verification or anomaly detection modules in order to protect the fusion systems from various attacks including intrusions, spam, and denial-of-service. In V2I communications like V2V communication, vehicles similarly receive large amount of data from the sensor nodes mounted on road-side units [29]. Then, the security against these undesired or malicious input data becomes a challenging task. Note that anomaly detection schemes can analyze data, identify suspicious strings (or even situations), setup an alarm and protect the vehicle network from possible attacks/failures. Also, based on pedestrian-to-vehicle communication, the current fusion scheme might further help to develop safety system for vulnerable road users and elderly people. It is important and necessary due to increasing rate of elderly people. For example, in Japan the current rate is about 23 %, which could be increased to 32 % in 2030, followed by 41 % in 2050 [111].

However, more complex test cases are needed to be considered to evaluate the recently developed fusion methods, for instance the algorithms are required to be performed well in different scenarios, including multi-lane condition, multiple vehicles passing, as well as in the presence of other moving obstacles. Another important issue is on the acquisition and real-time integration of data based on the time period of heterogeneous sensors used. Since one could be always found some positioning error and missing information due to the time synchronization of various sensors.

For context-awareness in ITS, we found that the recent progress have been made in the areas of effective ontology modeling, hybrid context modeling, beacon massaging. Various context models and contextual ontologies have been used in hybrid context modeling to incorporate the benefits of different modeling approaches. Furthermore, effective beaconing techniques have been suggested to improve the context awareness in ITS through smart information dissemination.

In fact, various things could be done for further improving context awareness. For example, we need to pay more attention to safety services particularly to the accuracy of calculated severity as a number of events depend on the accuracy. In this context, more precise reasoning could be considered for safety services, such as using higher level abstraction based on fuzzy logic [112]. The other possibility could be to apply fuzzy logic model to measure the severity of congestion for the applications of RCN (Road Congestion Notification) and AACN (Advanced Automatic Collision/Crash Notification) [113]. In case of commercial services, there are still room for improvement by adding more rules to the ontology and thereby deploying new facts about the provided services. An example of generating new rules might be to infer RSU subgroups of similar services so that if any service of the subgroup is found matched to the context of the vehicle, the other similar services within the group could be dispatched without calculating the relevancy. Generally speaking, compared to mobile environments we observed that the research of accurate generation of the context, smart dissemination of contextual information, and proper use of available context, in vehicular environments are yet at the preliminary stage. Although context awareness is a key component for the implementation of new context-aware applications in ITS.

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