

A Review on Intersection Management Systems and recent IoT Integrated Approaches

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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. In addition, different proposals based on the Internet of Things (IoT) have been used to handle different traffic issues at intersections, taking advantage of the features it provides regarding hardware, software and communications. This work presents a comprehensive review on Intersection Management Systems (IMS), from a component-based point of view, and a special remark on how IoT-based solutions have been adopted recently in this area is presented as well.

I. INTRODUCTION

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

The aim of Intelligent Transportation Systems is to address these issues by taking advantage of improvements in information and communication technologies. These ITS include 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 [1, Ch.1] and [2]. 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 [3] states that 40% of reported traffic accidents in the US were intersection related. Also, in [4], is reported that for Colombia in 2011, most of the accidents in the main cities were at intersections.

On the other side, the Internet of Things has enabled the creation of new sources of data due to the development of low-cost and low-power devices. In addition, the computing capabilities of those devices are increasing constantly, allowing the implementation of complex applications in different areas.

One of the areas where IoT-based solutions are integrated is transportation, with great adoption in the intersection management systems field.

In section II, a general description and a review on intersection management systems are presented, from early developments until recent works. Section III describe how IoT-based solutions have been adopted into the field of transportation, specially for optimisation and control at intersections. Finally, in section IV some comments are given and future steps in the area are discussed.

II. INTERSECTION MANAGEMENT SYSTEMS

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

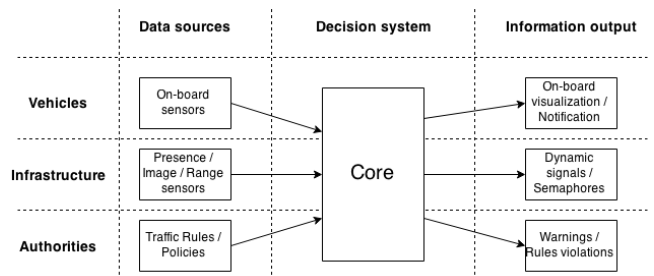


Fig. 1. Generic block diagram of an Intersection Management System.

A. 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 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 a graph is presented, showing aforementioned components and elements within them, and next, a description of each component is given.

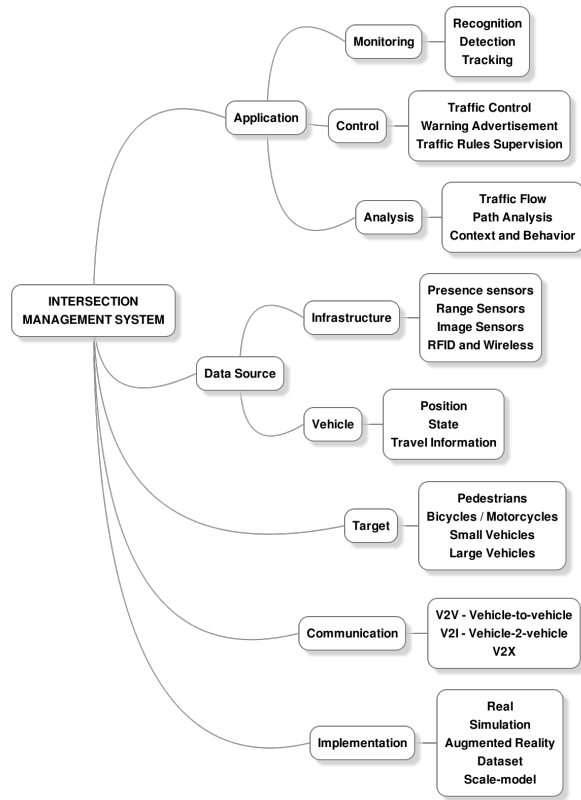


Fig. 2. Components of an Intersection Management System application.

1) *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.

2) *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.

3) *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.

4) *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 standards 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.

5) *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.

B. Developments in Intersection Management Systems

In the table I is presented a compilation of several developments within IMS field from the last 20 years. For each work a description is given in which target and implementation components are highlighted. Additionally, Data source, communication and application components are detailed in their own column.

