Multisensor Architecture for an Intersection Management System

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- Updated link for last version downloading
- Detailed processing levels in JDL model (1.1.1) and detailed categories in data fusion architectures (1.1.2)
- Fixed V2I description in figure 1.6 (1.2.1)
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Abstract

Intersections or junctions are critical points in transportation systems due to their dynamic behaviour, making them prone to safety or efficiency problems. For this reason the use of technology in monitoring intersections has increased over the last years. After a comprehensive review on this topic, a multisensor architecture for an intersection management system is conceived, having as main features its scalability and modularity. This architecture is composed by four main elements: communication structure, data model, information structure and processing blocks. An example implementation of the architecture is made using the publisher/subscriber approach along with different tools and technologies that allow the whole system to fulfill the proposed criteria, to be scalable and modular. After testing the system using a dataset containing data from camera sensors and lasers sensors, it has been found that the use of heterogeneous data can lead to better results, at a low cost in complexity using the proposed framework. Comments about obtained results, future developments and integration with current needs and new trends, are discussed.

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Introduction

Traditionally, the vision of transport systems has been constrainted to the set of elements belonging to infrastructure and the vehicles using it. As population increases and cities growth, the number of vehicles using roads also increases, but the growth rate of road network is lower. This situation leads to low quality in transportation; congestion and collisions affect movility in all cities in the world and development of efficient and long-lasting solutions carries high costs.

One of the critical places where is imperative to improve safety and efficiency is at vehicular intersections, because at these points many vehicles with different directions and speeds meet each other, increasing probability of incidents. Almost 40 percent of traffic accidents reported in US in 2008, were intersection related [18]. In Colombia, at 2011 most of accidents in main cities were at intersections [20].

In order to address different issues presented at intersections, several types of systems and applications have been proposed for different purposes like intersection management, vehicle counting, events warning, etc. These applications relies on different type of monitoring mechanisms, going from human supervision to automated sensors, but, because a high volume of data is generated in an intersection, it is not enough to have just one source of information.

For this reason, various sensors have been used for intersection monitoring, like magnetic sensors, laser-scanners and cameras, each of them providing different types of information about the scene. This information needs to be merged into a single model that represents the intersection state. The reliability of this model depends on the quality of the processing and on the fusion scheme selected for the data. The more reliable the model is, the more precise and efficient management over the intersection will be.

Based on this need of reliabilty in the scene model, the main goal set for this work is to conceive a multisensor architecture for an intersection management system and deploy it in a simulated scenario. In order to achieve this goal, these objectives were set:

- To make a literature review on intelligent transportation systems, focusing on developments about intersection management

- To define system architecture and specifications, and choose a platform which fits requirements for the deployment

- To develop and implement an intersection monitoring system based on laser and video sensors using sensor fusion techniques
- To propose and deploy a method for incident estimation and warning generation
- To set a test and evaluation protocol for the developments made on the choosen platform

The following chapters of this report are structured as follows:

Chapter 1 contains a comprehensive review on sensor fusion in intersection management systems, divided in three sections, first, sensor fusion approaches and model are described. Second, intersection management systems definition is presented along with a proposed taxonomy of those systems. Also a comprehensive list of developments is presented. Third, a review on IMS deployments that include a component of sensor fusion is described.

Chapter 2 describes the proposal, starting on explaining what kind of processing is required and how sensor fusion could be performed in an intersection management system. Then, two validation approaches for an IMS are considered, simulators and datasets. Also, four components for the architecture proposal are detailed, i.e communication scheme, data model, information structure and processing blocks.

Chapter 3 presents the result of two test implementations using the proposed architecture: 1) Using one camera and 2) Using multiple laser and one camera. For the later, 4 different fusion strategies are evaluated. These test cases are implemented and compared using traffic flow status as comparison indicator.

Chapter 4 summarizes the conclusions of the development of the whole work, remarking on contributions made like software and applications generated, academic products, and future developments and improvements for the system, including application performance, platforms upgrade, UX/UI improvements, scalability and integration with Internet of Things (IOT) and Smart Cities solutions.

Chapter 1

Multisensor Data Fusion and Intersection Management Systems

> "The goal is to turn data into information, and information into insight"
>
> Carly Fiorina

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.

1.1 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"[65]. Luo refers to multisensor fusion and integration as "synergistic combination of sensory data from multiple sensors to provide more reliable and accurate information"[43] and "to achieve inferences that are not feasible from each individual sensor operating separately"[45]. 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"[24]. In [14] 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.

1.1.1 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 [32] 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 ((1.1). 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.

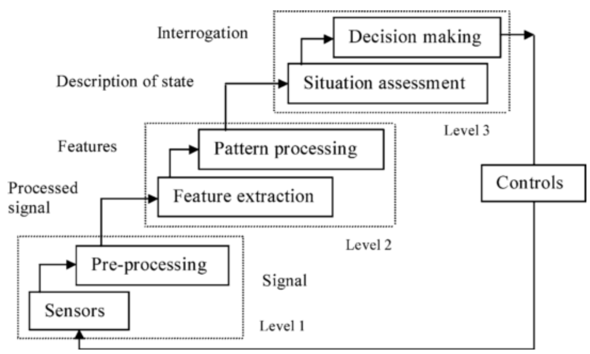

Figure 1.1: Waterfall model (from [26]).

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 [31] and [42]. 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 (1.2), and are not meant to be execute sequentially, and can also be executed concurrently.

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. ***Level-4*** is in the border of the whole diagram because its tasks are not just about sensor fusion but also on resource management. This level monitors the overall data fusion process to assess and improve real-time system performance and allocate sensors and sources to collect relevant information for the process.

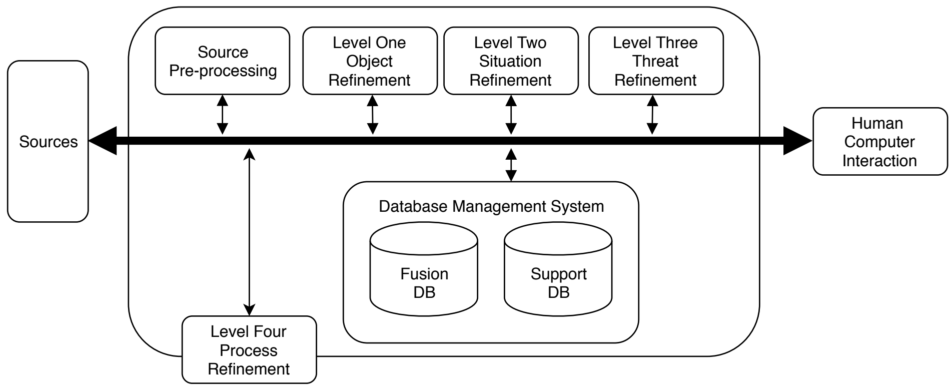

Figure 1.2: JDL fusion model. (from [31]).

Multisensor Fusion Integration model

Luo and Kai, in [46, 44], 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 [45] (figure 1.3).

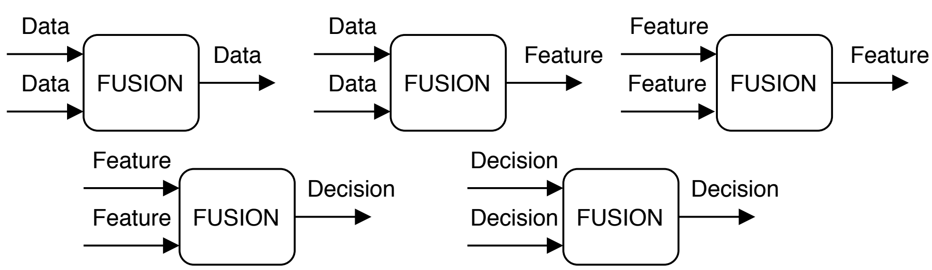

Figure 1.3: Five classes of Multisensor Fusion.

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 1.4, 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.

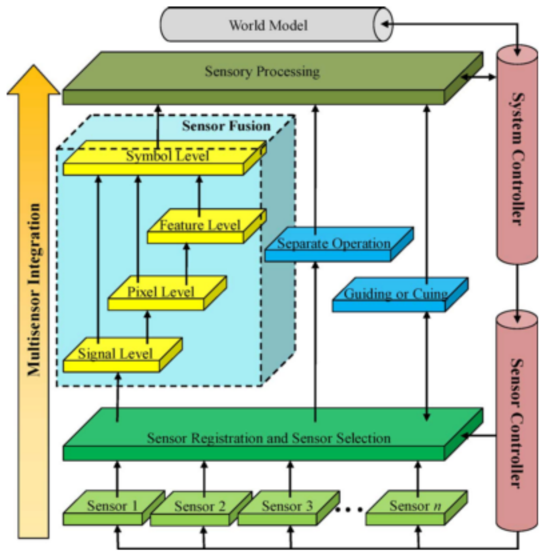

Figure 1.4: Multisensor Fusion Integration architecture (from [45]).

