RoadAhead - enhanced vision for traffic management

Miguel Baúto

INESC-ID/IST
Distributed Systems Group
Rua Alves Redol N. 9,1000-029 Lisboa, Portugal
miguel.bauto@ist.utl.pt

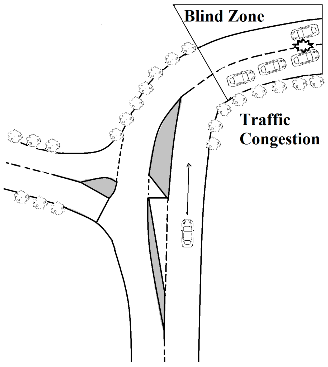
Abstract. Over the past years traffic congestion has become a serious problem, contributing in a way that affects the lives of millions of vehicle drivers everyday. In order to mitigate this problem several systems have been developed. Most of these systems commonly use a centralized architecture denominated Vehicle-to-Infrastructure (V2I). However, this architecture has major drawbacks regarding response-time and fault-tolerance. In order to solve these problems architectures such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Vehicle-to-Infrastructure (V2V2I) have gained interest in recent years. Nevertheless, these architectures require extra equipment attached-to or built-in vehicles to operate properly.
Due to these issues we propose in this work a decentralized system called RoadAhead which is by itself an improvement of the V2I architecture w.r.t response-time. This system offers a broader vision of the traffic conditions in real-time in order to help vehicle drivers make better decisions much in advance when compared to today's situation. This is done through the deployment of road sensors along the roads that collect relevant information about the current traffic (e.g. Vehicle instantaneous velocity). Moreover, this information is analyzed and displayed to vehicle drivers by using the capabilities of light emitting diodes (LEDs), which are disposed along the roads and change their color according to the traffic condition (i.e. Green, Yellow, Red).

Keywords: intelligent transport system, traffic management, traffic congestion, increased visibility, real-time information, road-sensors, light emitting diodes (LEDs)

1 Introduction

In modern society, vehicles are a part of people's life. As the number of vehicles increases, more the traffic situation becomes a serious and complicated issue that can lead to several problems such as traffic congestion (i.e. traffic demand exceeding the roadway capacity) [1].

To prevent these problems, transport infrastructures can be built but they are not feasible mainly due to cost issues [2]. In addition to this physical capacity constraint, external events can also have a major effect on traffic congestion.



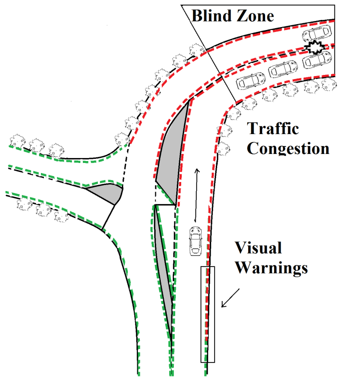


Fig. 1. Vehicle driver reaching blind zone **Fig. 2.** Vehicle driver with a broader vision

These include traffic incidents such as vehicle accidents and breakdowns, work zones, adverse weather conditions, and special events [3].

Moreover, traffic congestion and road incidents contribute negatively to the quality of life (i.e. waste of time for vehicle drivers, air pollution and fuel consumption), particularly when vehicle drivers are the cause of them.

The fact that vehicle drivers only view a portion of the road ahead is a major limitation while driving, mainly when there are adverse weather conditions (i.e. rain, fog, ice, snow, and dust), other vehicles ahead or intersections between roads.

Consider for example a vehicle driver that is traveling to a given location and reaches a road curve with low visibility that prevents him from seeing what lies behind it. As Fig. 1 shows, when approaching the road curve the vehicle driver is faced with heavy traffic congestion caused by an accident involving several vehicles. Since the vehicle driver only reacts to this situation while around the road curve, his reaction time will be longer which may lead yet to another accident. Ideally, such reaction time would be much shorter, if a warning were displayed to an electronic road panel or to the driver's car dashboard alerting the vehicle driver of the traffic situation ahead.

1.1 Objectives

The goal of this work is to develop a system called **RoadAhead** which offers a broader vision of the traffic conditions in real-time. This is performed by detecting existing vehicles on the road and displaying crucial information to vehicle drivers in an intuitive and visual manner as illustrated in Fig. 2).