TABLE I
DEVELOPMENTS ON INTERSECTION MANAGEMENT SYSTEMS

Reference	Comment	Application	Data Source	Communication
[5], [6]	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
[7]	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
[8]	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
[9]	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
[10]	Development of a simulator for an Intersection Collision Warning System. Physical and MAC layers were modeled	Intersection collision warning simulator	N/A	V2V
[11]	Traffic monitoring for two context: Left-Turn-Across-Path-Opposite-Direction and Dilemma zone and red light violation	Intersection Monitoring	Radar	N/A
[12]	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
[13]	Analysis of Left-Turn-Across-Path-Opposite-Direction conflict situation.	Intersection Monitoring	Radar; Steering, speed sensors and GPS on-board	V2X
[14]	Based on [10], this works includes and improvement, including network layer and driver behaviour model.	Intersection Simulator Architecture	N/A	V2X
[15]	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
[16]	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
[17]	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
[18]	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, communication is performed. Validation of proposal is done using a custom microscopic simulator.	Intersection Communication Scheme	N/A	V2I
[19]	A multiagent-based intersection control protocol called autonomous intersection management (AIM) is proposed. Based on a custom simulation, vehicles are modeled and they communicate 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 like stop lights and traffic lights.	Intersection Management	On-board state sensors	V2I
[20]	Based on [10] and [14], 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
[21]	Based on [16], 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
[22]	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 implemented	Collision avoidance	N/A	V2I
[23]	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
[24]	Based on [21], 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

Reference	Comment	Application	Data Source	Communication
[25]	Monitoring dilemma zone and effectiveness of control policies using cameras and loop detectors on an intersection	Intersection monitoring	Cameras, loop detectors	N/A
[26]	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
[27]	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
[28]	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
[29]	The use of intelligent objects in vehicles is proposed. With sharing vehicle state information and journey 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
[30]	A system for traffic flow measurement based on anomalies detection is presented. Multiple cameras are used SIFT and unsupervised SVM-based clustering are performed for trajectories analysis.	Intersection monitoring	Cameras	N/A
[31]	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
[32]	An intersection control protocol based on V2V communication is proposed. This protocol is in charge of handling other vehicles messages and determines if it is 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
[33]	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
[34]	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 ([24]) to get better results at tracking.	Object detection and tracking	Lasers	N/A
[35]	A Multiagent-based system is proposed. They define a Vehicle Agent 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
[36]	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
[37]	In this work is presented the setting and configuration of a multi-sensor network, based on 14 lasers, 10 cameras, GPS and V2I unit. Calibration and spatial-temporal alignment is performed.	System Architecture	Cameras, Lasers	V2I
[38]	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
[39]	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
[40]	A new method for object detection based on lidars data is proposed. After perform background removal, they use DBGrid-SCAN 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
[41]	On top of AIM ([19]) 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 II
IOT-BASED DEVELOPMENTS FOR IMS

Reference	Comment	Implementation
[42]	Proposal of using IOT-based set of sensors as source of data for intersection control	Simulation
[43]	IOT-based approach for traffic light control to reduce congestion for environmental conservation	Proposal
[44]	IOT device development for traffic flow metering and traffic light control using 3rd party IoT ready infrastructure as backend	Prototype
[45]	Microcontroller-based device for lane monitoring at intersection with a Web application for user interaction	Prototype
[46]	Full stack implementation (hardware, communications, web server) for traffic flow metering	Prototype
[47]	Metering and control at intersections within a emergency vehicles priority scheme. It includes sensing, control and communication stages	Prototype

III. INTERNET OF THINGS AT INTERSECTIONS

Given that the IoT concept is related to the whole stack of a solution, which include hardware, communication, infrastructure and visualization, the benefits that it can provide to IMS is great. For this reason, in the recent years IMS applications have been increasing their scope, including almost all of the components described in the previous section.

For example, with the reduced cost of making new sensors, it has been possible to deploy more prototypes rather than work in simulated scenarios. Or instead of make architecture proposal of intersection management systems, current IoT infrastructure and platform are ready to deploy such proposed architectures. This can be seen in table —II, where a description of IoT-based developments are summarized.

IV. CONCLUSIONS

Intersection are complex scenarios that still face efficiency and safety issues, although different approaches have been proposed and implemented. The Internet of things adds a new set of tools for several applications, offering improvements and all the stack of an Intersection Management System application, from the hardware up to the control and user interaction.

Since the establishment of IoT, intersection management system applications have moved from simulated and proposed scenarios to prototype creation and real world deployments, because the creation of sources of data and the implementation of computing systems is not longer expensive as it was 5 or more years ago.

Oncoming advances in computing capabilities, low-power platforms, and a variety of communication protocols, open a door to newer and optimized solutions. Also, these allow the generation of joint solution with a wider scope, not just for transportation, but for social or environmental scenarios, having a higher impact on society.