1.1.2 Classification of Data Fusion Architectures

Elmenreich in [24] classify fusion models in three categories: Abstract models, generic architectures and rigid architectures. ***Abstract models*** 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 table 1.1.

Category	Data Fusion Model
Abstract Model	Waterfall Model [32] Boyd Loop [15]
Generic Architecture	JDL Model [65] Multisensor Fusion Integration Model [46] Omnibus model [13]
Rigid Architecture	LAAS Architecture [3] DFuse Architecture [39] Time-triggered Model [25]

Table 1.1: Classification of data fusion models

1.1.3 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 [45] 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 [37] 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 1.2 and 1.3.

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 1.2: Classification of fusion algorithms based on level of fusion

1.2 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 [61, Ch.1] and [66]. 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 [18] states that 40% of reported traffic accidents in the US, were intersection related. Also, in [20], is reported that for Colombia in 2011, most of the accidents in the main cities were at intersections.

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 1.3: Classification of fusion algorithms based on challeging problems in data

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 1.5

1.2.1 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 1.5 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

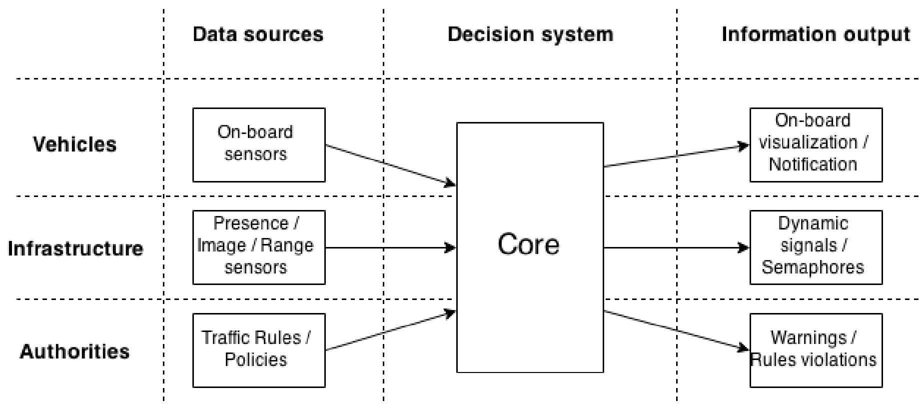

Figure 1.5: Generic block diagram of an Intersection Management System.

on most cases, more than one component could be involved in the same development. In figure 1.6 a graph is presented, showing aforementioned components and elements within them, and next, a description of each component is given.

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.

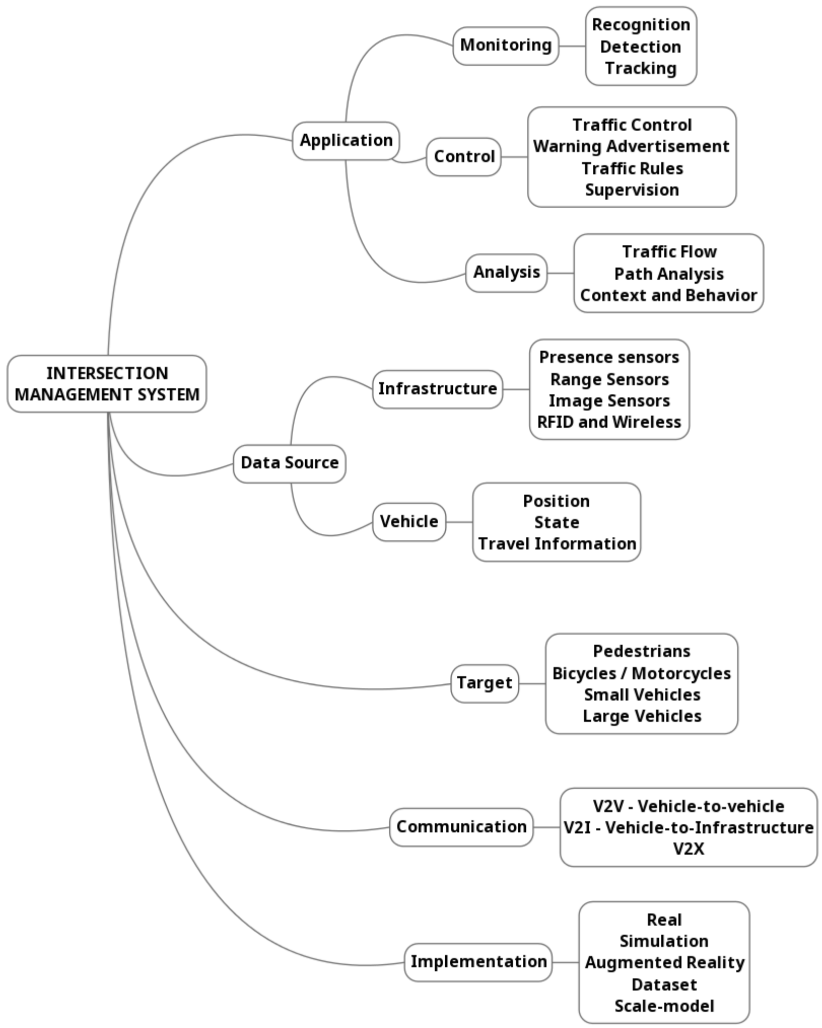

Figure 1.6: Components of an Intersection Management System application.

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.

1.2.2 Developments in Intersection Management Systems

In the table 1.4 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**
[35, 36]	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

Reference	Comment	Application	Data Source	Communication
[62]	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
[63]	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
[53]	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
[21]	Development of a simulator for an Intersection Collision Warning System. Physical and MAC layers were modeled	Intersection collision warning simulator	N/A	V2V
[17]	Traffic monitoring for two context: Left-Turn-Across-Path-Opposite-Direction and Dilemma zone and red light violation	Intersection Monitoring	Radar	N/A
[4]	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

Reference	Comment	Application	Data Source	Communication
[16]	Analysis of Left-Turn-Across-Path-Opossite-Direction conflict situation.	Intersection Monitoring	Radar; Steering, speed sensors and GPS on-board	V2X
[6]	Based on [21], this works includes and improvement, including network layer and driver behaviour model.	Intersection Simulator Architecture	N/A	V2X
[64]	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
[70]	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
[23]	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
[40]	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

Reference	Comment	Application	Data Source	Communication
[22]	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
[33]	Based on [21] and [6], 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
[68]	Based on [70], 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
[56]	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
[54]	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

Reference	**Comment**	**Application**	**Data Source**	**Communication**
[67]	Based on [68], 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
[8]	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
[47]	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
[55]	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
[10]	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

Reference	Comment	Application	Data Source	Communication
[9]	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
[12]	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
[7]	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
[19]	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
[69]	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 ([67]) to get better results at tracking.	Object detection and tracking	Lasers	N/A

Reference	Comment	Application	Data Source	Communication
[34]	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
[48]	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
[29]	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
[28]	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
[30]	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
[50]	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

Reference	Comment	Application	Data Source	Communication
[5]	On top of AIM ([22]) 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 1.4: Developments related to Intersection Management Systems.

1.3 Sensor Fusion in Intersection Management

Cameras are a wide used sensors for surveillance and monitoring applications because they provide a lot of information for scene understanding, but the transmitting and processing of such information requires high computational resources. For this reason low resolution cameras and low frame rates configurations are commonly deployed. On the other hand, range sensor, such as lasers and lidars, have been recently included in Intersection management systems, as unique sensors or with cameras too. One of the benefits of range sensors is that because of information volume is less than provided by cameras, its processing requirements are lower. Using both cameras and range sensors for intersection management systems makes it possible to take advantages of each type of sensor, and obtain a better representation of the environment.

Although many works based on cameras are found, there are two main developments that make use of range sensors along cameras to implement an IMS. The first one, developed by POSS research group at Peking University[1], is the POSSi project, for which main objective is monitoring a dynamic environment through fusion of laser and video. In this project, a set of laser scanners are deployed on corners of an intersection and a camera is installed over a pedestrian bridge. They perform a fusion over laser data and after detection and recognition of vehicles and pedstrians, this info is backprojected on video stream.

