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Data Fusion for ITS: Techniques and Research Needs

Nour-Eddin El Faouzi[1] and Lawrence A. Klein[2*]
[1]*Université de Lyon, F-69000, Lyon, France*
IFSTTAR, LICIT, F-69500, Bron
ENTPE, LICIT, F-69518, Vaulx en Velin
[2]*Klein & Associates, Santa Ana, California, U.S.A.*
nour-eddin.elfaouzi@ifsttar.fr, larry@laklein.com

Abstract
Intelligent transportation system (ITS) infrastructures contain sensors, data processing, and communication technologies that assist in improving passenger safety, reducing travel time and fuel consumption, and decreasing incident detection time. Multisource data from Bluetooth® and IP-based (cellular and Wi-Fi) communications, global positioning system (GPS) devices, cell phones, probe vehicles, license plate readers, infrastructure-based traffic-flow sensors, and in the future, connected vehicles enable multisource data fusion to be exploited to produce an enhanced interpretation of the monitored or observed situation. This occurs by decreasing the uncertainty present in individual source data. Although demonstrated for more than two decades, data fusion (DF) is still an emergent field as related to day-to-day traffic management operations. Data fusion techniques applied to date include Bayesian inference, Dempster-Shafer evidential reasoning, artificial neural networks, fuzzy logic, and Kalman filtering. This paper provides a survey of ITS DF applications, including ramp metering, pedestrian crossing, automatic incident detection, travel time prediction, adaptive signal control, and crash analysis and prevention, and indicates directions for future research. The encouraging results so far should not conceal the challenges that remain before widespread operational deployment of DF in transportation management occurs.

Keywords: Sensor and data fusion, data fusion, information fusion, data fusion in ITS

1 Introduction

Timely and accurate information enable transportation systems to monitor and manage operations that maximize the safety and efficiency of the highway system. As connected and autonomous vehicles proliferate, the need to provide traffic flow, collision avoidance, and dangerous-condition warning information becomes both a major challenge and a major opportunity for the public agencies and private companies that support Intelligent Transportation Systems (ITS). Simultaneously, the spread of

* Corresponding author

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Bluetooth® and Internet Protocol (IP)-based (cellular and Wi-Fi) communications technologies has increased travelers' proclivity for accurate road traffic information. Traffic sensors that monitor traffic flow at a given point are often ineffective in supplying the data required by modern transportation management systems. Therefore, other data sources, such as surveillance cameras, global positioning system (GPS), cell phone tracking, probe vehicles, license plate readers, and soon connected vehicles, increasingly supplement the information provided by conventional measurement systems. In addition, traffic management agencies normally archive traffic flow data by time-of-day, day-of-week, month, season, and recurring special events. This offline information, together with sensor real-time data, often is useful in predicting traffic trends.

Multisource data may be complementary in nature and, if this is the case, multisource data fusion can be applied to produce a better interpretation of the observed situation by decreasing the uncertainty present in individual source data, thus allowing traffic management centers and traffic information providers to achieve their goals more effectively (El Faouzi 2011). The objectives of this paper are to introduce readers to the basic tenants of data fusion (DF), acquaint them with the most significant applications of DF to ITS, and to indicate directions for future research.

The paper contains eight sections. Section 2 defines sensor and data fusion and describes one of the models utilized in developing its applications. Section 3 explores sensor and data fusion architectures suitable for ITS applications. Opportunities and challenges of ITS data fusion appear in Section 4, whereas Section 5 presents examples of data fusion applications to traffic management. Suggestions for selecting a data fusion algorithm for an ITS application are described in Section 6. Section 7 explores the ongoing need for data fusion research and Section 8 contains conclusions and suggestions for future research topics.

2 Sensor and Data Fusion Definitions and Models

Data fusion is concerned with:

1. The representation of information within a computational database, particularly the information gained through data fusion.
2. The presentation of this information in a manner that supports the required decision processes when a human operator or decision maker is involved.

Data fusion should not be the goal or end result of a transportation management strategy. Rather the goal is to provide a control system, in the form of a machine or a human, the information necessary to support making automated or semi-automated decisions where vehicle systems or operators may have to take corrective actions to ensure safety.

Several definitions of sensor and data fusion are found in the literature. The Joint Directors of Laboratories (JDL) model, perhaps the most widely cited, defines data fusion as "a multilevel, multifaceted process dealing with the automatic detection, association, correlation, estimation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats and their significance" (Kessler 1991; Waltz 1990, p. 1). The Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society's definition is "the process of combining spatially and temporally-indexed data provided by different instruments and sources in order to improve the processing and interpretation of these data." The University of Skövde provides a definition in terms of information fusion as "the study of efficient methods for automatically or semi-automatically transforming information from different sensors and different points in time into a representation that provides effective support for human or automated decision making" (Boström, Andler, Brohede, Johansson, Karlsson, van Laere, Niklasson, Nilsson, Persson, Ziemke 2007, p. 5). These definitions provide different insights into the role of sensor and data fusion. Their existence is a reflection of the diverse applications for sensor and data fusion