ARTICLE IN PRESS

Information Fusion xxx (2011) xxx–xxx

Contents lists available at ScienceDirect

Information Fusion

journal homepage: www.elsevier.com/locate/inffus

Guest Editorial

Information fusion for cognitive automobiles

During the last decades, the steady increase in road transportation of people and goods has had a significant negative impact on traffic efficiency, safety, and the environment. The problems arising from the growing automobile usage have motivated researchers from all over the world to develop solutions – many of them based on information and communications technology – to reduce traffic congestion, air pollution, and road traffic fatalities.

Consequently, automobiles are increasingly being equipped with a number of different sensors and will likely be capable of automatically communicating and exchanging information with other cars and with a technical environment in the future. Moreover, a high amount of prior knowledge, especially about the road network and the traffic infrastructure, will be carried onboard. Based on more powerful communications protocols and devices, road users will be capable of accessing large pieces of information from different sources, e.g., through the recent IEEE 802.11p standard [1]. However, the question arises, how this multitude of available data, information and knowledge from both onboard and external sources can be fused and utilized to enable cars to develop cognitive capabilities and act intelligently – and thus to make them safer, more efficient, comfortable, and environmentally sound.

'Information Fusion' has already devoted a recent special issue to Intelligent Transportation Systems (ITS), in which a broad overview of both the state-of-the-art of the ITS infrastructure and the upcoming ITS applications was offered [2]. For this reason, fusion technologies explicitly involving infrastructure elements are beyond the scope of this special issue. The focus is rather on onboard fusion technologies enabling cognitive functions, such as assisting the driver or even making him superfluous, as is the case in autonomous cars.

To implement such advanced cognitive functions, perception and understanding of the environment are crucial prerequisites. This encompasses several basic skills. First, the automobile needs to sense its environment in a comprehensive way based on complementary sensors. Then, the acquired sensor data has to be transformed into a symbolic representation, in which the objects in a scene along with their types and relationships are identified. Finally, semantic information has to be extracted, such as the 'meaning' of different object constellations or the intentions of other road users. Due to the criticality of this field of application, all algorithms should operate in real-time and behave robustly in the presence of noise, variable lighting or weather conditions, occlusions, dynamic backgrounds, and other influencing factors.

As a response to the call for papers that announced this special issue, a large number of original technical contributions covering new methods and algorithms were submitted by teams from all over the world. After a careful review process, five of them were selected to assemble this special issue. An additional survey article is included to offer an up-to-date overview of information fusion for automotive applications and highlight the connection between the papers of this special issue [3]. The guest editors believe that the featured articles offer a representative coverage of the methodical and technological advances in the field of cognitive automobiles, and hope that this special issue will serve as a helpful introduction to a rapidly-evolving area.

1. Papers in this special issue

The special issue starts with the survey article by *Stiller* et al., in which the authors introduce along with a short overview about the recent history, the state-of-the-art, and some key information fusion methods required to increasingly equip automobiles with cognitive functions. To this end, basically traffic participants and other relevant objects are to be detected, and their essential state variables are to be dynamically estimated. Unfortunately, this detection-estimation problem is ill-posed, since detections based on measured data are generally error-prone, and similar measurements do not necessarily relate to the same empirical evidence. Traditionally, this so-called association problem between measurements (features or object hypotheses) and actual object or track data has been solved heuristically. Based on probabilistic association techniques and/or finite set statistics, it is possible to consider several association possibilities simultaneously and to output a set of object hypotheses at one time step.

The next series of articles consists of three papers dedicated to object detection and tracking. The paper by *Lundquist* and *Schön* presents a joint estimation of ego-motion and road geometry based on the information from sensors typically available in modern premium automobiles: front radar, front camera, steering wheel angle sensor, wheel speed sensors, and inertial sensors. The data fusion is performed by an extended Kalman filter (EKF), whereas the dynamic motion model of the road represents the core innovation of the contribution.

Although most state estimation methods perform well at or near steady-state conditions, extreme dynamic situations (e.g., strong accelerations, or high speed on bends) may lead to significant errors. The article by *Ndjeng Ndjeng* et al. compares the performance of the well-known Interacting Multiple Model (IMM) and EKF filters when determining the position and dynamics of the ego-vehicle in such extreme situations based on an IMU, an odometer, and a GPS receiver.

Finally, the contribution by *Kirchmaier* et al. describes a novel method to track objects three-dimensionally based on stereo images and stereo audio data. In a first step, both the image and audio data are processed separately to obtain lateral position and directional estimates, respectively. Based on particle swarm

1566-2535/$ - see front matter © 2011 Published by Elsevier B.V.
doi:10.1016/j.inffus.2011.04.001

optimization, the subsequent fusion yields the 3D position and is able to track objects with arbitrary dynamics. The method is not only computationally inexpensive, its application is also not restricted to the automotive domain.