The second relevant project, Ko-PER project[2], was developed by the Institute of Measurement, Control and Microtechnology at Ulm University under Ko-FAS research initiative. Ko-PER project aims to capture a complete picture of the local traffic environment. In order to do so, a full deployment of

[1] http://www.poss.pku.edu.cn/index.html
[2] http://ko-fas.de/english/ko-per—cooperative-perception.html

Project	Sensors	Target	Fusion	Framework
POSSi [70]	Laser	Vehicles, pedestrians	-	No
POSSi [59]	Lasers	Pedestrians	Low-Level	No
POSSi [68]	Lasers	Vehicles, pedestrians	Low-Level	No
POSSi [67]	Lasers, Camera	Vehicles, pedestrians	Low-Level, High-Level	No
POSSi [69]	Lasers	Vehicles, pedestrians	Low-Level	No
Ko-PER [29]	Lasers, Cameras	Vehicles, pedestrians	Low-Level, Mid-Level	No
Ko-PER [48]	Lasers	Pedestrians	Low-Level	No
Ko-PER [49]	Lasers	Vehicles, pedestrians	Low-Level	No
Ko-PER [52, 50]	Lasers, Cameras	Vehicles, pedestrians	Low-Level, Mid-Level	No
Ko-PER [60]	Cameras	Vehicles	Low-Level	No
Ko-PER [51]	Lasers, Cameras	Vehicles, pedestrians	Low-Level, Mid-Level	No
Proposed work	**Lasers, Cameras**	**Vehicles**	**Low-Level, Mid-Level, High-Level**	**Yes**

Table 1.5: Summary of recent developments involving sensor fusion for Intersection Management Systems

infrastructure was made, using 14 laserscanners, 10 cameras, a GPS and a V2I communication unit. Also, they perform a low-level fusion over same type sensor first, and then they merge outputs of each subsystem for improve detection and analysis results.

In the proposed work, there is not a deployment of sensors in an intersection scenario, but datasets will be used instead for validations purposes. Also, one of the objectives is to explore and propose a modular fusion architecture/framework for IMS based on cameras and laser sensors. In table 1.5 a summary of aforementioned developments is presented, including proposed work.

1.4 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 for 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 with 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, and a review of developments in Intersection Management Systems is presented.

Chapter 2

Architecture Description and System Specification

"Perfect is enemy of good"

Voltaire

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 manufacturing and computing capabilities. Such enhancements allows to deploy more of those types of sensors per scenario and it is required to define some processing stages from raw data capture through decision and control stages. It is also needed to test and validate the developments prior to a real and full functional implementation. The first part of this chapter describes the main stages in a intersection management system, from data preprocessing to situation assesment. Then, two validation tools for IMS applications are described, simulation models and datasets. And finally, the proposed architecture for the implementation of an IMS system is presented.

2.1 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, detect with more accuracy the objects in the intersection, and prevent possible incidents. For designing a single-sensor or multi-sensor IMS, 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 which is the better fusion approach to use and in which of the processing stages this fusion should be performed, in order to get better results than a single-sensor based system.

2.1.1 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: preprocessing, feature analysis, pattern recognition and situation assessment. The aim of the first stage is to extract data of interest from the raw sensor information, using filtering to remove noise and irrelevant data, and background subtraction techniques to get the foreground of the scene. Spatial-temporal alignment of data is also performed in this stage. 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 situations or events of interest. This output could be delivered to an automated or semi-automated stage of decision and control, to a human operator, or to a traffic agent or institution, to take immediate actions on traffic control, issue traffic tickets, warn drivers about possible incidents or improve transportation policies in a long-term basis. In figure 2.1, previously described stages are depicted, including a list of common tasks performed at each of these stages.

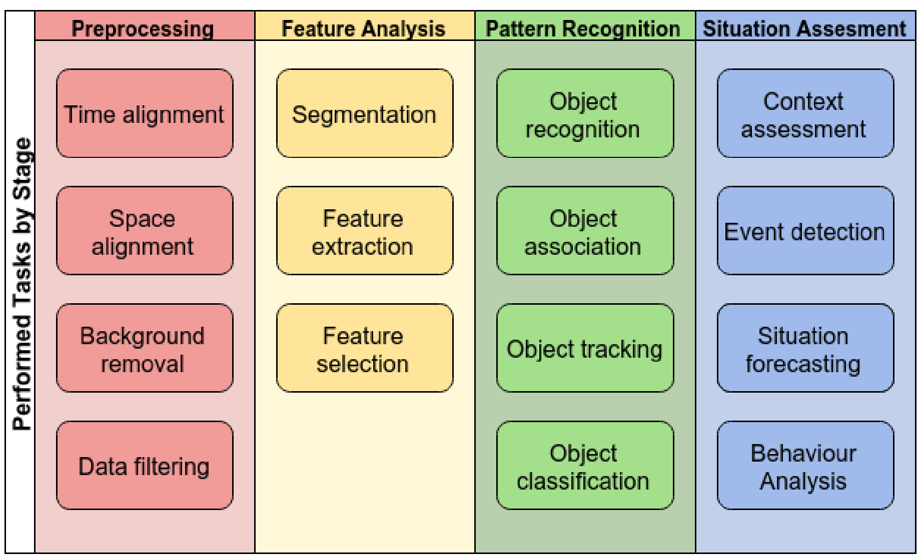

Figure 2.1: Processing stages in an IMS and commonly performed tasks within each of them

2.1.2 Fusion approaches

Depending on wheter the system has multiple sensors of the same type or different type, a data fusion approach should be chosen. When data came from same-type sensors, it is usually fused at low levels using techniques for temporal-spatial alignment, depending on sensors configuration. This is the case for a network of lasers or lidars or for multi-camera systems. If the system have different type of sensors, data from them may be fused at mid level, based on extracted features or classes on each subsystem; or may be fused at high level if each subsystem delivers control or decision outputs. The tasks shown in each of the processing stages (Figure 2.1), could be used as fusion blocks for homogeneous or heterogeneous data.

2.2 Validation approaches

Before deploying an IMS, it is needed to test some of its components and validate their results. Two commonly used tools for this purpose are traffic simulation models and datasets, depending on the component to be tested. Below, a description of each one is presented.

2.2.1 Transportation and Traffic Simulation

Transportation is a highly complex activity where different elements, like infrastructure, vehicles and pedestrians, affect efficiency, safety and quality of traffic. Intersections are special cases because there exists a high interaction between those mentioned elements making of these places critical points for mobility. For this reason, it is needed to have traffic models to allow the simulation of new policies or deployments intended to enhance transportation.

Three widely-known models for this kind of analysis are macroscopic model, microscopic model and mesoscopic model. The macroscopic model of traffic flow is based on a hydrodynamic analogy, modeling traffic as a fluid process characterized by three main variables, density, volume and speed, and the objective is to describe time-space evolution of those variables. The microscopic model aims to detail at a high detail inter-vehicles interactions and their individual state. For example, in a lane-change maneuver the state of the car doing the action and those affected by it, is individually tracked. The mesoscopic model tries to include features of both macroscopic and mesoscopic model. In this case, the same lane-change maneuver could be seen as an instant action triggered by lane density rather than on individual interactions.

A more detailed analysis of traffic simulation models and simulation platforms could be found in [2, 11, 38, 41]

2.2.2 Intersection monitoring Datasets

As mentioned in section 1.3, POSS-i [1] and Ko-PER [2] projects are leading the development of multisensor Intersection Management Systems. One of the contributions of these projects is the creation of datasets of such systems. They

[1] Available at http://www.poss.pku.edu.cn/download.html
[2] Available at http://www.uni-ulm.de/in/mrm/forschung/datensaetze.html

provide camera and laser information of a monitored intersection in Peking, China and Aschaffenburg, Germany, respectively.

2.3 Architecture proposal

The proposal presented in this work is based on MFI model processing entities in the sense that a processing block could take one or more inputs related between them and generate an output of the same type or a higher level output, that means that some blocks perform fusion while others just do some processing on incoming data. The communication or data exchange approach is based on JDL model, in which data is available over a "bus", where the processing blocks can write to or read from. And an information model is defined for abstract the elements of the scene, set a format for message exchange and define global and local configuration parameters. A general block diagram is shown in figure 2.2.

