Multisensor Architecture for an Intersection Management System

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Introduction

Chapter 2

Multisensor Data Fusion and Intersection Management Systems

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 algorithms and frameworks used for this task. The second section contains a short review on intelligent transportation systems and intersection management systems, including a description of elements involved in the development of an IMS application. Finally, some projects that include multisensor data for intersection managing applications are presented.

2.1 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"[56]. Luo refers to multisensor fusion and integration as "synergistic combination of sensory data from multiple sensors to provide more reliable and accurate information"[39] and "to achieve inferences that are not feasible from each individual sensor operating separately"[41]. 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"[22]. In [12] 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.

2.1.1 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.

Waterfall model

Harris and Markin in [30] 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 ((2.1). 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.

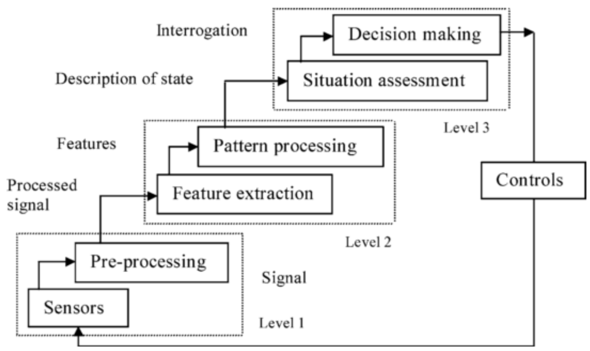

Figure 2.1: Waterfall model (from [24]).

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 [29] and [38]. The JDL 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 (2.2), and are not meant to be execute sequentially and can also be executed concurrently.

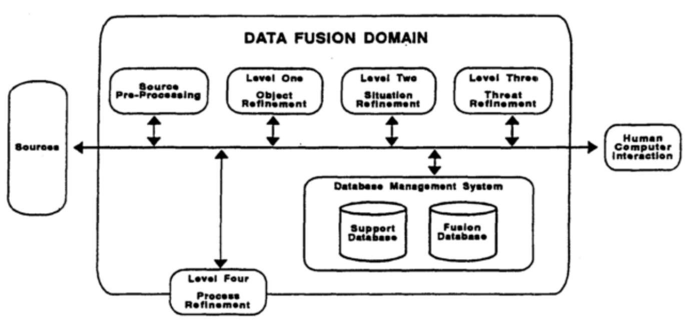

Figure 2.2: JDL fusion model. (from [29]).

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.

Multisensor Fusion Integration model

Luo and Kai, in [42, 40], 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 [41] (figure 2.3).

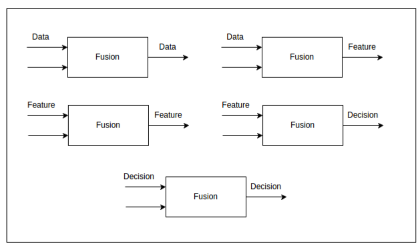

Figure 2.3: Five classes of Multisensor Fusion.

Also, they made a clear distinction between multisensor fusion and multisensor 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 2.4, 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.

2.1.2 Classification of Data Fusion Architectures

Elmenreich in [22] 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

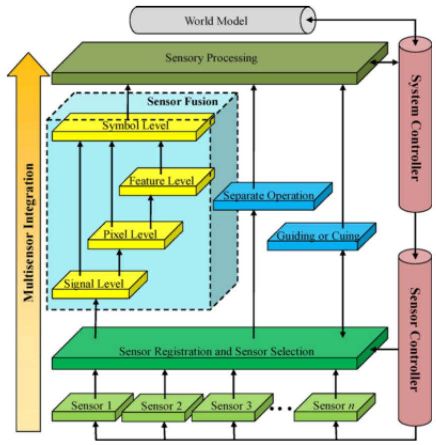

Figure 2.4: Multisensor Fusion Integration architecture (from [41]).

