# Ontology-Based Architecture to Improve Driving Performance Using Sensor Information for Intelligent Transportation Systems

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**Abstract.** Intelligent transportation systems are advanced applications with aim to provide innovative services relating to road transport management and enable the users to be better informed and make safer and coordinated use of transport networks. A crucial element for the success of these systems is that vehicles can exchange information not only among themselves but with other elements in the road infrastructure through different applications. One of the most important information sources in this kind of systems is sensors. Sensors can be located into vehicles or as part of an infrastructure element, such as bridges or traffic signs. The sensor can provide information related to the weather conditions and the traffic situation, which is useful to improve the driving process. In this paper a multiagent system using ontologies to improve the driving environment is proposed. The system performs different tasks in automatic way to increase the driver safety and comfort using sensor information.

**Keywords:** Intelligent transportation systems · Ontology · Reasoning Agents · Sensors

## 1 Introduction

Today, it is known as Intelligent Transportation Systems, the set of applications and technological systems created with the aim of improving safety and efficiency in road transport. These systems allow to control, manage and monitoring the different elements of roads.

The continuing evolution of intelligent transportation systems has ushered in a new era of interconnected intelligent systems, which certainly has been a quantitative leap in safety of road transport. These systems enable the exchange of information between different applications, and the subsequent analysis to improving the safety of drivers and eases travel and comfort in road travel.

One of the most important information sources in this kind of systems is sensors. Sensors can be located into vehicles or as part of an infrastructure element, such as bridges or traffic signals.


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The increasing miniaturization of computers raises the idea of developing extremely small, inexpensive computers that communicate wirelessly and are organized independently. A sensor network is a network of tiny computers (nodes) equipped with sensors which collaborate on a common task [1]. These nodes have certain sensory capabilities and wireless communications that enable ad hoc networking without any preset physical infrastructure or central administration. Sensor networks are a relatively new concept in data acquisition and processing for multiple applications in different fields such as industry, medicine, home automation, military environments, environmental detection, etc. Their main features (to be small, cheap, autonomous, easy to deploy, self-configurable and able to perform efficient energy management) have made sensor networks a very active research field, in which systems as diverse as Berkeley Motes [2], Pico-Radio [3], Smart-Dust [4] and WINS [5] have been developed.

Due to its high degree of expressiveness, the use of ontologies is crucial to ensure greater interoperability among software agents and different applications involved in intelligent transportation systems. Ontologies provide a common vocabulary in a given domain and allow defining, with different levels of formality, the meaning of terms and the relationships between them.

This paper presents a multiagent architecture using ontologies to improve the driving environment. The system performs different tasks in automatic way to increase the driver safety and comfort using sensor information.

The paper is organized as follows. Section 2 is a review of the state of the art in ontologies for road transportation systems, Sect. 3 presents the architecture of the proposed multiagent system. In Sect. 4 the cases of study are explained. Finally the conclusions and lines of future work are summarized in Sect. 5.

## 2 Related Works

There are some previous works focused on ontology for road transportation systems. In [6] an ontology to represent traffic in highways has been developed. Its aim was the construction of reliable Traffic Information System providing information about roads, traffic, and scenarios related to vehicles in the roads. It also provides ways to the Traffic Information System to analyze how critical a specific situation is. For example, an ambulance may need to know about the congestion status of a toll plaza. Requesting this information is critical if the ambulance is moving to the scene of an accident. On the other hand, if a common vehicle is moving through a road without hurry, then its information requested is not critical.

In [7] they proposed a high-level representation of an automated vehicle, other vehicles and their environment, which can assist drivers in taking “illegal” but practical relaxation decisions (for example when a car damaged does not allow the circulation, take the decision to move to another lane crossing a solid line and overtake the stopped car, if the other lane is clear). This high-level representation includes topological knowledge and inference rules, in order to compute the next high-level motion an automated vehicle should take, as assistance to a driver.

In [8] an ontology-based spatial context model was proposed. The work takes a combined approach to modeling context information utilized by pervasive transportation services: the Primary-Context Model facilitates interoperation across independent Intelligent Transportation Systems, whereas the Primary-Context Ontology enables pervasive transportation services to reason about shared context information and to react accordingly. The independently defined, distributed information is correlated based on its primary-context: location, time, identity, and quality of service. The Primary-Context Model and Ontology have been evaluated by modelling a car park system for a smart parking space locator service.