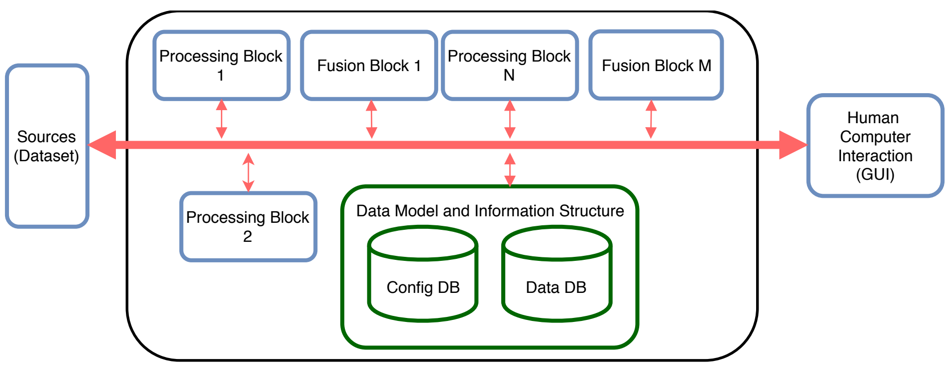

Figure 2.2: General overview of proposed architecture and its components. Red for the communication scheme, green for data model and blue for processing blocks

As the implementation of a full Intersection Management System is a joint effort among different fields of engineering (Hardware, software, IT, civl) and even non-engineering areas, The two main features chosen for this proposal are scalability and modularity. Scalability is desired in the cases where an initial deployment needs to expand or increase its complexity in any of its areas, for example, new communication approaches, add new sensors or hardware, develop new features or policies, etc. Modularity allows that the internal blocks of system could be modified, exchanged or enhanced without disturbing the overall function of the deployment. This criteria is achieved with the four proposed elements of this architecture: communication scheme, data model, information structure and processing blocks.

2.3.1 Communication scheme

In order to isolate the processing tasks of the communication system, a Publisher-Subscriber approach is selected. The benefits of this option is that data can be shared between diferent blocks without generating a dependency from publishers to subscribers. Another benefit is that exposing a defined mechanism for publishing or subscribing, allows the system to be implementation agnostic.

Taking these reasons into account, Redis is chosen as communication platform. As stated in their website, "Redis is an open source (BSD licensed), in-memory data structure store, used as a database, cache and message broker"[57] which support Publisher-Subscriber paradigm, allowing greater scalability and a more dynamic network topology.

For publishers and subscribers to exchange messages, channels are defined with labels using a namespace approach that describe the source of data and the kind of data. For example a channel containing raw data from a laser scanner could be labeled as `/sensors/range/laser_1/data/raw`.

Redis is also used as in-memory storage for configuration data that is not part of the processing flow, like sensor parameters, intersection model and control options. This information is loaded into Redis from a configuration file formatted using JavaScript Object Notation (JSON), and once loaded in Redis, it is available for any client requiring it.

2.3.2 Data Model

The data model proposed for the system includes the abstraction of the sensing elements and the intersection model. For the sensing elements, a Sensor base class and two derived classes, RangeSensor class and ImageSensor class, are defined.

The intersection has been modeled as a class with attributes like a label, a Map object, a set of RangeSensors and CameraSensors objects, a set of Leg objects, and a set of Area objects, for inner areas of the intersection. The Map class contains information about the geometry of the intersection and the coordinate system, including a image intended for visualization of configuration and processing.

The sensors sets are composed of zero or more sensor objects, as defined previously. An Area class is defined as having a bounding box and a label. From this class, a derived class, Leg, is defined for containing additional information about the legs of the intersection, such as heading of the leg, approaching or departure type. In figure 2.3 is shown an UML diagram for the aforementioned classes and their relationships

The purpose of all the labels attributes within each class is to serve as an identifier of the channel in which the entity is publishing or subscribing to; in other words, to identify where data is generated from or where data is going to. For example, channel `/sensors/range/laser_1/data/raw` contains raw data from a laser scanner labeled as `"laser_1"` and `/legs/leg_3/occupancy/` refers to the occupancy level of the leg labeled as `leg_3`.

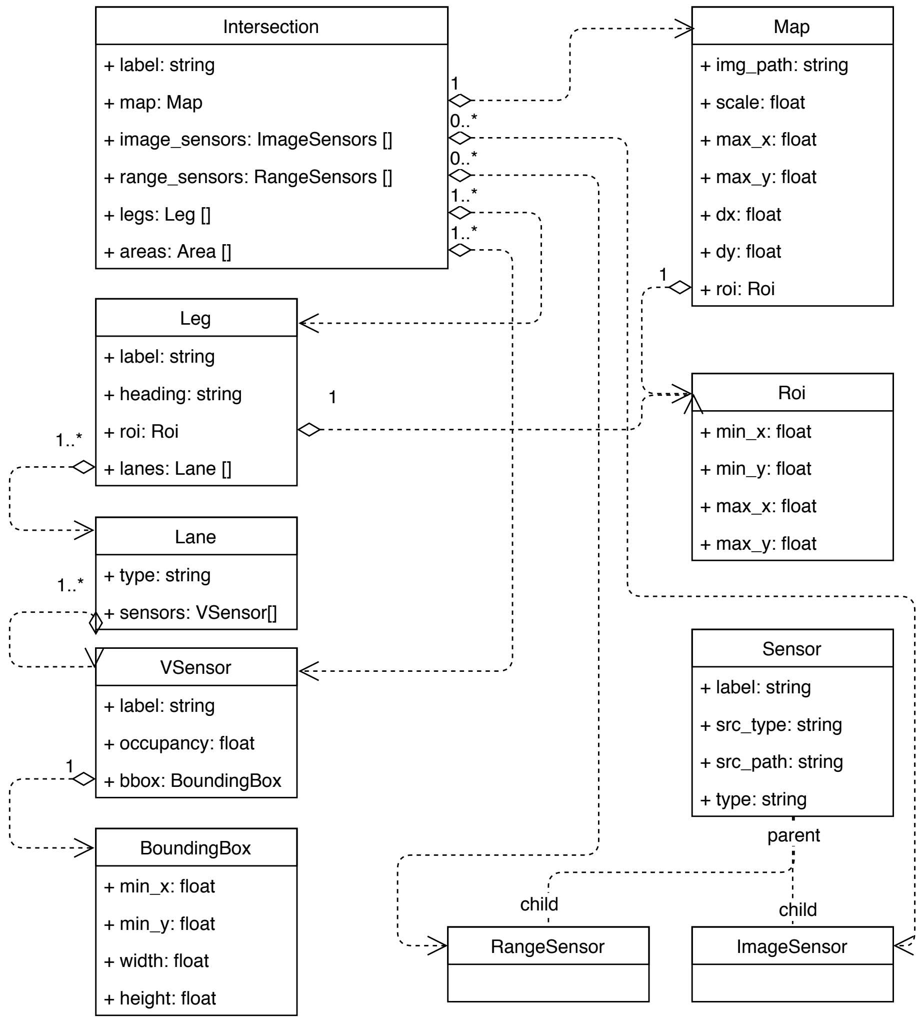

Figure 2.3: UML diagram of defined entities and their relationships

2.3.3 Information Structure

Data exchanged between processing blocks or any paramater stored in Redis, is formatted using JSON, allowing to use any JSON parser/formatter available in different languages. In addition, it is possible to create simple scripts to interact with the system. Below are described the two types of data used by the systems: the .imscfg file and the messages and configuration parameters.

.imscfg file

For running, the systems requires first a .imscfg file which describes the scenario and the sensors configuration. This information is stored as a JSON object with the properties decribed in table 2.1.

Property	Description
name	Name of the configuration
map	Information of the scene, including map, coordinate system and region of interest.
cameras	List of camera sensors information
range_sensors	List of range sensors information
legs	List of legs information
intersection	Information of area of the intersection

Table 2.1: Properties in .imscfg JSON file

data messages and configuration parameters

In addition to .imscfg file, there are different types of messages and parameters which have its own structure, for example used for sensors configuration or processed data. The table 2.2 gives a description of the types of information used.

2.3.4 Processing Blocks

As stated in previous section, there are defined four stages in the processing flow, namely, preprocessing, feature analysis, pattern recognition and situation assessment. Within each of these stages there are different methods and techniques used to process the data and it is possible that those methods are suitable to perform fusion between homogeneous or heterogeneous data.

Below are detailed different processing blocks implemented as part of the whole architecture proposal, classified by the stage of processing in which are located in the process flow. Also, it is shown the format of data input, data output and parameters needed for configuration and execution.

