Multisensor Architecture for an Intersection Management System

Gustavo Velasco-Hernández

1 Introduction

An intersection is a highly-dynamic scenario that can be monitored using a wide range of sensors. For this reason, an efficient and accurate fusion of the information is needed. This chapter is divided into two sections. In the first section a brief overview of multisensor data fusion is presented, remarking in different architectures proposed in the literature and different approaches used for laser and video data fusion are described. The second section contains a short review on intelligent transportation systems and intersection management systems, including current research on this topic. Finally, some projects that include fusion of laser and video data for intersection managing applications are presented.

2 Multisensor Data Fusion

Data fusion, also referred as mutisensor data fusion, information fusion or sensor fusion, has received several definitions from different authors in the literature. For example, Joint Directors of Laboratories defined data fusion as "multi-level, multifaceted process handling the automatic detection, association, correlation, estimation, and combination of data and information from several sources"[25]. Luo refers to multisensor fusion and integration as "synergistic combination of sensory data from multiple sensors to provide more reliable and accurate information"[19] and "to achieve inferences that are not feasible from each individual sensor operating separately"[21]. Elmenreich states that sensor fusion is "the combining of sensory data or data derived from sensory data such that the resulting information is in some sense better than would be possible when these sources were used individually"[11]. In [4] there is a compilation of more definitions of information fusion and the author summarize in his own statement as follows: "Information fusion is the study of efficient methods for automatically or semi-automatically transforming information from different sources and different points in time into a representation that provides effective support for human or automated decision making".

All of previous definitions can be seen as a way to answer these three questions about data fusion:

- What is involved in data fusion?
  Combine, merge or integrate homogeneous or heterogeneous data.
- What is the aim of data fusion?
  Get a better representation of a process or the environment, infer underlying information, improve quality of the data.
- How to apply data fusion?
  Data fusion is a multi-level task, depending of the nature of the sensors, the final application and the environment.

It is clear, now, that multisensor data fusion is a multidisciplinary field, because information in a typical process, flows from sensors to applications, passing through stages of filtering, data enhancement and data extraction. It is for this that knowledge in a wide range of fields are required, e.g. signal processing, machine learning, probability and statistics, etc. Also, it would be pointless to try to define a general method, technique or architecture that fits the requirements of any system, for applying data fusion in it.

2.1 Data Fusion Architectures and Models

Although there is not a general rule of how to design or implement a sensor fusion system, many authors have proposed some models, architectures and guidelines for this task. Three well-known models are Waterfall model, JDL fusion model and Multisensor integration fusion model.

2.1.1 Waterfall model

Harris and Markin in [16] and CITE, proposed a model named Waterfall, in which they describe the fusion process as an information flow through sensing to decision-making. They describe 3 levels of processing with 2 inner stages each ((1). The first level is about transform the raw data from sensor to a better representation of the measured phenomena through signal processing and having in mind sensor models and nature of the process itself. The second level objective is to find a meaningful description of the data, reducing its volume while maximising information. This is done using feature extraction and pattern recognition techniques. The third level is the high level of the process in which situation assessment and decision making are performed, based on data available, configuration parameters, database information or human interaction. Finally, a feedback from high-level to low-level (sensor) is done, advising the whole system for re-calibration or reconfiguration.

2.1.2 JDL fusion model

One of the first proposals of fusion architecture, and probably one of the most widely used, is the JDL fusion model, originated from the US Joint Directors of Laboratories and described by Hall and Llinas in [15] and [17]. The JDL

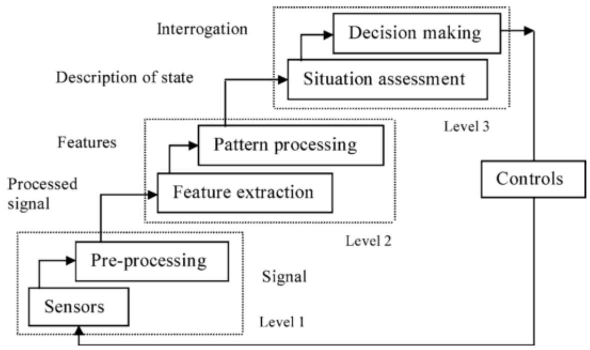

Fig. 1: Waterfall model. (from [12]).

fusion model was conceived to aid the developments of military applications and comprises 5 levels of data processing at which data fusion could be done. These levels and a database are connected by a bus (2), and are not meant to be execute sequentially and can also be executed concurrently.