The work proposed in [9] is an approach to create a generic situation description for advanced driver assistance systems using logic reasoning on a traffic situation knowledge base. It contains multiple objects of different type such as vehicles and infrastructure elements like roads, lanes, intersections, traffic signs, traffic lights and relations among them. Logic inference is performed to check and extend the situation description and interpret the situation e.g. by reasoning about traffic rules. The capabilities of this ontological situation description approach are shown at the example of complex intersections with several roads, lanes, vehicles and different combinations of traffic signs and traffic lights.

In the work in [10] an ontology for traffic management is proposed, adding certain concepts of traffic to general sensor ontology A3ME [11]. The added concepts are specializations of position, distance and acceleration sensor classes, and the different actions that take place in the car motions. The ontology is developed in OWL, using the JESS reasoner with SWLR [12] rules.

In [13] an ontology-based Knowledge Base, which contains maps and traffic regulations, was introduced. They can aware over speed situations and make decisions at intersections in comply with traffic regulations, but they did not consider important elements such as traffic signals and weather conditions.

Most of the works found in the literature focus on describing very specific traffic situations such as finding parking, actions of emergency vehicles and intersection situations. But none of them is general and expressive enough to encompass a wide variety of traffic situations. Therefore it's necessary to develop ontologies in the domain of road traffic expressive enough to describe any traffic situation. The ontologies should be richer with respect to the various sensor inputs, and use it to drastically improve the general routing mechanism.

## 3 System Architecture

The proposed system is composed of four interconnected layers, as shown in Fig. 1. At the bottom is the sensor layer, in which the different sensors collect the information related to the traffic environment. That information is stored in the Database. The next one is the ontological layer, where we have developed a general ontology of the domain of road traffic in OWL. The ontology has many SWRL rules, which are used for the reasoner to infer new knowledge. Finally in the upper layer are the agents, who perform their tasks accessing the information stored in the ontology through SPARQL queries.

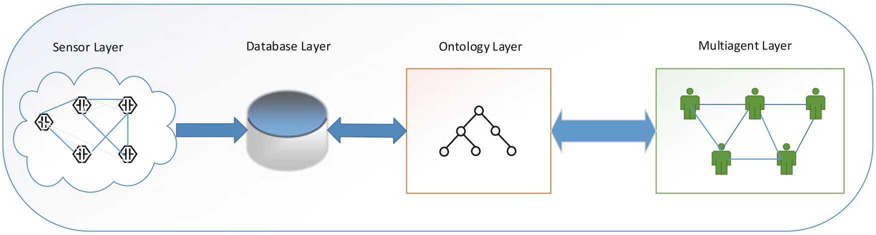


**Fig. 1** System architecture

### 3.1 The Ontology

In the ontology layer of the system, an ontology that relates the different road traffic entities has been developed. The ontology was implemented in OWL-RDF language [14] using the protégé tool [15]. In this work we used the reasoner Pellet [16], which is implemented in Java; it is freely available and allows checking the consistency of the ontology.

For better understanding, we divided the knowledge in the traffic ontology divided in different groups of interrelated concepts.

The main group is related to vehicles. The taxonomy of vehicles is composed of: commercial vehicles, public vehicles (bus and taxi), private vehicles (car, bicycle and motorbike) and priority vehicles (ambulances, fire trucks and police cars). Different relationships between vehicles and other entities are defined also in this group. Some of these entities are: location, showing the exact location (latitude and longitude) of a vehicle, route point or infrastructure item; information about drivers and the vehicle's types which they can drives by license.

The second group organizes the elements related to road infrastructure. In this group the most important concept represents the roads, which in Japan are classified as local roads, prefectural roads, national highways and national expressways.

For better management of traffic situations the roads have been divided into segments, connected through intersections. Each segment contains lanes, and different signs such as stop signs or speed control, traffic lights or road markings are in each lane. Each signal has an action associated following the Japanese traffic regulations.

Here we focused in the third group, which is concern with the concepts related with the different types of sensors used in intelligent transportation system scenario. Figure 2 shows the sensor taxonomy and the relations between the sensors with other concepts of the ontology. The sensors can be located in both the vehicles as in different infrastructure elements, for example as part of bridges, roads, traffic signs, etc.