Additionaly, there are included some tools and generic blocks used for dataset reading, data visualization and interactive control.

Preprocessing

laser_background_remove

This block takes as input a message of type laser_pol_msg, which contains raw readings from laser sensor. Also, it takes a laser_cfg parameter which includes a background model for the laser sensor, generated from a set of scans and taking the maximum measurement in each angle of scanning, defined as follows:

Name	Description
laser_pol_msg	Contains a timestamp, an array of N angles and and array of N measurements
laser_cart_msg	Contains a timestamp, an array of N (x, y) coordinates
laser_cfg	Contains position and orientation information, also has a background model for the laser sensor
occgrid_msg	Contains a timestamp and an occupancy grid in the form of an MxN array
occgrid_cfg	Contains occupancy grid configuration for the scene
clusters_msg	Contains a set of clusters, each of them with an ID and a set of points
clusters_cfg	Contains configuration about clustering algorithm and parameters
camera_msg	Frames generated by camera
camera_cfg	Information and parameters of the camera sensor
blobs_msg	Bounding boxes detected as objects within a frame from the camera
blobs_cfg	Parameters used by the image detection process
vs_occ_msg	Indicates the occupancy level of a virtual sensor, representing the entrace to or exit from the intersection
vs_merge_cfg	Parameters for configuring the merging process of different vs_occ_ms messages.
flow_rate_msg	Indicates the flow rate entering or exiting the intersection
flow_cfg	Parameters for estimation of the flow rate, flow status and flow merging configuration
flow_status_msg	Indicates the flow status of an entrance or exit at intersection. This is a binary value, with value either "Traffic flowing" or "Traffic stopped".

Table 2.2: Description of diferent types of messages and parameters used

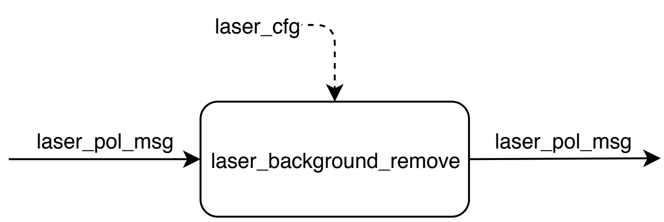

Figure 2.4: laser_bg_remove

Let suppose we have N scans from the laser and $d_{\theta i}$ be the distance measure at angle θ in scan i. Thus, the background value for that angle θ is $bg_\theta = max(\{d_{\theta i} | 1 < i < N\})$ and the background model is $bg = \{bg_\theta | \theta \in \Theta\}$ where Θ is the set of angles of scanning, in this case from -90°to 90°with 0.5°step.

laser_polar2cart

This block takes as input a message of type laser_pol_msg for converting it into cartesian coordinates referenced to global system. For this reason,

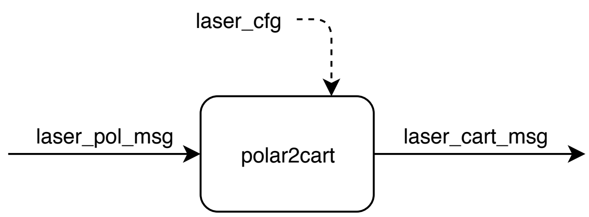

Figure 2.5: polar_to_cartesian

it also takes a laser_cfg parameter to include laser position information in the conversion. Output message contains a set of x, y points, referenced to a global coordinate system. This output is obtained from the following equations:

$$
\begin{aligned}
O_x &= I_\rho * \cos\phi + S_x \\
O_y &= I_\rho * \sin\phi + S_y \\
\phi &= I_\theta + S_\theta
\end{aligned}
$$

Where:

(S_x, S_y, S_θ): Position and orientation of the laser
(I_ρ, I_θ): Input message (distance and angle arrays)
(O_x, O_y): Output message (x and y arrays)

laser_cart_merge

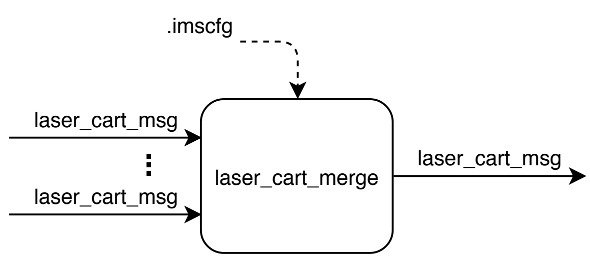

Figure 2.6: laser_cart_merge

This block takes as input messages of type laser_cart_msg coming from different sensors and merges them into a single message, based on a sampling period T. The objective of this stage is to set a common time-frame and synchronize all the messages to feed to the next blocks.

Feature Analysis

points_to_cluster

The input message for this block is a set of points corresponding to objects scanned by lasers. Clustering is performed over this input to identify the points belonging to the same object. The algorithm used in this implementation is DBSCAN, which stands for Density-Based Spatial Clustering of Applications with Noise. This algorithm does not need an estimated number of clusters as input, instead of this, it requires only two parameters: a minimum number of points per cluster, m, and a neighbourhood measure, ϵ. A detailed description of the algorithm, can be found in [27].

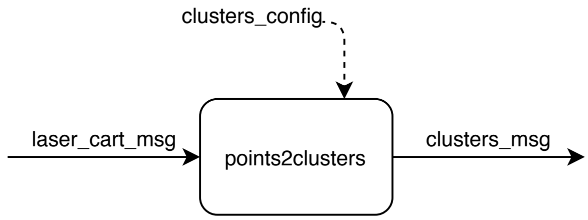

Figure 2.7: points_to_clusters

The input message for this block is a set of points corresponding to objects scanned by lasers. Clustering is performed over this input to identify the points belonging to the same object. The algorithm used in this implementation is DBSCAN, which stands for Density-Based Spatial Clustering of Applications with Noise. This algorithm does not need an estimated number of clusters as input, instead of this, it requires only two parameters: a minimum number of points per cluster, m, and a neighbourhood measure, ϵ. A detailed description of the algorithm, can be found in [27].

As output, a message of type clustering_msg, containing information like clusters ID and set of points belonging to each cluster, is delivered.

points_to_occgrid

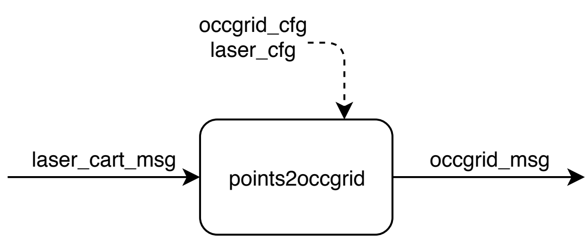

Figure 2.8: points_to_grid

This block generates a occupancy grid based on cartesian data from laser sensors. The cartesian data received from sensors is merged in a timeslot basis, filling a buffer for each sensor and processing available data using a defined period T_{om}. As parameters, this block receives a cell size for the grid, the laser sensors configuration and the scene configuration. The grid size is of N_C Columns and N_R rows, obtained as follows:

$$\begin{aligned} X &= x_{max} - x_{min} \\ Y &= y_{max} - y_{min} \\ N_C &= ceil(X/C) + 1 \\ N_R &= ceil(Y/C) + 1 \end{aligned}$$

Where (x_{min}, y_{min}) and (x_{max}, y_{max}) are the bottom-left and top-right coordinates of the region of interest in the scene, respectively.

Each cell of the grid will store a value indicating a probability of that cell being occupied. Initially, all cells have a value of 0.5. In order, to update the grid using data from laser, the points corresponding to laser position and measures, should be located in a cell of the grid, and then mark it as occupied. The following equations show how a point $P = (P_x, P_y)$ is tranformed to a cell C_{ij}, where i is the column and j is the row in the grid:

$$\begin{aligned} i &= ceil((P_x - x_{min})/C - 0.5) \\ j &= N_R - ceil((P_y - y_{min})/C - 0.5) \end{aligned}$$

Then, the cells that form a straigh line between the cell of laser position and the cells of each laser measure, should be marked as empty. To get the list of these cells Bresenham's algorithm is used. This algorithm is widely used in computer graphics due to it simplicity and because it uses integer arithmetics, making it computationally cheap. The input of this algorithm is a pair of coordinates, the endpoints of the line, and as result, the set of points that completes the line between, is returned.