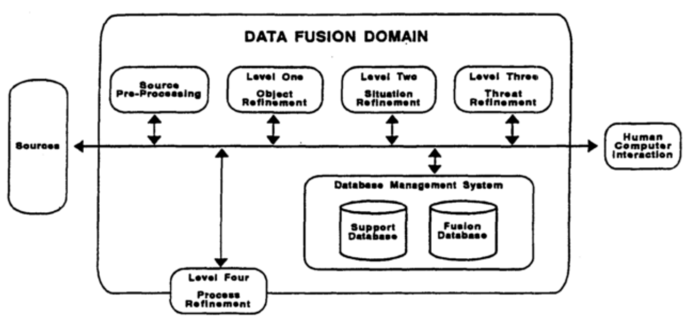

Fig. 2: JDL fusion model. (from [15]).

The first stage, referred as level-0 is the source preprocessing in which raw data is handled to concentrate the more pertinent data for the current situation. The level-1 is for object refinement, starting with the alignment of the data in a commonly space-time reference frame. Then, performs identification and tracking of objects using different techniques. Situation refinement is at level-2, which takes observed and partially-observed object from level-1 and tries to find a contextual description between them. Level-3, threat refinement, is the level in which results from level-2 are interpreted looking for possible advantages and disadvantages for the system to operate, based on previous knowledge and predictions about executing an action.

2.1.3 Multisensor Fusion Integration model

Luo and Kai, in [18, 20], proposed a full integration model for data fusion in which they define a three-level hierarchy for sensor fusion: data-fusion, feature-fusion and decision-fusion. This model separate MFI in five classes, based on Input/Output pair: Data in-data out fusion, data in-feature out fusion, feature in-feature out fusion, feature in-decision out fusion, and decision in-decision out fusion [21] (figure 3).

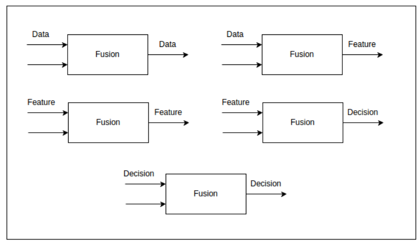

Fig. 3: Five classes of Multisensor Fusion.

Also, they made a clear distinction between multisensor fusion and multi-sensor integration, being the former the process in which information provided by a set of sensors is combined in any of the three levels aforementioned, and the latter is how sensor fusion could be integrated in a full system in order to assist in a particular task. As is depicted in figure 4, sensor fusion is an element of the whole MFI architecture, which also includes block for sensor managing tasks, like control, selection and registration of sensors, previously to the fusion process. A sensor processing stage and a system controlling module are also included after the sensor fusion stage.

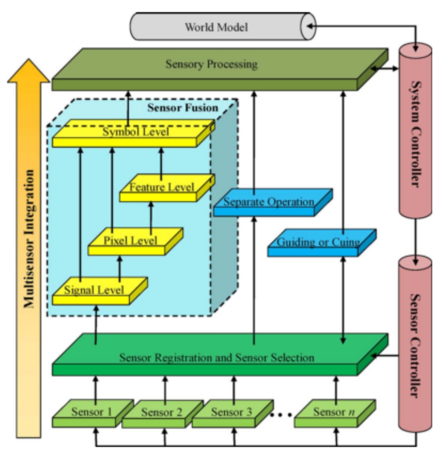

Fig. 4: Multisensor Fusion Integration architecture (from [21]).

2.2 Classification of Data Fusion Architectures

Elmenreich in [11] classify fusion models in three categories: Abstract models, generic architectures and rigid architectures. Abstract model are not intended to show how to implement a sensor fusion system, but to explain which processes are done in it. Generic architectures gives an outline on how a system could be implemented in an application, but do not specify what type of hardware, database or communication system could be used. Finally, rigid architectures, are a good guide for implementation of data fusion in certain applications, at the cost that several design decisions have been already taken, making expensive the migration to another architecture.

In addition to models previously mentioned, there exists more proposal for data fusion architectures in literature, as can be viewed in figure 5.