REFERENCES

- [1] J. M. Sussman, *Perspectives on Intelligent Transportation Systems (ITS)*. Boston, MA: Springer US, 2005. [Online]. Available: <http://link.springer.com/10.1007/b101063>
- [2] B. Williams, *Intelligent Transport Systems Standards*. Artech House, INC., 2008.
- [3] E.-H. Choi, "Crash Factors in Intersection-Related Crashes: An On-Scene Perspective," U.S. Department of Transportation, Springfield, VA, Tech. Rep. September, 2010.
- [4] Corporación Fondo de Prevención Vial, "Anuario Estadístico de Accidentalidad Vial." Bogotá, Colombia, Tech. Rep., 2010.
- [5] S. Kamijo, Y. Matsushita, K. Ikeuchi, and M. Sakauchi, "Traffic Monitoring and Accident Detection at Intersections," in *IEEE/IEEE/ISAI International Conference on Intelligent Transportation Systems*, 1999.
- [6] —, "Traffic monitoring and accident detection at intersections," *IEEE Transactions on Intelligent Transportation Systems*, vol. 1, no. 2, pp. 108–118, Jun. 2000. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=880968>
- [7] H. Veeraraghavan, O. Masoud, and N. Papanikolopoulos, "Vision-based Monitoring of Intersections," no. September, pp. 7–12, 2002.
- [8] H. Veeraraghavan, O. Masoud, and N. P. Papanikolopoulos, "Computer vision algorithms for intersection monitoring," *IEEE Transactions on Intelligent Transportation Systems*, vol. 4, no. 2, pp. 78–89, 2003.
- [9] S. Messelodi, C. M. Modena, and M. Zanin, "A computer vision system for the detection and classification of vehicles at urban road intersections," Tech. Rep., 2004.
- [10] A. Dogan, G. Korkmaz, Y. Liu, F. Ozguner, U. Ozguner, K. Redmill, O. Takeshita, and K. Tokuda, "Evaluation of intersection collision warning system using an inter-vehicle communication simulator," in *2004 IEEE Intelligent Transportation Systems Conference*. Washington, D.C., USA: Ieee, 2004, pp. 1103–1108. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1399061>
- [11] C.-y. Chan, D. Marco, and R. F. Station, "Traffic Monitoring at Signal-Controlled Intersections and Data Mining for Safety Applications," pp. 355–360, 2004.
- [12] S. Atev, H. Arumugam, O. Masoud, R. Janardan, and N. Papanikolopoulos, "A Vision-Based Approach to Collision Prediction at Traffic Intersections," *IEEE Transactions on Intelligent Transportation Systems*, vol. 6, no. 4, pp. 416–423, Dec. 2005. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1549845>
- [13] C.-Y. Chan and B. Bouglar, "Evaluation of cooperative roadside and vehicle-based data collection for assessing intersection conflicts," in *IEEE Proceedings. Intelligent Vehicles Symposium, 2005*. IEEE, 2005, pp. 165–170. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1505096>
- [14] A. Avila, G. Korkmaz, Y. Liu, H. Teh, E. Ekici, F. Ozguner, U. Ozguner, K. Redmill, O. Takeshita, K. Tokuda, M. Hamaguchi, S. Nakabayashi, and H. Tsutsui, "A complete simulator architecture for inter-vehicle communication intersection warning systems," in *Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems*. Vienna, Austria: Ieee, 2005, pp. 461–466. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1520092>
- [15] H. Veeraraghavan, P. Schrater, and N. Papanikolopoulos, "Switching Kalman Filter-Based Approach for Tracking and Event Detection at Traffic Intersections," *Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Control and Automation Intelligent Control, 2005.*, pp. 1167–1172, 2005. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1467180>
- [16] H. Zhao and R. Shibasaki, "Joint tracking and classification of moving objects at intersection using a single-row laser range scanner," in *Proceedings of the IEEE Intelligent Transportation Systems Conference*, Toronto, Canada, 2006, pp. 287–294.
- [17] J. Eguchi and H. Koike, "Discrimination of an Approaching Vehicle at an Intersection Using a Monocular Camera," in *Proceedings of the 2007 IEEE Intelligent Vehicles Symposium*, Istanbul, Turkey, 2007.
- [18] K. KURAMOTO, K. FUJIMURA, and T. HASEGAWA, "The Multi-Class Zone ITS Communication Scheme for Real-time Communications in Intersections," in *Proceedings of the 2007 IEEE Intelligent Transportation Systems Conference*, 2007, pp. 431–435.
- [19] K. Dresner and P. Stone, "A Multiagent Approach to Autonomous Intersection Management," *Journal of Artificial Intelligence Research*, vol. 31, pp. 591–656, 2008.
- [20] B. Jarupan, Y. Balcioglu, E. Ekici, F. Özgüner, and U. Özgüner, "An Integrated Wireless Intersection Simulator for Collision Warning Systems in Vehicular Networks," in *Proceedings of the 2008 IEEE International Conference on Vehicular Electronics and Safety*, Columbus, USA, 2008, pp. 340–345.
- [21] H. Zhao, J. Cui, H. Zha, K. Katabira, X. Shao, and R. Shibasaki, "Monitoring an intersection using a network of laser scanners," in *Proceedings of the 11th International IEEE Conference on Intelligent Transportation Systems*. Beijing, China: Ieee, 2008, pp. 428–433. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4732613>
- [22] Z. Y. Rawashdeh and S. M. Mahmud, "Intersection Collision Avoidance System Architecture," *2008 5th IEEE Consumer Communications and Networking Conference*, pp. 493–494, 2008. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4446413>