Besides object tracking, in automotive applications it is important to identify the types of objects (e.g., cars, pedestrians, or static obstacles) in a scene to be able to make sensible decisions. The article by *Pérez Grassi* et al. deals with detection of pedestrians based on thermal infrared imagery and lidar data. Whereas the infrared images represent the main source of information, lidar is utilized to normalize the image data, thus enabling a scale-independent analysis. Based on invariant features obtained by integration, information about the pedestrian movement is extracted without using any tracking technique. The feature classification is performed by a support vector machine.

The last paper of the special issue, written by *Sathyanarayana* et al., deals with an important component of future active vehicle safety systems: the detection of driver distraction. To cope with the variability between drivers and maneuvers, a speech-based driver identification and a maneuver recognition system are applied first, thus reducing the complexity of the distraction detection to only intra-driver variability. Just as the subsequent distraction detection module, all subsystems employ a Gaussian Mixture Model/Universal Background Model and a likelihood maximization learning scheme.

2. Further R&D required

There is not much doubt that the topic of this special issue will remain relevant for many years. This becomes particularly evident when considering the current abilities of driverless cars: their accident rates are still several orders of magnitude higher when compared with human-driven cars [3]. To fill the gap between the state-of-the-art and the demands of a sustainable and safe road transportation, further development of several technologies will be of crucial importance:

- As an enabling technology, sensors have contributed to a significant boost in the field of cognitive automobiles. New image, range, and position sensors have had an enormous impact on the quality of the data (sensitivity, accuracy, measurement range, sampling rate, etc.) and the range of applications deployed in this area. It can be expected that the ongoing progress in this field will further constitute an important innovation engine.
- Despite the recent advances in information fusion of dynamic processes, the detection and estimation problems are mostly treated independently one from another. However, this fact is only partly due to the increased computational complexity of modern probabilistic state estimation filters. In the future, more processing power will become available, and more sophisticated algorithms will likely be implemented in automotive applications.
- Furthermore, for a thorough interpretation of traffic scenes, not only a mere description of the relevant objects and tracks is needed, but also detailed representations of their attributes, identities, mutual relationships, and potential maneuvering intentions. There are many ad-hoc approaches to overcome the gap between the signal-level description delivered by sensors and the requested symbolic representation in different application domains. However, general solutions to this tremendously challenging abstraction problem are not to be expected in the next few years.
- Besides perception and environment modeling, information fusion can also be applied to trajectory and mission planning as well as to operation strategy optimization. Although significant activities in this regard are documented in numerous publications, these research fields have been somehow underrepresented so far, but are nevertheless expected to grow in the future.

As stated above, many of these fusion technologies are quickly evolving, and thus their state-of-the-art is highly dynamic. For this reason, it is especially important to keep track of them. To this end, there are several specific periodicals [4,5] and annual conferences [6,7], in which the interested reader may regularly find useful information on these topics.

Acknowledgements

The guest editors would like to thank all of the authors that have contributed to this special issue for their high-quality work as well as the reviewers for their valuable comments. Deserving special thanks is the Editor-in-Chief of the Journal, Dr. Belur V. Dasarathy, who supported this special issue from the very beginning, for both his extraordinarily quick responsiveness and his useful suggestions throughout the whole preparation process.

References

[1] IEEE Standard 802.11p, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 6: Wireless Access in Vehicular Technologies, 2010.
[2] H. Leung, N.-E. El Faouzi, A. Kurian, Intelligent transportation systems (ITS), Information Fusion 12 (1) (2011) 2–3.
[3] C. Stiller, F. Puente León, M. Kruse, Information fusion for automotive applications – an overview, Information Fusion 12 (4) (2011).
[4] IEEE Transactions on Intelligent Transportation Systems.
[5] IEEE Intelligent Transportation Systems Magazine.
[6] IEEE Intelligent Vehicles Symposium.
[7] IEEE Conference on Intelligent Transportation Systems.

Fernando Puente León *
Institut für Industrielle Informationstechnik,
Karlsruhe Institute of Technology (KIT),
Hertzstr. 16, 76187 Karlsruhe, Germany
* Corresponding author.
E-mail address: puente@kit.edu

Jürgen Beyerer
Fraunhofer Institute of Optronics,
System Technologies and Image Exploitation (IOSB),
Fraunhoferstr. 1, 76131 Karlsruhe, Germany

Institute of Anthropomatics,
Vision and Fusion Lab, Karlsruhe Institute of Technology (KIT),
Adenauerring 4, 76131 Karlsruhe, Germany
E-mail addresses: juergen.beyerer@iosb.fraunhofer.de