Category	Data fusion model	From
Abstract Model	Waterfall Model	[Harris1998]
	Boyd Loop	[Boyd1987]
Generic Architecture	JDL Model	[White1991]
	Multisensor Fusion Integration Model	[Luo1997]
	Omnibus Model	[Bedworth1999]
Rigid Architectures	LAAS Architecture	[Alami1998]
	DFuse Architecture	[Kumar2003]
	Time-Triggered Model	[Elmenreich2001]

Fig. 5: Classification of some data fusion models

2.3 Algorithms in Data Fusion

Low level fusion		Medium level fusion	High level fusion
Estimation methods		Classification methods	Inference methods
Recursive: • Kalman filter • Extended Kalman filter Non-recursive: • Weighted average • Least squares	Covariance-based: • Cross covariance • Covariance intersection • Covariance union	• Parametric templates • Cluster analysis • K-means clustering • Learning vector quantization • Kohonen feature map • Artificial neural network • Support vector machines	• Bayesian inference • Particle filters • Dempster-Shafer theory • Expert system • Fuzzy logic

Fig. 6: Fusion algorithms based on level of fusion. (from [21])

2.4 Laser and Video Data Fusion

3 Intersection Management Systems

El concepto de sistemas inteligentes de transporte (ITS), presenta un amplio campo de acción transversal a diferentes áreas del conocimiento e igualmente presenta una gran variedad de aplicaciones y servicios. Para la clasificación de estos servicios se han definido diferentes taxonomías como las descritas en [24, Ch.1] y en [26]. De las clases y categorías descritas, se tiene un subgrupo de los ITS que debe ser contemplado para cumplir con el objetivo de este proyecto, que es el que incluye los servicios y sistemas para la administración y operación del tráfico (o Sistemas Avanzados de Administración de Tráfico, del inglés ATMS, Advanced Traffic Management Systems).

Uno de los escenarios donde se busca mejorar la eficiencia y la seguridad usando estos sistemas son las intersecciones viales, ya que son puntos donde se encuentran vehículos en diferentes direcciones a diferentes velocidades, lo cual incrementa la probabilidad de incidentes y choques. Cerca del 40% de los accidentes de tránsito reportados en Estados Unidos en 2008, estaban relacionados con intersecciones [7]. En Colombia, para el 2011 la mayoría de accidentes en las principales ciudades del país se concentraba en intersecciones [9].

Para afrontar esta problemática aparecen diferentes tipos de aplicaciones y sistemas para realizar tareas como monitoreo y administración de intersecciones, detección de vehículos, advertencia de incidentes, prevención de colisiones, entre otros. El esquema de comuniciación de estos sistemas se basa en la interacción entre los vehículos y la infraestructura, comúnmente dividida en 3 tipos: Comunicación vehículo a vehículo (V2V), vehículo a infraestructura (V2I) y la combinación de las dos anteriores (V2X).

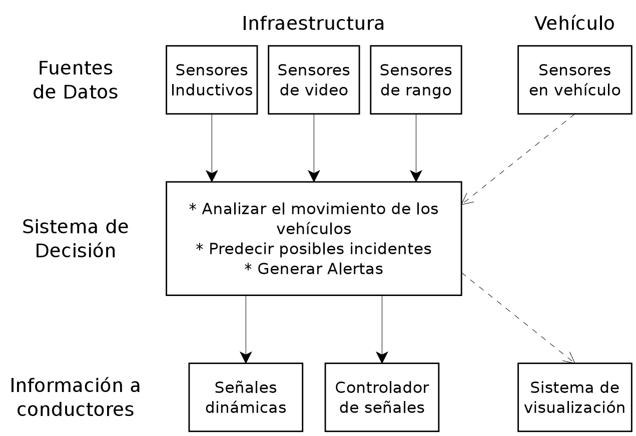

Fig. 7: Diagrama de bloques general de un sistema de control en una intersección [6].

En la figura 7, se presenta un diagrama de bloques general de un sistema de administración de una intersección en donde se destacan 3 componentes: (a) Las fuentes de los datos, que pueden ser sensores en la infraestructura, como sensores inductivos, sensores de rango, cámaras, o sensores en el vehículo. (b) Sistema de decisión o administración, que es el encargado de analizar la información de los vehículos y el entorno, predecir incidentes futuros y enviar señales de alerta. y (c) La presentación de información de control, que puede ser en la infraestructura con señales dinámicas, control de los semáforos, como también puede ser en el vehículo mediante un dispositivo de visualización.