- [23] R. S. Mundewadikar, S. S. Dorle, A. G. Keskar, and M. B. Chakole, "Intersection Collision Detection and Warning Protocol: Design Approach," in *First International Conference on Emerging Trends in Engineering and Technology*. Ieee, 2008, pp. 869–872. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4580024>
- [24] H. Zhao, J. Cui, and H. Zha, "Sensing an Intersection Using a Network of Laser Scanners and Video Cameras," *IEEE Intelligent Transportation Systems Magazine*, pp. 31–37, 2009.
- [25] M. Abbas and P. Li, "Advanced real-time intersection data collection system for safety evaluation," *2009 12th International IEEE Conference on Intelligent Transportation Systems*, pp. 1–6, Oct. 2009. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5309688>
- [26] P. Babaei, "Vehicles tracking and classification using Traffic zones in a hybrid scheme for intersection traffic management by smart cameras," in *2010 International Conference on Signal and Image Processing ICSIP*. Islamic Azad University, West Tehran Branch, Iran. Ieee, 2010, pp. 49–53.
- [27] D. Meissner and K. Dietmayer, "Simulation and calibration of infrastructure based laser scanner networks at intersections," *2010 IEEE Intelligent Vehicles Symposium*, pp. 670–675, Jun. 2010. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5547970>
- [28] M. Quinlan, T.-C. A. T.-C. Au, J. Zhu, N. Sturca, and P. Stone, "Bringing simulation to life: A mixed reality autonomous intersection," *Intelligent Robots and Systems IROS 2010 IEEE/RSJ International Conference on*, no. October, pp. 6083–6088, 2010. [Online]. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5651993
- [29] R. Ball and N. Dulay, "Enhancing Traffic Intersection Control with Intelligent Objects," *Urban IOT 2010 Urban Internet of Things Towards Programmable Realtime Cities*, 2010. [Online]. Available: <http://webthings.com/urban-iot/2010/pdfs/Ball.pdf>
- [30] P. Babaei and M. Fathy, "Abnormality Detection and Traffic Flow Measurement Using a Hybrid Scheme of SIFT in Distributed Multi Camera Intersection Monitoring," *2011 7th Iranian Conference on Machine Vision and Image Processing*, pp. 1–5, Nov. 2011. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6121564>
- [31] F. Basma, Y. Tachwali, and H. H. Refai, "Intersection collision avoidance system using infrastructure communication," *2011 14th International IEEE Conference on Intelligent Transportation Systems ITSC*, pp. 422–427, 2011. [Online]. Available: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=6083007
- [32] R. Azimi, G. Bhatia, R. Rajkumar, and P. Mudalige, "Intersection Management using Vehicular Networks," pp. 1–13, Apr. 2012. [Online]. Available: <http://www.sae.org/technical/papers/2012-01-0292>
- [33] L. Conde Bento, R. Parafita, and U. Nunes, "Intelligent traffic management at intersections supported by V2V and V2I communications," in *2012 15th International IEEE Conference on Intelligent Transportation Systems*, Anchorage, Alaska, USA, 2012, pp. 1495–1502.
- [34] H. Zhao, J. Sha, Y. Zhao, J. Xi, J. Cui, H. Zha, and R. Shibasaki, "Detection and Tracking of Moving Objects at Intersections Using a Network of Laser Scanners," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 2, pp. 1–16, 2012.
- [35] Q. Jin, G. Wu, K. Boriboonsomsin, and M. Barth, "Advanced Intersection Management for Connected Vehicles Using a Multi-Agent Systems Approach," in *2012 Intelligent Vehicles Symposium*, Alcalá de Henares, Spain, 2012.