The principal sensors we use in this work are related to environmental measures and to flow detection. As environmental sensor we have snow and fog detectors, temperature and humidity sensors. Regarding to flow detection we use crowd, pedestrians and car sensors.

As we can see in the figure, sensors can be classified taking into account their energy requirements into active and passive; regarding the nature of the measures into magnetic, chemical, mechanic and thermic; and regarding the nature of the output into digital, analogic or temporal.

We have defined the relation *has_output_nature* (brown color) to specify the nature of each sensor output; the relation *has_measure_nature* (yellow color) to specify the nature of the physical variable measured; and finally the relation *has_energy_requirements* (gray color) is used to differentiate between the sensors that generate the output signal without the need for external power supply, of those that require power to perform this function.

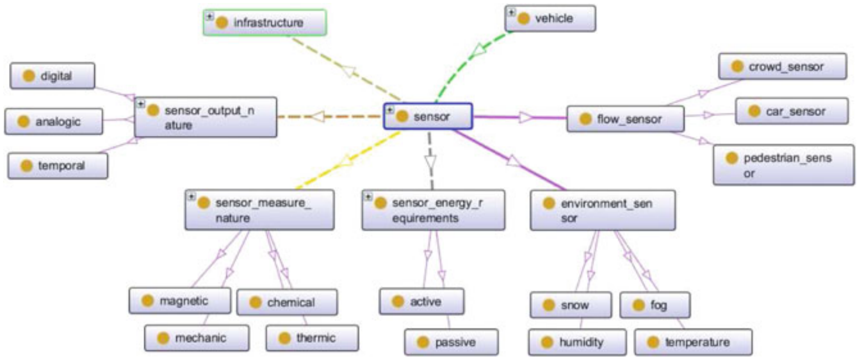


**Fig. 2** Concepts related to sensors

## 3.2 The Multi-agent System

At the top layer is the multiagent system. Here the different agents perform their tasks using the information stored in the ontology through different queries. The multiagent platform was developed using de *Java Agent Development Framework* (*JADE*). As ontology query language, SPARQL [17] has been used.

The agents that we have defined in the system are:

- *Driver Personal Agent*: This agent is in charge of performing the driver personal tasks, taking into account the driver preferences and the driver behavior.
- *Environment Agent*: This agent is responsible of providing the information related to the environment, measured by the vehicle sensors, for example the temperature and the humidity values.
- *Air Conditioner Agent*: The principal task of this agent is the air conditioner settings, taking into account the values of temperature and humidity measured inside and outside the vehicle and the driver's preferences.
- *Car Agent*: This agent was defined to perform in automatic way, the different actions related to the car movements following the specific route, the traffic signs and traffic regulations.
- *Road Agent*: This agent is responsible of performing the tasks related to the road, for example, determine if the road is congested taking into account the information of the traffic flow collected by the sensors.
- *Traffic Light Agent*: This agent perform the tasks related with the traffic light settings, such as: adjust the duration of the traffic light taking into account the traffic flow and the weather conditions.

- *Weather Agent*: This agent performs the tasks related to the weather conditions, for example provide the weather information to the rest of the agents of the system and make predictions related to the weather.

# 4 Cases of Study

Two different cases of study are presented in this section. The first one is concerned with the air conditioner settings depending on the temperature and humidity values measured inside and outside the car, and also the user's preferences regarding the environment parameters. The second one is related to the traffic light duration time adjustment taking into account different traffic elements such as the level of congestion of the roads and the weather conditions. With the accomplishment of these tasks the system allows the improvement of the safety and comfort of the driving process.

## 4.1 The Air-Conditioner Setting Scenario

This is a simple example scenario and consist in regulate the air conditioning of the car for better comfort while driving. As we can see in Fig. 3, three agents are involved in this task, the air-conditioner agent, the environment agent and the driver personal agent. To perform this task, the temperature and humidity sensors located in the vehicles are needed.

The air conditioning setting task consists in compare the temperature and humidity measured inside the car with the temperature and humidity outside. With these values and the values of the driver's preferences (managed for the driver personal agent), the air-conditioner agent is able to make the decision of adjust the temperature and humidity of the car. The accomplishment of this task allows the comfort of the driving ambient.