Category	Data Fusion Model
Abstract Model	Waterfall Model [30]
	Boyd Loop [13]
Generic Architecture	JDL Model [56]
	Multisensor Fusion Integration Model [42]
	Omnibus model [11]
Rigid Architecture	LAAS Architecture [2]
	DFuse Architecture [36]
	Time-triggered Model [23]

Table 2.1: Classification of data fusion models

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 table 2.1.

2.1.3 Algorithms in Data Fusion

Different types of algorithms have been used in implementing data fusion systems, depending on a variety of conditions like, level of fusion, type of the data, nature of environment, etc. Constrains like processing and memory limitations, centralised or distributed schemes, human-interactive or completely autonomous process, also determine which algorithms should be used in fusion process.

Luo in [41] propose a classification for fusion algorithms based on the level of fusion. Low-level fusion refers to the merge of raw data or signals, mid-level fusion refers to the fusion of features and High-level fusion refers to the process of fuse decisions. Khaleghi in [35] describes a classification for fusion algorithms based on challenging problems that arise from the data to be fused, due to the variety of sensors and the nature of the application environment. This classification is not on the algorithms directly, but on the theory or framework in which they originate. Four types of data are enumerated: Imperfect data, correlated data, inconsistent data and disparate data. These two approaches of fusion algorithms classification are summarized in tables 2.2 and 2.3.

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 networks • Support vector machines	• Bayesian inference • Particle filters • Dempster-Shafer theory • Expert systems • Fuzzy logic

Table 2.2: Classification of fusion algorithms based on level of fusion

Data Problem	**Framework**
Imperfection	Probabilistic Evidential Fuzzy reasoning Possibilistic Rough set theoretic Hybridization Random set theoretic
Correlation	Correlation elimination Correlation presence
Inconsistency	Sensor validation Stochastic sensor modeling Prediction Augmented state framework Combination rules Dempsters' rule
Disparateness	Dempster-Shafer theoretic framework Human-centered data fusion Hard-soft data fusion

Table 2.3: Classification of fusion algorithms based on challeging problems in data

2.2 Intersection Management Systems

Intelligent Transportation Systems includes a wide range of applications and services transversal to many knowledge areas. For classifying those services, some taxonomies have been proposed like the ones presented in [52, Ch.1] and [57]. From described categories and classes, Advanced Traffic Management Systems have to be considered when an intelligent handling of traffic needs to be deployed.

One of the most desirable scenarios to improve efficiency and safety is an intersection. This because intersections are places where vehicles arrive from different directions at different velocities, increasing the chances for incidents and crashes. Choi [16] states that 40% of reported traffic accidents in the US, were intersection related. Also, in [18], is reported that for Colombia in 2011, most of the accidents in the main cities were at intersections.

Different types of applications and systems are conceived to address these issues. Some tasks performed by those systems are intersection monitoring, vehicles detection, incident warning, collision avoidance, among others. A typical Intersection Management System is composed by three main components: Data source, that could be infrastructure sensors, like inductive loops, range sensors or cameras, and vehicle sensors and traveling data; decision system, which is the core of the whole system, is in charge of analyse and process information provided by infrastructure, vehicles and authorities in order to identify objects, recognise patterns, predict future incidents, control traffic and generate safe decisions and warnings alerts; and finally, is the presentation and displaying of the output of decision system, through infrastructure using dynamic signals, traffic light controlling, or using direct communication with drivers or vehicles through on-board visualisation/notification system. A block diagram of a generic IMS is presented in figure 2.5