- [36] D. Meissner, S. Reuter, and K. Dietmayer, "Real-time detection and tracking of pedestrians at intersections using a network of laserscanners," *2012 IEEE Intelligent Vehicles Symposium*, pp. 630–635, Jun. 2012. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6232226>
- [37] M. Goldhammer, E. Strigel, D. Meissner, U. Brunsman, K. Doll, and K. Dietmayer, "Cooperative multi sensor network for traffic safety applications at intersections," in *2012 15th International IEEE Conference on Intelligent Transportation Systems*. IEEE, Sep. 2012, pp. 1178–1183. [Online]. Available: <http://www.scopus.com/inward/record.url?eid=2-s2.0-84871208763&partnerID=tZOtx3y1>
- [38] M. Friesen, R. Jacob, P. Grestoni, T. Mailey, and R. McLeod, "VEHICULAR TRAFFIC MONITORING USING BLUETOOTH," in *2013 26th IEEE Canadian Conference Of Electrical And Computer Engineering (CCECE)*, 2013.
- [39] J. A. Guerrero-Ibañez, C. Flores-Cortés, J. M. Ramírez-Alcaraz, P. Santana, T. Mendoza-Robles, H. A. Vizcaíno-Anaya, E. Peña Cárdenas, and A. Anguiano-Mancilla, "Sistema Inteligente basado en comunicación V2X para prevención de colisiones en intersecciones viales," in *Décima Segunda Conferencia Iberoamericana en Sistemas, Cibernética e Informática. CISCi 2013*, Orlando, FL, 2013.
- [40] D. Meissner, S. Reuter, and K. Dietmayer, "Road user tracking at intersections using a multiple-model PHD filter," in *2013 IEEE Intelligent Vehicles Symposium (IV)*, no. Iv. IEEE, Jun. 2013, pp. 377–382. [Online]. Available: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6629498>
- [41] T.-c. Au, S. Korea, S. Zhang, and P. Stone, "Autonomous Intersection Management for Semi-Autonomous Vehicles," 2015.
- [42] G. Tan, K. Wang, and Y. Wang, "A coordination feedback adaptive control method of traffic network," *Proceedings - 2011 6th IEEE Joint International Information Technology and Artificial Intelligence Conference, ITAIC 2011*, vol. 1, pp. 347–351, 2011.
- [43] C. E. Turcu, V. G. Gaitan, and C. O. Turcu, "An internet of things-based distributed intelligent system with self-optimization for controlling traffic-light intersections," *2012 International Conference on Applied and Theoretical Electricity, ICATE 2012 - Proceedings*, 2012.
- [44] H. F. Chong and D. W. K. Ng, "Development of IoT device for traffic management system," in *2016 IEEE Student Conference on Research and Development (SCORED)*. IEEE, dec 2016, pp. 1–6. [Online]. Available: <http://ieeexplore.ieee.org/document/7810059/>
- [45] M. Z. Talukder, S. S. Towqir, A. R. Remon, and H. U. Zaman, "An IoT based automated traffic control system with real-time update capability," in *8th International Conference on Computing, Communications and Networking Technologies, ICCCNT 2017*. IEEE, jul 2017, pp. 1–6. [Online]. Available: <http://ieeexplore.ieee.org/document/8204095/>
- [46] V. S. Nagmode and S. M. Rajbhoj, "An IoT Platform for Vehicle Traffic Monitoring System and Controlling System Based on Priority," *2017 International Conference on Computing, Communication, Control and Automation, ICCUBEA 2017*, pp. 1–5, 2018.
- [47] A. Khan, F. Ullah, Z. Kaleem, S. U. Rahman, H. Anwar, and Y.-Z. Cho, "EVP-STC: Emergency Vehicle Priority and Self-Organising Traffic Control at Intersections Using Internet-of-Things Platform," *IEEE Access*, vol. PP, pp. 1–1, 2018. [Online]. Available: <https://ieeexplore.ieee.org/document/8523674/>