El monitoreo en las intersecciones viales es una tarea requerida en los sistemas inteligentes de transporte para aplicaciones de alto nivel como análisis de tráfico, conteo y clasificación de vehículos, detección de eventos, prevención de accidentes y aplicaciones de seguridad y vigilancia. Para cumplir con estas tareas se han propuesto diversas soluciones para obtener la información del entorno, ya sea proveniente de los vehículos, por ejemplo monitoreando conexiones a redes móviles, como Bluetooth [13], detectando su presencia usando sensores inductivos o etiquetas RFID, y también tomando datos desde la infraestructura, usando cámaras [5], sensores láser o arreglos de estos [28] o sistemas que integran múltiples tipos de sensores [27][22]. Otras aplicaciones además de monitorear y supervisar las intersecciones, están orientadas al control del tráfico en estas con el objetivo de maximizar el flujo, disminuir la accidentalidad y aumentar la seguridad. Diversos trabajos se han hecho y aunque su finalidad es similar, existe variedad entre sí, ya sea según el tipo de comunicación en la que se basan (V2V, V2I o V2X), el tipo de sensores e información que usan, el entorno de ejecución (simulación, real o realidad aumentada) y el tipo de vehículos (con conductores humanos o vehículos autónomos).

En [2] y [1] se proponen arquitecturas basadas en comunicación intervehicular, donde cada auto envía a los demás información correspondiente a su posición, velocidad, destino y otros datos, y así coordinan el acceso a la intersección. En [14] se presenta un sistema que además de trabajar en modo V2V, presenta la opción V2I que incluye sensores inductivos y módulos RFID para detectar vehículos. La información adquirida es procesada por un controlador de intersección, el cuál se encarga de administrar el ingreso al cruce vial. Otro sistema basado en V2I es [3] donde tambien se usan nodos de sensores magnéticos inalámbricos que se comunican con una estación base, la cual mediante algoritmos de predicción determina posibles colisiones y advierte a los conductores mediante un sistema de visualización en la infraestructura. Por otro lado, [10] y [8] presentan aplicaciones en simulación para el control de las intersecciones usando agentes y aplicado en vehículos autónomos. En [23] se hace una implementación en realidad aumentada del sistema propuesto por Dresner y Stone [10]. En esta implementación, los vehículos que se aproximan a la intersección solicitan autorización al controlador para ingresar y es este quien decide cuando pueden cruzar, dependiendo de las politicas de administración definidas.

3.1 Intersection Management Systems and Multisensor Data Fusion

4 Conclusions

Multisensor data fusion can be defined as the process of combine, merge or integrate data from homogeneous or heterogeneous set of sensors in order to get a better representation of a process, the environment or a situation, through the inference of underlying information and the improve of quality of data.

Depending of the nature of the sensors and the source of information, fusion can be done in several manners, i.e., sensor-level fusion, feature-level fusion or decision-level fusion.

Several models, architectures and frameworks have been proposed in literature; some of them to show how a data fusion system should work and some other providing guidelines on how to implement it in a given application.

References

[1] Reza Azimi, Gaurav Bhatia, Raj Rajkumar, and Priyantha Mudalige. Intersection Management using Vehicular Networks. pages 1–13, April 2012.

[2] Rudi Ball and N Dulay. Enhancing Traffic Intersection Control with Intelligent Objects. *Urban IOT 2010 Urban Internet of Things Towards Programmable Realtime Cities*, 2010.

[3] Fadi Basma, Yehia Tachwali, and Hazem H Refai. Intersection collision avoidance system using infrastructure communication. *2011 14th International IEEE Conference on Intelligent Transportation Systems ITSC*, pages 422–427, 2011.

[4] Henrik Boström, SF Andler, and Marcus Brohede. On the definition of information fusion as a field of research. Technical report, University of Skövde, 2007.

[5] N. Buch, S. a. Velastin, and J. Orwell. A Review of Computer Vision Techniques for the Analysis of Urban Traffic. *IEEE Transactions on Intelligent Transportation Systems*, 12(3):920–939, September 2011.

[6] C.-Y. Chan and Bénédicte Bougler. Evaluation of cooperative roadside and vehicle-based data collection for assessing intersection conflicts. In *IEEE Proceedings. Intelligent Vehicles Symposium, 2005.*, pages 165–170. IEEE, 2005.

[7] Eun-Ha Choi. Crash Factors in Intersection-Related Crashes: An On-Scene Perspective. Technical Report September, U.S. Departament of Transportation, Springfield, VA, 2010.

[8] Luís Conde Bento, Ricardo Parafita, and Urbano Nunes. Intelligent traffic management at intersections supported by V2V and V2I communications. In *2012 15th International IEEE Conference on Intelligent Transportation Systems*, pages 1495–1502, Anchorage, Alaska, USA, 2012.

[9] Corporación Fondo de Prevención Vial. Anuario Estadístico de Accidentalidad Vial. Technical report, Bogotá, Colombia, 2010.