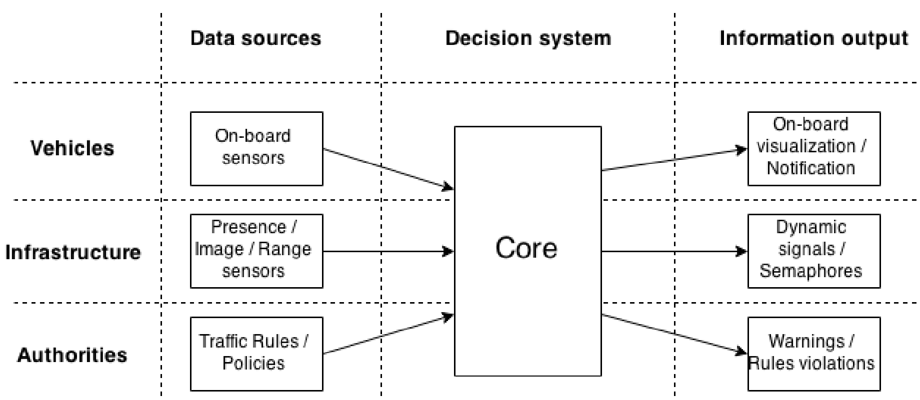

Figure 2.5: Generic block diagram of an Intersection Management System.

2.2.1 Components in IMS application

Intersection monitoring is a required task to be done within intelligent transportation systems for high-level applications like traffic analysis, counting and classification of vehicles or pedestrians, event prediction, incident detection and security and surveillance systems. Those applications have to take into account some of the elements depicted in figure 2.5 and developments in IMS have a wide range of approaches and objectives. In order to study IMS applications, five components have been defined, which are present on these applications, and on most cases, more than one component could be involved in the same development. In figure 2.6 a graph is presented, showing aforementioned components and elements within them, and next, a description of each component is given.

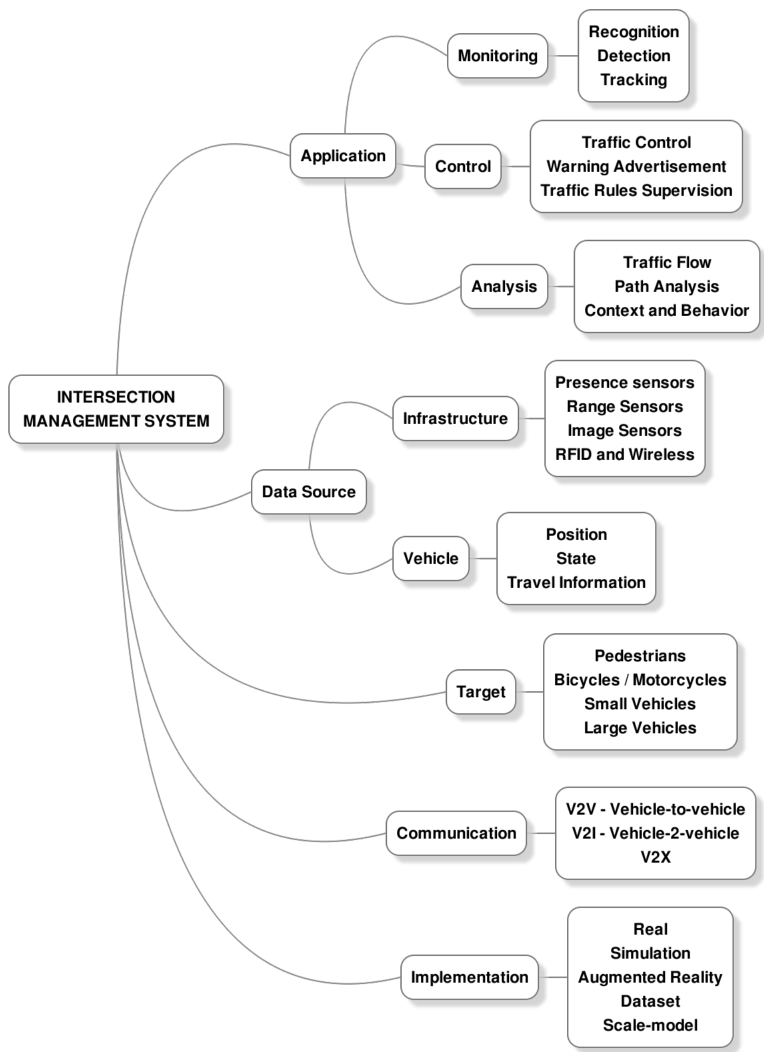

Figure 2.6: Components of an Intersection Management System application.