By observing the visual warnings (i.e. Green, Yellow, Red) displaced at the roadside, vehicle drivers are able to make better decisions about the route, speed, etc. much in advance (e.g. when compared to the current situation), preventing this way potential incidents that may occur.

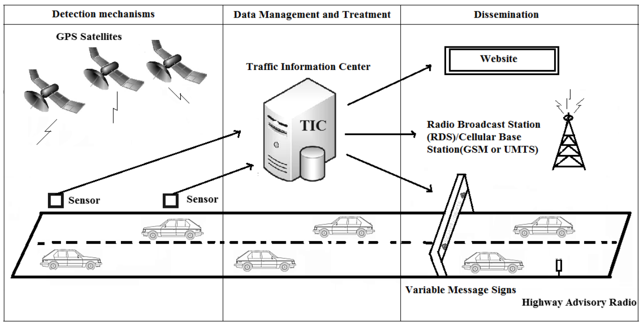


Fig. 3. ITS Overview

The system is required to be reliable, efficient and accurate regarding the collection, management and dissemination of information to vehicles on the road. Other requirements of the system are to behave as promptly as possible i.e. fast response-time and to be non-intrusive to drivers.

In addition, it must be scalable and continue to operate properly independently of traffic density and penetration level (i.e. vehicles that participate on the system). Additionally, the system is required to preserve the vehicle driver's privacy by not collecting any information that could infer his exact position or any previously routes made by him.

Finally, it's necessary to ensure that the system operates correctly without any extra equipment attached-to or built-in vehicles in order to reach all possible drivers of a given road.

To achieve the goal and fulfill the above mentioned requirements, RoadAhead must deal with the following challenges: i) efficient gathering of information about vehicles that travel in a given road, ii) efficient management and treatment of the collected information, iii) dissemination of processed information, iv) fast-response time (soft real-time), and v) guaranty vehicle driver's privacy.

The remainder of this paper is organized as follows. Section 2 describes the related work. Section 3 presents the proposed architecture and how it fulfills the challenges that have been identified. Section 4 describes how the system is implemented. Further, in Section 5 we explain the evaluation our system. To conclude, Section 6 summarizes the work done.

2 Related Work

This section addresses the related work suitable to the system mentioned in Section 1, focusing on the different aspects required to the current solution.

Initially, several architectures for ITS (i.e. Intelligent Transport System) are presented and analyzed. Furthermore, we describe the three essential components of any ITS (Fig. 3): detection mechanisms for vehicles on road, and dissemination of the processed information.

Finally, we show currently existing solutions stating briefly their weaknesses.

2.1 Architectures

So far there are three architectures that are used for ITS: Vehicle-to-Infrastructure (V2I) [4], Vehicle-to-Vehicle (V2V) [5]. and Vehicle-to-Vehicle-to-Infrastructure (V2V2I) [6].

Regarding V2I, it's a centralized architecture constituted by sensors deployed along the roads and a Traffic Information Center (TIC) which receives all the information collected by the sensors and delivers it through Variable Message Signs, Radio Tools, etc.

Concerning V2V, it's a decentralized architecture where vehicles communicate between each other by establishing Vehicular Ad-hoc Networks (VANET) [7]. Thus, they periodically exchange information about observed traffic conditions to other vehicles within their transmission range.

Regarding V2V2I, it's a hybrid of the V2V and V2I architectures (i.e. a combination of a Vehicular Ad-hoc Network (VANET) with a Traffic Information Center). In the V2V2I architecture, the transportation network is divided into several different areas. These areas are pre-configured which means that both the vehicles and the Traffic Information Center know where the vehicles are situated. Each area is assigned with a vehicle, known as Super-Vehicle that receives information (i.e. speed, location) from other vehicles in that area and communicates it to the Traffic Information Center, as well as, to other Super-Vehicles in adjacent areas. Thus, the Traffic Information Center can obtain a well-defined scenario of the traffic situation by analyzing all the information sent from all the Super-Vehicles within each area.

After all this said, Table 1 shows a summary of the requirements that are satisfied by each of the previously described architectures. It's worthy to note that none of these architectures fulfills all the requirements imposed by **RoadAhead**. However, one can see that V2I architecture is the one that best suits **RoadAhead** failing only to satisfy fast-response time and least overall cost possible.