As the output, this block generates an occupancy grid of the scene, which is published at a rate defined by the previous period T_{om}.

camera_blobs

The purpose of this block is to detect the vehicles from the streaming of video from a camera. To accomplish this task, the YOLOv3 detection system [58] was wraped into a block. The algorithm used by this detector, applies a single neural network to the full image. This network divides the image into regions and predicts bounding boxes and probabilities for each

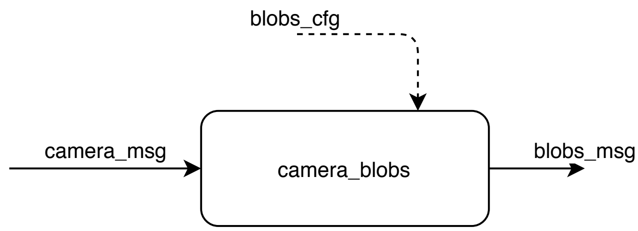

Figure 2.9: camera_blobs

region. These bounding boxes are weighted by the predicted probabilities. The output of this block, are the bounding boxes with high probabilty of being a vehicle.

camera_blobs2occgrid

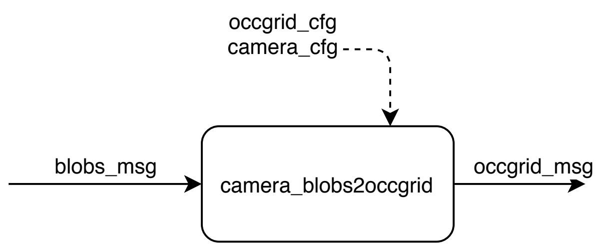

Figure 2.10: camera_blobs2occgrid

This block receives bounding boxes corresponding to vehicles and transform them from image coordinate system to the global reference system, Then, it maps the area covered by the boxes into an occupancuy grid in order to mark those cells as occupied in the same fashion as described for the block "points_to_occgrid" 2.8.

Pattern Recognition

virtual_sensor_occupancy

This block accepts different types of inputs, cluster_msg and occgrid_msg. It process the incoming data, and generate bounding boxes based on the clusters or based on the occupancy grid, according to the input. Having these bounding boxes, which represent detected vehicles, scene configuration data is loaded and the geometric parameters of the legs and lanes are used to generate virtual sensors at the entry and exit points of the intersection and check the overlaping of detected vehicles with aforemetioned virtual sensors. The output generated by this block is the occupancy percentage of the virtual sensor, represented as a message of type vs_occ_msg.

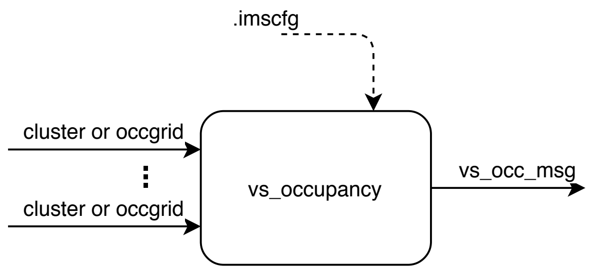

Figure 2.11: Virtual_sensor_occupancy

virtual_sensor_merge This block is intended to take as inputs different messages of type vs_occ_msg and merging them to increase the reliabilty of detection. First, a moving average is calculated over each input to reduce the effect of false positives or false negatives in a single frame. After this, the inputs are merged by a defined method like average, weighted average, maximum or minimum. Then, a new vs_occ_msg message is dispatched as output.

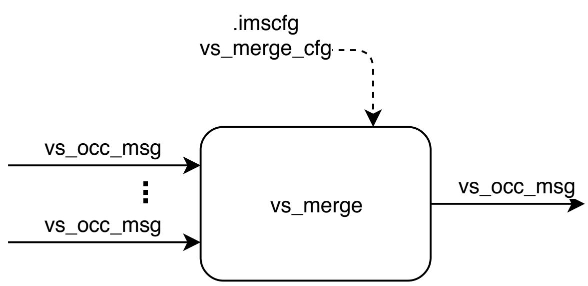

Figure 2.12: virtual_sensor_merge

Situation Assesment

virtual_sensor_to_flow_rate

When a message of type vs_occ_msg arrives, it is evaluated using a threshold vo_{th}, if the occupancy percentage of a virtual sensor is greater than vo_{th}, it is considered that there is a vehicle over the sensor in that frame, this is defined as occupied state. This detection is made in a frame basis, thus, a vehicle counter v_{cnt} is incremented by one when a transition from occupied state to empty state is detected in a new frame.

Then, a time interval t_c is defined for calculating the flow rate v_r. Defined as the number of transitions during that interval divided by t_c. The output message type is flow_rate_msg.

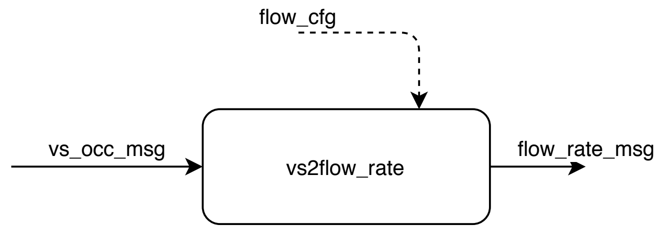

Figure 2.13: virtual_sensor_to_flow_rate

flow_rate_to_flow_status

This block process one or more inputs of type flow_rate_msg. If there are more than one input, it merges them using defined policy, like average or maximum. Then, if the flow rate v_r is above a flow threshold f_{th}, it is considered that the traffic is flowing. Otherwise, traffic is considered stopped.

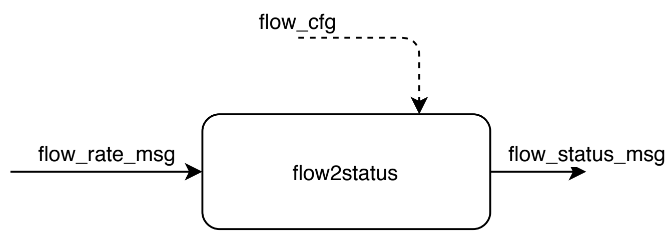

Figure 2.14: flow_rate_to_flow_status

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Tools and Utilities

laser_publisher

These blocks are intended to read dataset files containing the information from the sensors and publish this data with the appropriate format and preserving the original rate of the sensors, if needed.

data_viewer

The objective of this block is to allow the visualisation of the data in any of the processing stages. It has the option to display and XY coordinate system, an occupancy grid or a map of the intersection overlaped with detections or metrics.

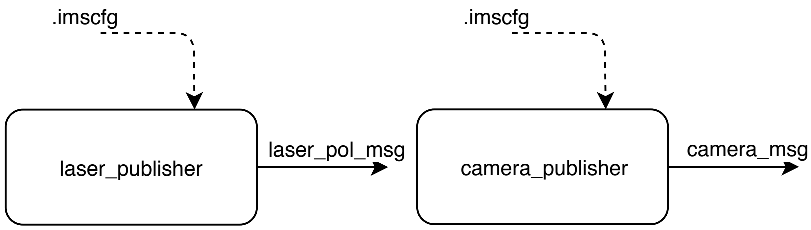


Figure 2.15: laser_publisher and camera_publisher

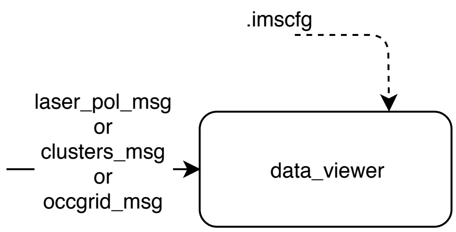


Figure 2.16: data_viewer

2.4 Conclusions

A whole intersection management system contains many different components, for example the instrumentation of the junction, the handling of data and information, the control policies and requirements, and the interaction between those elements. None of these items is more relevant than the others and it is for this reason that each one of them should be well conceived having in mind a common framework that allows their scalability, modularity and reliability. When these three features are accomplished, a change or an upgrade of any part of the system will not affect the remaining ones.

It is also important that an Intersection Management System should be flexible, not tied to one deployment or scenario, but also that allows to perform tests over new datasets or junctions, at no extra cost or just with some configuration adjustments. Although it is hard to have a one-rules-them-all system due to the variety of intersections (crossroads with different numbers of legs, roundabouts, T-shaped, Y-shaped, etc.), there are common needs, features and requirements that makes relevant to use an interesection management system looking forward to monitor, control and improve safety and efficiency in transportation.