Application

Application component could be seen as the final objective of the system. Generally, this includes high-level tasks like monitoring, analysis or control. Monitoring or surveillance systems execute actions like recognition, detection and/or tracking of objects in the scene. Other systems analyse the behaviour and interactions between detected objects to recognise path patterns, determine the context of the environment and predict some events of interest. At a higher level there are systems which make decisions based on detection of certain traffic conditions to handle traffic lights, control intersection access, generate warnings to drivers or issue traffic tickets when a rule violation exists.

Data Source

The origin of data is considered an independent component because of the variety of possible sources and posterior processing stages. From infrastructure side, data can be captured using a wide range of sensors like inductive loops, lasers, lidars and cameras. Also, monitoring connections to wireless networks. On the other side, data from vehicles is also useful for the system to enhance its representation of the scene and take decisions. This could be low-level data like vehicle state variables, for example, speed, orientation, acceleration, etc., or high-level data like travel information.

Target

In an intersection many objects of different kinds interact between them. Pedestrian and vehicles are found at intersections, and latter includes bicycles, motorcycles, cars, vans, buses, trucks and some other types of vehicles. For this reason some applications are designed for a specific element or group of elements. Pedestrian tracking, motorcycles recognition or car counting are examples of targeted applications.

Communication

One of the keypoints of ITS is how information technologies and communication advances are included in transportation. The main goal of this is to allow information sharing between vehicles and infrastructure entities. For this reason, 3 communication approaches appear: Vehicle-to-vehicle or Inter-vehicle communication (V2V), vehicle-to-infrastructure communication (V2I) and vehicle to both vehicle and infrastructure (V2X). Several protocols and standars have been proposed for these communication approaches, for example DSRC, WAVE and IEEE 802.11p, but research and development on this component is still active.

Implementation

Not all IMS applications are implementable on a real scenario, maybe because is not the scope of the application or because it is in a early stage and it could be validated in other ways. This types of developments are sometimes implemented and evaluated using simulators, making functional prototypes or deploying scale-models. Some other projects use datasets to evaluate new algorithms and data processing techniques, and then compare obtained results with previous works. Augmented reality is also used as a tool for evaluating and validate developments, taking advantage of the interaction of a real system with a simulated/artificial scenario.

2.2.2 Developments in Intersection Management Systems

In the table 2.4 is presented a compilation of several developments within IMS field. For each work a brief comment is given, and a remark of how certain components (Data source, communication and application) are related to it. Target and implementation components could be infered from the comment.

Developments on Intersection Management Systems				
Reference	**Comment**	**Application**	**Data Source**	**Communication**
[33, 34]	They show an intersection monitoring system based on a fixed camera. This system is divided in three stages: Background modeling, object tracking and accident detection. They propose an innovative feature for accident detection using HMM.	Accident detection	Camera	N/A
[53]	Passive video-based system for monitoring an intersection. They implemented Stauffer's Method for background modeling, PCA for oriented bounding box computation, and Graph-based tracking and motion estimation. Also a simple methods for classification and calibration are described.	Accident detection	Camera	N/A
[54]	They present 4 stages for IMS: background modeling, motion tracking, feature extraction, calibration. They propose a 2-level tracking: Blob tracking as low-level and position using Kalman filter as high-level.	Accident detection / prediction	Camera	N/A

Reference	Comment	Application	Data Source	Communication
[48]	A Full implementation of an IMS in a town in northern Italy. The system claims to be independent of intersection geometry and it is based on a monocular camera. Processing stages of the system and classification approaches are described.	Intersection Monitoring	Camera	N/A
[19]	Development of a simulator for an Intersection Collision Warning System. Physical and MAC layers were modeled	Intersection collision warning simulator	N/A	V2V
[15]	Traffic monitoring for two context: Left-Turn-Across-Path-Opposite-Direction and Dilemma zone and red light violation	Intersection Monitoring	Radar	N/A
[3]	A collision prediction system based on computational geometry is presented. The two main stages are low-level vision system for foreground optimization, with shaking compensation and noise removal, and a collision prediction system based on bounding boxes instead of bounding rectangles.	Collision prediction	Camera	N/A
[14]	Analysis of Left-Turn-Across-Path-Opossite-Direction conflict situation.	Intersection Monitoring	Radar; Steering, speed sensors and GPS on-board	V2X
[5]	Based on [19], this works includes and improvement, including network layer and driver behaviour model.	Intersection Simulator Architecture	N/A	V2X
[55]	Tracking system based on Kalman filter for tracking and event detection at intersections, capable of detect 4 events: Acceleration, uniform velocity, stop and turns.	Tracking and event detection	Camera	N/A