2.2 Detection mechanisms for vehicles on road

The efficient detection of vehicles is crucial to an ITS system that tracks in real time the road traffic conditions. Such a system must provide reliable information about the current state of the road to the vehicle drivers. To fulfill this requirement a proper detection of the vehicles presence, as well as, speed, volume and other relevant functions must be performed. Without this vital information, the correct functioning of the system is compromised; thus, the detection of vehicles is a major concern **w.r.t** accuracy and reliability of the system.

There are several mechanisms that allow the detection of vehicles and consequently of their traffic parameters which can be grouped into two distinct categories: **infrastructure-based detectors** and **vehicle-based detectors**.

Requirements	Architecture		
	V2I	V2V	V2V2I
Reliable	✓		✓
Accurate	✓		✓[a]
Fast Response-Time		✓	✓
Scalable	✓	✓	✓
Non-Intrusive	✓[b]		
Indifferent to Traffic Density	✓		✓
Indifferent to Penetration level	✓[2]		
Respects Driver's Privacy	✓[2]		
No Extra-Equipment in Vehicle	✓[2]		
Least Overall Cost Possible		✓	

Table 1. Fulfilled requirements per architecture

[a] with high penetration level
[b] depends upon the sensor-technology used for the detection of vehicles

Regarding infrastructure-based detectors, they require the installation of hardware by specialized personnel along several points on a given road where vehicles need to be detected and can be divided into two different groups: **intrusive detectors** (i.e. devices that are placed along the road usually in the pavement or underneath) and **non-intrusive detectors** (i.e. devices that are deployed along the roadside or above the roadway) [8,9]. Examples of intrusive devices are [8,10]: **inductive loops**, **magnetic sensors**, **piezoelectric sensors** and **pneumatic road tube sensors**; non-intrusive devices are [8,10,11]: **infrared sensors**, **microwave radar sensors**, **video image processor**, **ultrasonic sensors** and **passive acoustic sensors**.

Regarding vehicle-based detectors are those that can be attached to or built-in vehicles, not requiring invasive procedures in the road but causing in some cases minimal disruption of the traffic for their installation. Examples of such devices are: **global positioning system** and **automatic vehicle identifiers**.

Table 2 presents an overview of the collection methods that have been previously mentioned, specifying for each one the traffic parameters that can infer and their overall cost. Since our system is required to be non-intrusive and available to all vehicle drivers, one can note that both intrusive and vehicle-based detectors can be discarded, and only non-intrusive detectors are able to fulfill the above mentioned requirements. Thus, by observing Table 2 one can conclude that the detector that best fits **RoadAhead** is the microwave radar sensor because when compared to the remaining non-intrusive detectors, it's able to infer several essential traffic parameters with a lower overall cost, being so considered the most cost-effective.

Detector Type		Collection Method	Volume	Presence	Speed	Occupancy	Classification	Travel Times	Position	Overall Cost[a](each in 1999\2000 U.S. $)
Infrastructure-based	Intrusive detectors	Inductive Loops	✓	✓	✓[b]	✓	✓[c]			Low[d]($500-$800)
		Magnetometer	✓	✓	✓[2]	✓				Moderate[4]($900-$6,300)
		Magnetic Induction Coil	✓	✓[e]	✓[2]	✓				Low to Moderate[4]($385-$2,000)
		Piezoelectric	✓	✓	✓[2]	✓	✓			Low to Moderate($1,100-$4,000)
		Road Tubes	✓	✓	✓[2]	✓	✓			Moderate($1650-$6,500)
	Non-intrusive detectors	Active infrared	✓	✓	✓[f]	✓	✓			Moderate to High($6,500-$14,000)
		Passive infrared	✓	✓	✓[6]	✓				Low to Moderate($700-$1,200)
		Microwave Radar	✓	✓[g]	✓	✓[7]	✓[7]			Low to Moderate($700-$3,300)
		Video Image	✓	✓	✓	✓				Moderate to High($5000-$26,000)
		Ultrasonic	✓	✓		✓				Low to Moderate($600-$1,900)
		Passive Acoustic Arrays	✓	✓	✓	✓				Moderate($3,100-$8,100)
Vehicle-based		GPS			✓		✓	✓	✓	
		AVI	✓		✓		✓[h]	✓	✓	

Table 2. Traffic parameters inferred by several collection methods and their overall cost [10,12]

[a] Installation, maintenance, and repair costs included.