Chapter 3

Deployment and Results

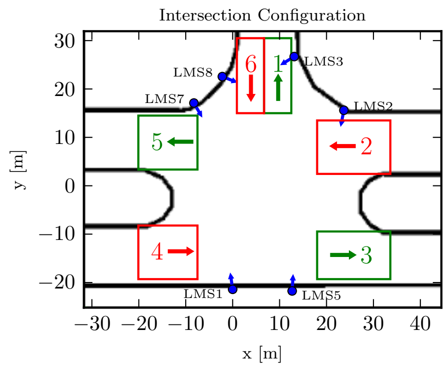
> ”Testing leads to failure, and
> failure leads to understanding”
>
> Burt Rutan

In this chapter is presented the experimental setup used to deploy and test the proposed architecture. First is described the data and hardware and software specifications. Then, two implemented configurations of the system are presented. Finally, results are summarized and analysed, comparing both configurations and different fusion approaches.

3.1 Experimental Setup

The selected dataset for testing the system is the one from POSSi project (section 2.2.2). It contains 6 laser-scanners raw readings and a video from a camera located over the intersection. Figure 3.1a depicts the configuration used by this dataset and the data from each type of sensors, laser scanners and camera. The ground truth data used for validation is the vehicle count over 3 of the 5 legs of the intersection, taking into account the time at which a vehicle appears. This groundtruth data was generated manually.

The platform used for the implementation is a laptop ASUS GL552VW, with 8GB RAM DDR4, a processor Intel Core i7 6700HQ @ 2.60GHz x 8 cores and graphic card Nvidia GeForce GTX 960M. The operating systems running on it is Ubuntu 16.04 LTS. The software was developed using primarily Python3 and C++ as programming languages. Used libraries are MatplotLib, Scikit, Numpy, OpenCV, and darknet for data processing and visualisation. For communication scheme redis was installed along some JSON parsers for formatting.



(a) Global configuration

(b) Overview of sensors data. Left: Laser scanners, Right: Camera.

Figure 3.1: Possi dataset configuration.

Proc. Stage	Block ID	Name
Data feeding	A	camera_publisher
	B	laser_publisher
Preprocessing	C	laser_bg_remover
	D	laser_pol2cart
	E	laser_cart_merge
Feature analysis	F	points2clusters
	G	points2occgrid
	H	camera_blobs
	I	camera_blobs2occgrid
Pattern recognition	J	virtual_sensor_occupancy
	K	virtual_sensor_merge
Situation Assesment	L	virtual_sensor_to_flow_rate
	M	flow_rate_to_flow_status

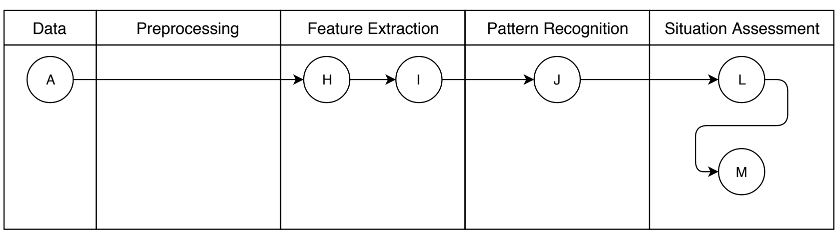
Table 3.1: Description of processing blocks used in test configurations

3.2 Test Configurations

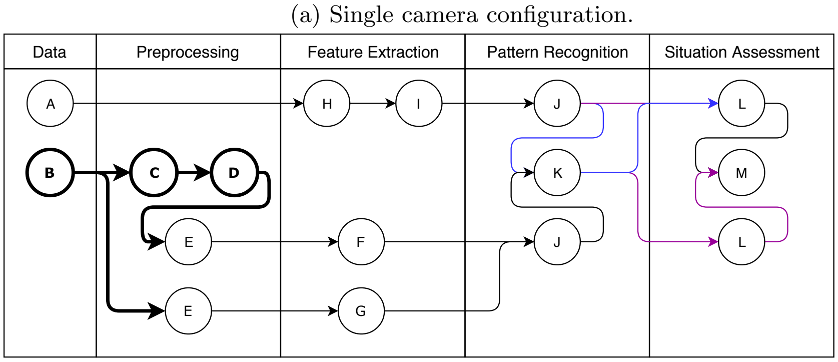
In order to test the proposed architecture, two different configurations have been selected. The first configuration is using just the camera information. The second configuration is based on multiple laser sensors along with the camera.

Each configuration consists of a set of processing blocks (as described in section 2.3.4) connected, aiming to take data from lasers and cameras, to produce an output of higher level. In this case, the binary status of a leg (traffic flowing, traffic stopped) is the output used for evaluation, derived from the vehicle count.

The table 3.1 lists all used blocks and assigns an ID for each one. Those IDs are used in the graph description in its own section. Also, bold nodes and connections indicate multiple instance of the same element. The figure 3.2 shows the configuration used for processing just video data the configuration when a set of lasers is added to the previous configuration. The blue line represents the fusion at node K, which is fusion on virtual sensors level (Mid-level fusion). The purple line represents the fusion at flow rate level (High-level fusion).



(a) Single camera configuration.



(b) Multiple lasers and camera configuration.

Figure 3.2: Test configurations.

As this is a binary classification system, the evaluation metrics used for these implementations, derived from the obtained confusion matrices, are Accuracy and True Positive Rate (TPR).

3.3 Results

3.3.1 Case 1: Single camera

As stated before, the flow status is used for comparing the system with the ground truth. This status is derived from the flow rate in vehicles per second. If this value is greater than a defined threshold, it is considerded to be in "traffic flowing" status.

As result of the first stages of processing, vehicle detection in three diferent frames are shown in figure 3.3. This is a representation of the output from node H, camera_blobs.

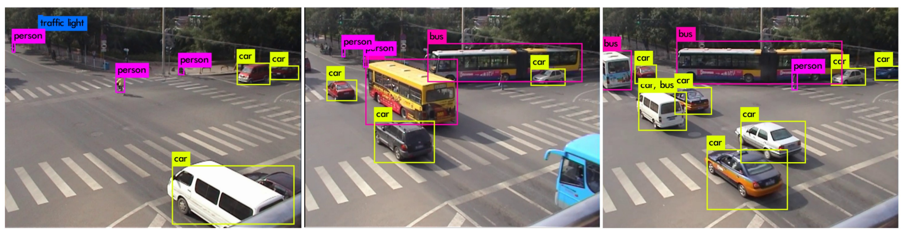


Figure 3.3: Vehicle detection using camera

In the figure 3.4 is shown the comparison between the flow profile obtained from the system and the generated by the ground truth. There is also remarked one of the intervals where the output is "traffic flowing". After evaluating the performance of the system in a frame basis, a confusion matrix is obtained (table 3.2), here F denotes the state "traffic Flowing" and S denotes "traffic Stopped" and we get an accuracy of 91.82% and a TPR (True Positive Rate) of 55.70%.

		Outcome		
		F	**S**	**total**
Actual value	F'	694	552	1246
	S'	26	5791	5817
	total	720	6343	

Table 3.2: Confusion matrix of the system based on video

3.3.2 Case 2: Camera and multiple lasers

In this test case, the information from the laser scanners is used with the purpose of increase the performance of the system. This required just to include the

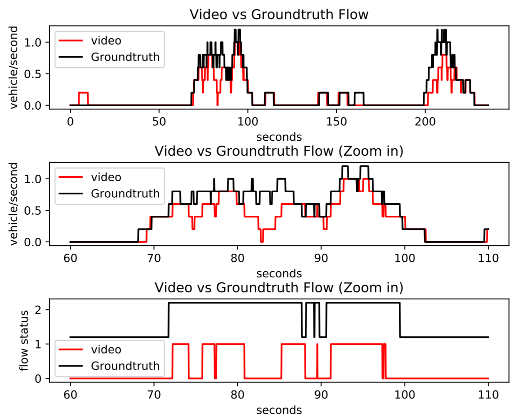


Figure 3.4: Results for the single camera implementation in one of the legs of the intersection

appropiate nodes for laser data processing, and replace some nodes from the video processing graph to allow data fusion from laser and cameras. An example of vehicle detection based on laser scanners is shown in figure 3.5. This is the output of the node F, points2clusters.

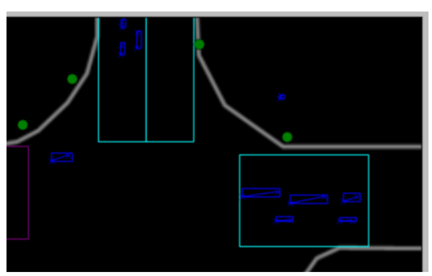


Figure 3.5: Vehicle detection using laser scanners

For merging information from laser and cameras, it was decided to perform the fusion at two levels, at the virtual sensor occupancy level and at the flow rate level. Both of these approaches were implemented using average and maximum policies. In the figure 3.6 is depicted the flow rate output for all of four configurations.