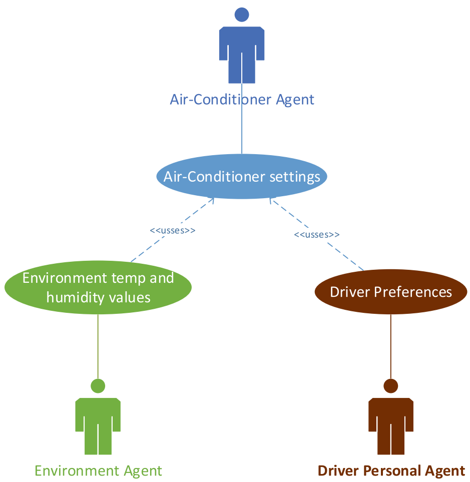


**Fig. 3** Use case diagram of the air-conditioner settings task

Figure 4 shows a sequence diagram of the air conditioner setting use case. As we can see in the figure, first, the air conditioner agent sends two request message regarding temperature and humidity, one asking for the temperature and humidity values to the environment agent and the other asking for the driver preferences to the driver personal agent. A person may have different preferences in terms of temperature depending on where is located.

Therefore, once the personal agent receives the request, he consults with the ontology to know the location of the person. Then, knowing the location, the agent queries the database for the user preferences for that particular location and sends that values to the air conditioner agent. Finally, knowing the driver preferences and the environment temperature and humidity values, the air conditioner sets the right combination of parameter values to ensure user comfort.

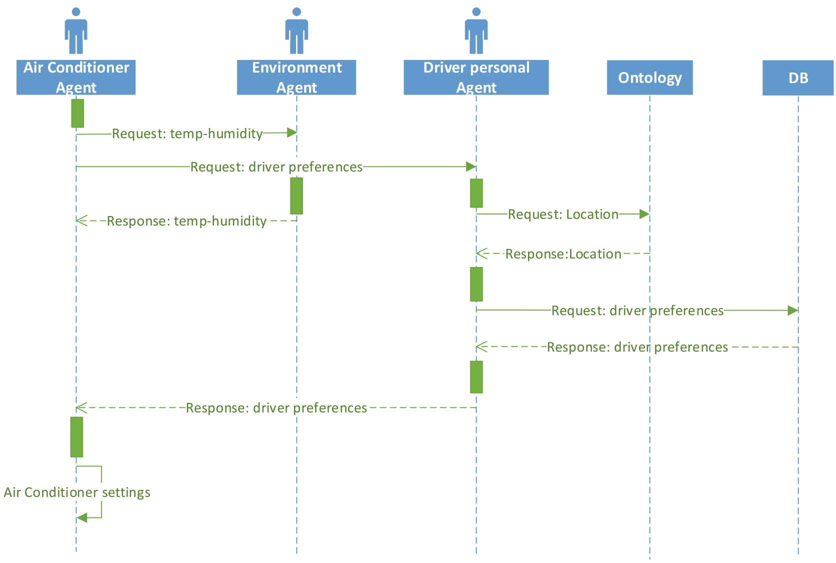


**Fig. 4** Sequence diagram of the air-conditioner settings task

## 4.2 Traffic Light Adjustment Scenario

The second scenario is related to the traffic light adjustment, taking into account the traffic flow and the weather conditions. Figure 5 shows the use case diagram of the traffic light adjustment scenario. Two use cases are involved in this task. These use cases are: the flow detection and the weather events detection in the specific road.

Figure 6 shows the sequence diagram to accomplish the traffic flow detection task. First, the agent queries to the ontology to obtain the information about the segment and

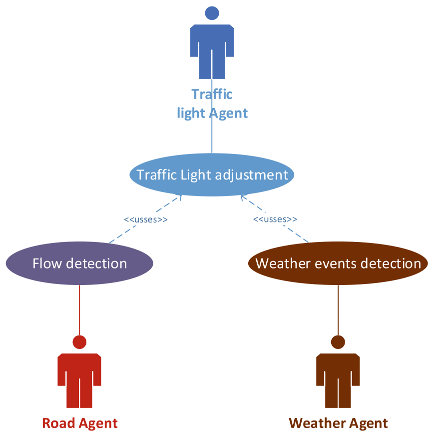


**Fig. 5** Use case diagram of the traffic light adjustment task

lane where the traffic light is located. The ontology contains detailed information on each segment and lane, such as its location (latitude and longitude) and the maximum density of the lane. From the coordinates of the beginning and end of each lane segment, using the SWRL rules, the reasoner can infer the length of the lane.