Reference	Comment	Application	Data Source	Communication
[61]	Object tracking and classification at intersection using a single laser scanner. The system identifies 3 classes: Pedestrians, 2-wheeled vehicle and cars. It is based on points clustering, KL transform and markov chains	Object tracking and classification	Laser	N/A
[21]	A system for discriminate an approaching vehicle to an intersection is described. It use a monocular camera and define a number of features for classification. Motion vectors are used too and determine the level of approaching.	Vehicle detection	Camera	N/A
[37]	A communication scheme based on nearest to intersection is described. Two zones are defined: nearest zone and quasi-nearest zone. Based on which zone vehicles are, communicaton is performed. Validation of proposal is done using a custom microscopic simulator.	Intersection Communication Scheme	N/A	V2I
[20]	A multiagent-based intersection control protocol called autonomous intersection management (AIM) is proposed. Based on a custom simulation, vehicles are modeled and they comunicate with an intersection manager which allows or deny access to intersection. It is possible to set different traffic policies, even for emulate current control approaches lke stop lights and traffic lights.	Intersection Management	On-board state sensors	V2I
[31]	Based on [19] and [5], this simulator architecture emphasize on wireless communications. Now the system allows to compare different communication protocols and traffic configurations.	Intersection Simulator Architecture	N/A	V2V

Reference	Comment	Application	Data Source	Communication
[59]	Based on [61], the system now includes more laser sensor for get a better representation of the scene, solving some occlusion issues. Clustering is used for grouping readings from different sensors belonging to the same object and a tracking approach based on angle of beam, range and time is presented.	Intersection monitoring	Lasers	N/A
[51]	Proposal of a communication architecture for vehicles approaching to an intersection. Two zones are defined: Control Channel Zone (CCHZ) and Service Channel Zone (SCHZ). Also, 3 different methods are described for the system to be implmented	Collision avoidance	N/A	V2I
[49]	Proposal of a physical-layer protocol for V2I communication at intersections. The system is evaluated in simulation using MATLAB	Collision detection and warning	N/A	V2I
[58]	Based on [59], now the system includes a camera for video capture. In this video, data obtained from the lasers-based system are projected, drawing bounding boxes for vehicles and lines for trajectories.	Intersection monitoring	Camera, Lasers	N/A
[1]	Monitoring dilemma zone and efectiveness of control policies using cameras and loop detectors on an intersection	Intersection monitoring	Cameras, loop detectors	N/A
[7]	Author presents a system for foreground extraction, vehicle detection and tracking. A novel algorithm is proposed based on image division in traffic zones to perform background removal and vehicle detection. This proposal is compared with traditional MoG approach.	Intersection monitoring	Camera	N/A

Reference	Comment	Application	Data Source	Communication
[43]	A semi-automatic calibration method for a network of lidar sensors is presented using a custom simulation environment. Also, a calibration object were designed based on simulation results.	Intersection Monitoring	Lidars	N/A
[50]	An augmented reality implementation of the system proposed in citeDresner2008 is presented. In this work, an autonomous vehicle is deployed in a mixed-reality platform and request to an virtual intersection manager for authorisation to cross and is the manager which decides if it is safe to cross or not, depending on the defined traffic policies and the state of virtual vehicles.	Intersection management	On-board state sensors	V2I
[9]	The use of intelligent objects in vehicles is proposed. With sharing vehicle state information and jouney plans, the system aims to better control traffic in intersection using a novel back-off protocol instead of time traffic control system.	Traffic control	On-board state sensors, Journey plans	V2V
[8]	A system for traffic flow measurement based on anormalities detection is presented. Multiple cameras are used SIFT and unsupervised SVM-based clustering are performed for trajectories analysis.	Intersection monitoring	Cameras	N/A
[10]	In presented system, wireless magnetic nodes are used to detect presence and to send data to a base station, which determines possible collisions and warns driver through a visualisation system in infrastructure.	Collision Avoidance	Presence sensors	N/A