[b] Speed can be measured by using two consecutive sensors with a known distance apart or estimated from one sensor, the effective detection zone and vehicle lengths.

[c] With specialized electronics unit containing embedded firmware that classifies vehicles.

[d] Includes underground sensor and local detector or receiver electronics.

[e] With special sensor layouts and signal processing software.

[f] With multidetection zone passive or active mode infrared sensors.

[g] With microwave radar sensors that transmit the proper waveform and have appropriate signal processing.

[h] The information must be on the tag.

2.3 Information Dissemination

The efficiency of an ITS system doesn't rely only on the collection and analysis of the traffic data, but also on the dissemination of the inferred information using this data to the intended receivers (e.g. vehicle drivers, ITS personnel, road users). Thus, data dissemination concerns the delivery of traffic information to these receivers, while meeting some requirements (e.g. low delay, high reliability, low message passing overhead).

Several systems are used for relaying traffic information to vehicle drivers such as Variable Message Signs (VMS), Highway Advisory Radio (HAR), Traffic Information Websites, Short Messaging Services (SMS), GPS Navigation Systems, Radio/Television Stations and other modern media tools.

However, these systems present several drawbacks such as high cost, requirement of extra-equipment in vehicles, constant interaction with the equipment which may reduce driver's attention and disclosure of trajectory data that may compromise the vehicle driver's privacy. Due to this, one can note that these systems are not appropriate to **RoadAhead**.

2.4 Existing Systems

In this section, we present existing systems that have some similarities with the system that is proposed in this document. Although, some of the systems might not share the same goal as ours they provide important insights to the development of **RoadAHead**. Examples of such systems are: **Integrated Traffic Control System (ITCS)** [15], **Vehicle Information and Communication System (VICS)** [15] and **Freeway Traffic Management System (COMPASS)** [16].

Regarding ITCS, it's a large-scale traffic management system implemented in Japan that achieves safe and smooth road traffic. This system presents some weaknesses regarding fault-tolerance due to a single point-of-failure i.e Traffic Control Center. Additionally, this Traffic Control Center is responsible for a relatively large area which might affect the system response-time to deliver in real-time traffic information to vehicle drivers. Finally, since it's necessary to install, manage and maintain a large number of roadside sensors this might become expensive.

Concerning VICS, it's a digital data communication system used in Japan that promptly provides the latest necessary road traffic information to vehicle drivers via car navigation equipment. This system requires extra-equipment attached-to vehicles which limits its availability to vehicle drivers that buy their specific equipment, the use of external equipment which might compromise driver's privacy and fault-tolerance due to a single point-of-failure i.e VICS Center.

Regarding COMPASS, it's a sophisticated advanced traffic management system run by the Ontario Ministry of Transportation (OTM) to regulate traffic flow on the 400-series highways. This system shares weaknesses with ITCS such as a single point of failure and the need to install, manage and maintain a large number of road sensors/traffic cameras which might become costly.

3 Proposed Solution

In this section we start by describing the **RoadAhead** system architecture focusing on its main components: road sensors, servers and light emitting diodes (LEDs), and how our solution fulfills the challenges that have been identified. Furthermore, we delineate our system implementation explaining the technologies that we used and outline the major reasons for the decisions taken.

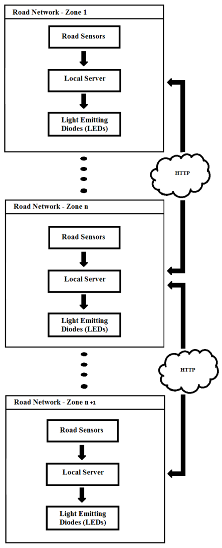


Fig. 4. System Architecture

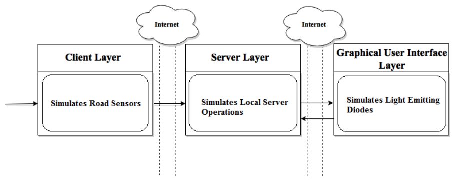


Fig. 5. System Implementation

3.1 System Architecture

RoadAhead uses a decentralized architecture, as depicted in Fig. 4, which is based on the existing Vehicle-to-Infrastructure (V2I) architecture.