[10] Kurt Dresner and Peter Stone. A Multiagent Approach to Autonomous Intersection Management. *Journal of Artificial Intelligence Research*, 31:591–656, 2008.

[11] Wilfried Elmenreich. A Review on System Architectures for Sensor Fusion Applications. In *Software Technologies for Embedded and Ubiquitous Systems Lecture Notes in Computer Science Volume 4761, 2007,*, pages 547–559, 2007.

[12] Jaime Esteban, Andrew Starr, Robert Willetts, Paul Hannah, Peter Bryanston-Cross, and Neural Comput. A Review of data fusion models and architectures: towards engineering guidelines. *Neural Computing and Applications*, 14(4):273–281, June 2005.

[13] M Friesen, R Jacob, P Grestoni, T Mailey, and R.D. McLeod. VEHICULAR TRAFFIC MONITORING USING BLUETOOTH. In *2013 26th IEEE Canadian Conference Of Electrical And Computer Engineering (CCECE)*, 2013.

[14] Juan Antonio Guerrero-Ibañez, Carlos Flores-Cortés, Juan Manuel Ramírez-Alcaraz, Pedro Santana, Tomás Mendoza-Robles, Hector Ali Vizcaíno-Anaya, Emmanuel Peña Cárdenas, and Álvaro Anguiano-Mancilla. Sistema Inteligente basado en comunicación V2X para prevención de colisiones en intersecciones viales. In *Décima Segunda Conferencia Iberoamericana en Sistemas, Cibernética e Informática. CISCI 2013*, Orlando, FL, 2013.

[15] David L Hall and James Llinas. An Introduction to Multisensor Data Fusion. *Proceedings of the IEEE*, 85(1):6–23, 1997.

[16] C. J. Harris, A. Bailey, and T. J. Dodd. Multi-sensor data fusion in defence and aerospace. *Aeronautical Journal*, 102:229–244, 1998.

[17] James Llinas and David L Hall. An introduction to multi-sensor data fusion. *ISCAS '98. Proceedings of the 1998 IEEE International Symposium on Circuits and Systems (Cat. No.98CH36187)*, 6:537–540, 1998.

[18] R. C. Luo and M. G. Kay. Multisensor integration and fusion in intelligent systems. *IEEE Transactions on Systems, Man and Cybernetics*, 19:901–931, 1989.

[19] R.C. Luo. Multisensor fusion and integration: approaches, applications, and future research directions. *IEEE Sensors Journal*, 2(2):107–119, April 2002.

[20] R.C. Luo and M.G. Kay. A tutorial on multisensor integration and fusion. In *[Proceedings] IECON '90: 16th Annual Conference of IEEE Industrial Electronics Society*, pages 707–722. IEEE, 1990.

[21] Ren C. Luo, Chih Chia Chang, and Chun Chi Lai. Multisensor Fusion and Integration: Theories, Applications, and its Perspectives. *IEEE Sensors Journal*, 11(12):3122–3138, December 2011.

[22] P. Pyykonen, Matthieu Molinier, and G.a. Klunder. Traffic monitoring and modeling for Intersection Safety. *Proceedings of the 2010 IEEE 6th International Conference on Intelligent Computer Communication and Processing*, pages 401–408, August 2010.

[23] M Quinlan, Tsz-Chiu Au Tsz-Chiu Au, J Zhu, N Stiurca, and P Stone. Bringing simulation to life: A mixed reality autonomous intersection. *Intelligent Robots and Systems IROS 2010 IEEERSJ International Conference on*, (October):6083–6088, 2010.

[24] Joseph M. Sussman. *Perspectives on Intelligent Transportation Systems (ITS)*. Springer US, Boston, MA, 2005.

[25] Franklin E. White. Data Fusion Lexicon. In *The Data Fusion Subpanel of the Joint Directors of Laboratories, Technical Panel for C3*, volume 15, page 15, 1991.

[26] Bob Williams. *Intelligent Transport Systems Standards*. Artech House, INC., 2008.

[27] Huijing Zhao, Jinshi Cui, and Hongbin Zha. Sensing an Intersection Using a Network of Laser Scanners and Video Cameras. *IEEE Intelligent Transportation Systems Magazine*, pages 31–37, 2009.

[28] Huijing Zhao, Jie Sha, Yipu Zhao, Junqiang Xi, Jinshi Cui, Hongbin Zha, and Ryosuke Shibasaki. Detection and Tracking of Moving Objects at Intersections Using a Network of Laser Scanners. *IEEE Transactions on Intelligent Transportation Systems*, 13(2):1–16, 2012.