Reference	Comment	Application	Data Source	Communication
[6]	An intersection control protocol based on V2V communication is proposed. This protocol is in charge of handling other vehicles messages and determines if is it safe or not to cross. They present two policies for managing intersection access: Concurrent Crossing-Intersection Protocol (CC-IP) and Maximum Progression-Intersection Protocol (MP-IP).	Intersection management	N/A	V2V
[17]	A microscopic simulator was developed, with a spatial-temporal-based approach for managing the intersection. It is possible to implement different traffic policies for comparison purposes and the system works on crossroads and roundabouts.	Intersection management	On-board state sensors	V2X
[60]	A novel approach for detecting moving objects and track them is presented. The focus of this work relies on process merged data from laser sensors ([58]) to get better results at tracking.	Object detection and tracking	Lasers	N/A
[32]	A Multiagent-based system is proposed. They define a Vehicle Agent and and Intersection Agent and propose a protocol for controlling intersection access based on timeslots, Also, the present a vehicle motion planning algorithm. Validation and testing was done using SUMO platform	Intersection Management	On-board state sensors	V2I
[44]	A set of laser scanners is used for detect and track pedestrians. GMM and DBSCAN are proposed for detection stage. For tracking purpose, a random finite set particle filter is used.	Pedestrians detection and tracking	Lasers	N/A

Reference	Comment	Application	Data Source	Communication
[27]	In this work is presented the setting and configuration of a multisensor network, based on 14 lasers, 10 cameras, GPS and V2I unit. Calibration and spatial-temporal alignment is performed.	System Architecture	Cameras, Lasers	V2I
[25]	A set of wireless probes are deployed to estimate traffic flow based on bluetooth connections. Then, using Zigbee, data is send to a master node which handle data for forwarding to a server / database for further processing.	Traffic monitoring	Wireless sensor network	N/A
[28]	Two modes of Intersection Access Control: V2I mode and V2V mode. Implementation was done using minirobots in a scale model of an intersection.	Intersection access control	Loop detectors and RFID nodes	V2X
[46]	A new method for object detection based on lidars data is proposed. After perform background removal, they use DBGridSCAN for 3D clustering and 2D pathway tracking. Then a combination of 2D-3D is done. The proposal is validated using OSPA metric.	Object Detection	Lasers	N/A
[4]	On top of AIM ([20]) Semi-AIM protocol is proposed. Assuming that human-driven vehicles to autonomous vehicles transition will be long, this system is intended for semi-autonomous vehicles. Also the author describe the human relation to a semi-autonomous vehicle and analyse how the features of autonomy employed by the car affects the traffic delay.	Intersection Management	On-board state sensors	V2I

Table 2.4: Developments related to Intersection Management Systems.

2.3 Sensor Fusion in Intersection Management

2.4 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. Also, a wide range of algorithms have been used to perform fusion of data, some classified by the nature of the fusion or by the nature of the data, but is finally the environment and the application itself which determines the approach to use.

On the other hand, intersection management systems are highly required to improve safety and mobility in transportation, due to the high complexity present in these places, for drivers and authorities too. There is not an IMS application that address all the needs and problems in an intersection, for this reason many developments with narrow scopes and many topics involved have been proposed through the years. To handle all these works and proposals, a new component-based classification scheme for IMS application has been proposed.