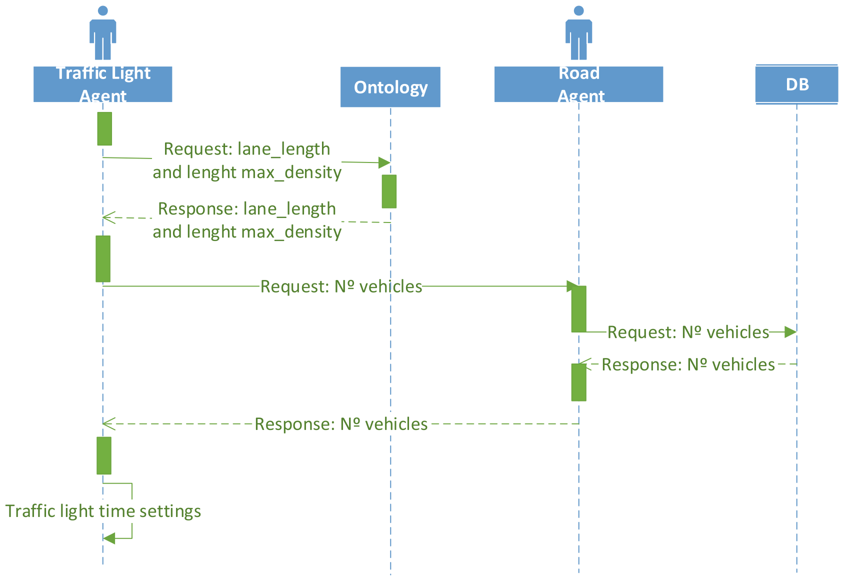


**Fig. 6** Sequence diagram of the traffic light duration time task

Taking into account the length of the lane and the number of vehicles detected by the road sensor, the traffic light Agent can compute the real density of the lane. The density is defined as the number of vehicles per unit length of the roadway at a specific time [18]. The equation of the density is the following:

$$density = \frac{N}{L},$$

where N is the number of vehicles detected by the road sensor in the specific lane, and L is the length of the lane. Once the lane density is computed, the value is compared to the maximum density. If the actual density is greater or equal than the maximum density, it is assumed that lane is congested.

Finally to decide the duration of the traffic light state we use the following rules: if the traffic light is in red, and the road segment is congested, then the duration time of the light is decreased; however, if the traffic light is in red and the road segment is not congested, then the duration time of the light is maintained in the default value. If the traffic light is green and the road segment is congested, then the duration time of the light is increased, while if it is not congested, the duration time is maintained.

## 5 Conclusions

In this paper a multiagent system using ontologies to improve the driving environment is proposed. The system performs different tasks in automatic way to increase the driver safety and comfort using sensor information.

The architecture of the proposed system consists of four interconnected layers. At the bottom is the sensor layer, in which the different sensors collect the information related to the traffic environment. The next one is the ontological layer, where we have developed a general ontology of the domain of road traffic in OWL. Finally in the upper layer are the agents, who perform their tasks accessing the information stored in the ontology through SPARQL queries. Examples of these tasks are the air conditioner parameters' setting and the adjustment of the traffic light duration time, taking into account the traffic flow and the weather conditions. This system allows us to give higher priority to road segments that are congested over others.

Several experiments have been performed, simulating actual road traffic situations. It has been shown that the automatic adjustment of the duration of the traffic lights contributes to optimize the traffic flow, allowing drivers to gain time along the route. To carry out this process, the system only takes into account the level of congestion and the weather conditions of the corresponding road segment. However there are many other factors involved in this process which have not been taken into account, such as the congestion level of other road segments along the route. Taking this into account, we propose as future work, to carry out different negotiation algorithms between the agents involved in deciding the status and duration of traffic lights along the route.

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