Performing the same frame-based analysis as for the video system, we obtain the confusion matrices presented in figure 3.7. It is noted that performing the fusion at virtual sensor occupancy level, the accuracy of the systems has almost no change, 92.2% and 91.48% for average and maximum policies respectively. For the TPR, there is a significative increase, having 88.12% and 63.56%, also for average and maximum policies.

When the fusion is performed at flow rate level using average policy, the accuracy and TPR values are reduced to 84.45% and 12.92%. Using maximum policy, there is a small decrement in the values, with an accuracy of 89.76% and a TPR of 57.46%. A summary of the results obtained on both test cases is presented in table 3.3.

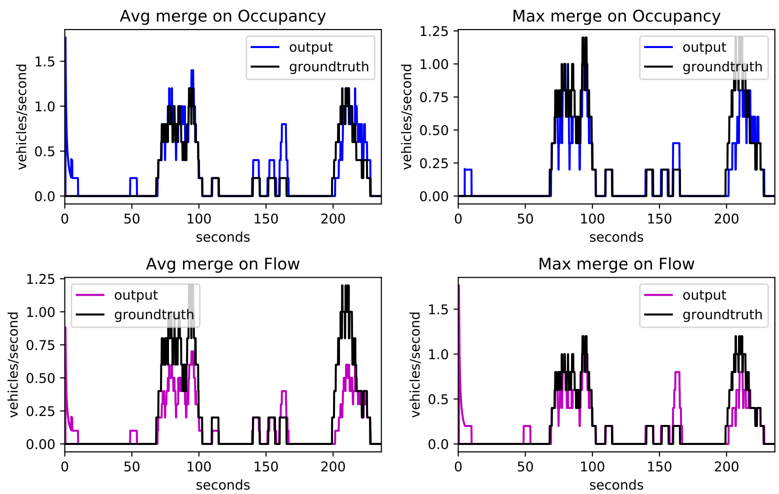


Figure 3.6: Results for the multisensor implementation using four different fusion approaches

Test Case	Sensors	Fusion Aproaches	Accuracy	TPR
Case 1	Camera	NA	91.82%	55.7%
Case 2	Camera + Lasers	Low-level, Mid-level (avg)	92.2%	88.12%
Case 2	Camera + Lasers	Low-level, Mid-level (max)	91.48%	63.56%
Case 2	Camera + Lasers	Low-level, High-level (avg)	84.45%	12.92%
Case 2	Camera + Lasers	Low-level, High-level (max)	89.76%	57.46%

Table 3.3: Summary of results

3.4 Conclusions

An intersection management system is a complex set of subsystems, and for a feasible implementation and deployment as a real solution it is needed for it to be easily tested, adapted and enhanced. In this case, after having a well-concieved block design, it was relatively straight forward to start building a video based system for getting an indicator about traffic flow in an intersection using a dataset.

For stakeholders of the system outcome, high level indicators are desired, like traffic status, no matter which low-level hardware or software are used.

Outcome (avg vs_occ)

Actual value	F	S	total
F′	1098	148	1246
S′	403	5414	5817
total	1501	5562	

Outcome (avg flow)

Actual value	F	S	total
F′	161	1085	1246
S′	13	5804	5817
total	174	6889	

Outcome (max vs_occ)

Actual value	F	S	total
F′	792	454	1246
S′	148	5669	5817
total	940	6123	

Outcome (max flow)

Actual value	F	S	total
F′	716	530	1246
S′	193	5624	5817
total	909	6154	

Figure 3.7: Fusion configurations: top-left, Average on virtual sensor occupancy. Bottom-left, Maximum on virtual sensor occupancy. Top-right, Average on flow rate. Bottom-right, Maximum on flow rate

For this reason, modularity and definitions on data and messages types, allow development of new features without compromising the integrity of the system. Also, new sources of information and data could be easily integrated if the processing of them is made according to the definitions. In that way, it was possible to integrate laser scanner data provided by the dataset, taking into account to generate outputs already defined by the messages specification.

For different sources of information it is not enough to perform a fusion strategy to obtain better results. It is needed to analyse the type of data and the level at which fusion should be performed. Also, it is important to understand if the fusion is competitive, complementary or cooperative, in order to select the appropiate strategy and increase the performance of the system. An example of this was demonstrated when fusing data from camera and lasers at two different levels and using different strategies. It was clear from the results (table 3.3) that altough the data was the same, one configuration increased the performace while another one decrease it.

Chapter 4

Conclusions

> ”If you can’t explain it simply, you don’t understand it well enough”
>
> Albert Einstein

The inclusion of information and communication technologies in transportation systems have been rapidly increasing during the last years, making it possible to test and deploy novel solutions to address issues like safety, congestion, rules violation and many other concerns that affect the quality of transportation.

Intersection monitoring is an active need in the purpose of improve traffic performance, and the option to measure its current state in an automated and intelligent way, is of great interest for local authorities and governments in order to develop policies and control schemes on short, mid or long-term basis.

When deploying a system for intersection monitoring, it is desirable to have variety of sensors, because this allows to have more complementary information in order to generate an accurate representation of the intersection. But more important than the quantity of sensors, is how the data for all installed sensors will be processed and unified.

For this reason, data fusion techniques are in constant development. Algorithms that were not feasible to use some years ago, are now being deployed thanks to improvements on computational capabilities, storage resources and communications systems.

Before deploying an interesection management system in a real scenario, validation is a must. Datasets are the best option for doing it, because simulators are still in an early stage. The most suitable simulators, although not conceived for this purpose, are the ones used for autonomous driving platforms. These simulators could allow to include complex sensors like lidars and cameras on infrastructure, and include vehicles with autonomous behaviour in the scenario.

4.1 Contributions

The main contribution derived from the execution of this project is a scalable, modular system for traffic monitoring at an intersection. This system was concieved for usage both in experimentation cases and real deployments. The software implementation of the system uses at its core a set of tools and libraries ready for industrial and commercial cases.

Another contribution is a comprehensive review on intersection management systems, including a classification scheme based on its components and its main application. This could serve to readers as an introductory resource on how such systems have been evolving and what is the future of them.

In addition to this, a set of software repositories are available, one for the application and another one summarizing available datasets containing intersection data. The purpose of this is to let community review, test and give their opinion about the system. This feedback would be used for new features and improvements.

On the other side, a couple of articles have been derived from this work. One article, titled "*A Review on Intersection Management Systems and Recent IoT Integrated Approaches*" is a review on intersection management systems, based on chapter 1. This article is also focused on how Internet of Things (IOT) has been used for IMS and it remarks recent developments and deployments on this field. This article has been submitted to the IEEE 5th World Forum on Internet of Things, which will be held during April 2019 at Limerick, Ireland [1].

Another article based on chapters 2 and 3, presents a full description of the architecture and an example implementation. This article is still on writing stage and is intended to be submitted to the national journal DYNA[2].

4.2 Future Work

Aiming to continue the work started by this project, there are several opportunities of improvement that have been identified. The more relevant and feasible in the short-term are the following:

Generation of our own dataset. Taking into account that PSI research group owns a laser-scanner, it would be great to generate a dataset for local intersections. It could be from a low-traffic intersection in the campus or from a high-traffic intersection in the surroundings. This would allow to test the system under different conditions and do not depend on 3rd party data.

Software and Platforms Improvements. As described, the system comprises different elements, and each of them could be improved. For example, evaluate alternatives in communication with low-latency. Optimize message exchange format in order to reduce bandwith usage. Software code optimization to reduce CPU comsumption. Improve user experience through the development of a more friendly interface, taking into account desktop, web and /or mobile options.

[1] http://wfiot2019.iot.ieee.org/
[2] https://revistas.unal.edu.co/index.php/dyna

New types of sensors. Although the system was tested with lasers and a camera, scalability is one of the main features of it. This allows to include new sensors, and develop the needed processing blocks to integrate their information into the dataflow of the system and improve its quality and its efficiency.

Integration with other technologies and new trends. At this moment, there are many advances and trends that could be used along an intersection management system to improve the usefulness and relevance of this kind of projects in real deployements. It is important that new versions of the system will be aligned with topics like Smart cities for authorities/Government integration, Internet of things as a new massive source of information, Cloud/Fog computing for scalable and distributed processing, or Big Data and Data Analytics for traffic insights and forecasting.

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