Chapter 3

System Description

Although several types of sensors are used for intersection monitoring and supervision, the use of cameras, lasers and lidars has increased due to advances in sensors and computing capabilities. These enhancements have allowed to deploy more of these types of sensors per scenario and is required to define some processing stages from raw data capture through decision and control. Also is needed to test and validate the developments prior to a real and full functional implementation. The first part of this chapter describe main stages in a intersection management system based on image and range sensors, fusion approaches and methods used in these stages and an architeture proposal for the implementation. In the second part, two validation tools for IMS application are compared, simulators and datasets.

3.1 Multisensor IMS

Multicamera and multilasers monitoring systems offer more information about environment that can be merged to provide a better representation of the whole scene, and detect more acurately the objects in the intersection and prevent possible incidents. For designing an single-sensor or multi-sensor IMS system, there are some basic processing stages to have into account. In the case of a multisensor system, it is also required to analyse and determine what is the better fusion approach to use and in which of the processing stages this fusion should be performed to get better result that a single-sensor based system. Below, processing stages, fusion approaches, methods and architecture proposal are presented.

3.1.1 Processing Stages

In the designing of an IMS, there are four main stages that have to be performed from the data source to final output: Filtering, feature extraction, pattern recognition and situation assessment. The aim of the first stage is to extract data of interest from the raw sensor information, using filtering and background subtraction techniques to get the foreground of the scene and remove noise and irrelevant data. In the second stage, the objective is to identify elements within the foreground and extract relevant features of them. The third stage receives the set of features from the previous stage and performs recognition and classification tasks. Also, tracking and prediction of objects'state is performed based on historic information. In the fourth stage, object behaviour and inter-objects interaction are analysed to identify context and detect situation or events of interest. This output could be delivered to an optional fifth stage of decision and control, or to a human operator, traffic agent or institution, for taking immediate actions on traffic control, issuing of traffic tickets, warning drivers about possible incidents or improving transporation policies in a long-term. In figure 3.1, are depicted the previously described stages, and how the data volume is reduced while data meaning increases in the last stages.

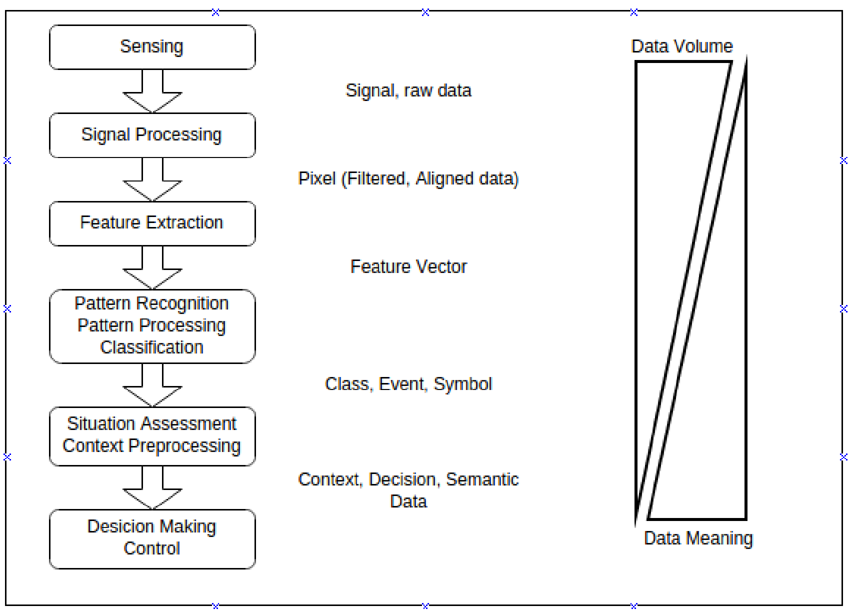

Figure 3.1: Processing stages in an IMS.

3.1.2 Fusion approaches

3.1.3 Methods and techniques

3.1.4 Architecture proposal

3.2 Validation approaches

3.2.1 Transportation and Traffic Simulations

Simulators Classification

3.2.2 Intersection monitoring Datasets

POSSi Dataset

KoPER Dataset

Appendices

Appendix A

Vehicular Environment Simulators

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