As one can see, **RoadAhead** divides the existing road network into several well defined zones with variable size (e.g. $Zone_1 ... Zone_n$), each containing one or more roads, depending upon the traffic flow of each road. Moreover, each zone relies on three major components which together manage to deliver the current traffic situation in real-time, namely: road sensors, a local server and light emitting diodes (LEDs).

Regarding road sensors, they are deployed along the roads and responsible for the collection of traffic information i.e. vehicle instantaneous velocity which is forwarded to the correspondent local server. There, this information is used to infer the current traffic situation by applying a traffic and congestion estimation and forecasting method which evaluates and divides it into three distinct states: <Free Flow> when the traffic is normal and fluid, <Slightly Congested> when there are light vehicle stops, and <Congested> when the traffic has long stoppages. Finally, the local server translates the calculated traffic congestion which is delivered to LEDs that are disposed parallel to the road by using a color grade system constituted by three different colors: Green, Yellow and Red, where each color corresponds to a traffic congestion state, respectively <Free Flow>, <Slightly Congested>, and <Congested>.

4 System Implementation

Due to the prohibitive cost of deploying a large sensor and light emitting diode network we followed the conventional approach used by most researches that rely on simulation tools. However, instead of using existing simulation tools we implemented our own due to the following reasons: **Flexibility** and **Complexity**.

Thus, our simulation tool contains the following layers, namely: client, server, and graphical interface layer where each one simulates a different **RoadAhead** component, respectively, road sensors, local server and light emitting diodes (LEDs).

Regarding the client layer, we implemented a stand-alone client-based application written in Java^{TM} language using Java Platform, Standard Edition that emulates the road sensor network by receiving as input several text files, each one representative of a given road sensor and containing road traffic information i.e. instantaneous velocities to be transmitted to the server layer.

Concerning the server layer, and in order to implement the business logic behind the local server, we used a solution widely used in systems integration and communication between different applications called **Oracle Weblogic Server WebServices**, which is one of the core components of **Oracle Weblogic Server**, a Java Platform, Enterprise Edition application server currently developed by Oracle Corporation.

Finally, we developed a graphical interface layer that shows in real-time an overview of several road sections and the changes that occur in each one of them after a certain time. To do so, we created a web page written in HyperText Markup Language, commonly referred to as HTML, which integrates Javascript and the Google Maps API.

5 Evaluation

We evaluated **RoadAhead** by using the simulation tool described in previous section. Thus, our simulation goals aim at optimizing the conditions in which **RoadAhead** should operate, respectively, its static parameters (α, $V_{average}(1)$, β, and γ) and the distance between road sensors.

Thus, a set of scenarios were defined based on these goals and setup, namely: **Free Flow**, when the road traffic is fluid and moving with velocity close to the maximum road velocity limit, **Slighty Congested**, when the road traffic is fluid but it starts to decrease until it gets near the minimum road velocity limit, and **Emergency/Congested**, when the road traffic is fluid but it is forced to move very slowly for an extended period of time or to a complete stop due to an road accident.

Afterwards, test cases were applied to these scenarios in a simulation environment that simulates the Portuguese A5 highway (Lisboa-Cascais), more specifically, a 10 km long road section. However, we considered only a flat, one lane, straight road, with no traffic lights nor intersections, and with direction Cascais-Lisboa.

Finally, in the obtained results we observed that **RoadAhead** operates at better conditions when we combine a lower distance between road sensors with a value $\alpha = 0.25$.

6 Conclusion

In this paper was analyzed the research that has been done in the field of ITS systems.

We started by presenting existing architectures stating their suitability to our system. Furthermore, we presented several mechanisms for vehicle detection, and how this data can be used as input for traffic and congestion estimation and forecasting methods in order to provide relevant information to the intended receivers. Moreover, existing systems were described stating their strengths and weaknesses.

In section 3, we described **RoadAhead** architecture which divides the existing road network into several well defined zones with variable size containing three major components, namely: road sensors, a local server and light emitting diodes (LEDs).

In section 4, we described **RoadAhead** implementation, where due to the prohibitive cost of deploying a large sensor and light emitting diode network we followed the conventional approach used by most researches that rely on simulation tools. Thus, we implemented our own.

To conclude, section 5 presents the test results, and from them we considered that **RoadAhead** operates at better conditions when we combine a lower distance between road sensors with a value $\alpha = 0.25$.

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