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An In-Vehicle Tracking Method Using Vehicular Ad-Hoc Networks with a Vision-Based System

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***Abstract*—Vehicle tracking is an important issue in intelligent vehicle automation systems since it can be used to increase safety, convenience and efficiency in driving. Many of the methods for vehicle tracking use a vision-based system to recognize the neighboring vehicles and provide a real time map of nearby vehicles. In other methods, wireless communication between vehicles has been used to locate the vehicles within range and provide tracking information for driving assistance applications. In this paper we present a combination of both a vision-based system and a wireless based system to provide more accurate real-time information about neighboring vehicles. We assume that some of the vehicles are equipped with GPS receivers, a Dedicated Short Range Communication (DSRC) transceiver and one or more cameras mounted on the vehicle. This tracking method has been implemented and evaluated in urban, highway and intersection scenarios under different adoption rates. The results show that a combined approach can be more effective.**

Keywords*— *Intelligent Transportation System; VANET-Based Vehicle Tracking System; Vision-Based Vehicle Tracking System

I. INTRODUCTION

Having information about the environment surrounding a vehicle can assist a driver in driving safer and making driving more convenient. Different sources of information can be available for use by vehicles. Having knowledge of neighboring vehicles can provide useful information for intelligent vehicle (IV) applications, such as collision warning systems or alternative route planning systems. With such information, the driver can make more reliable decisions and has a better chance of reacting properly in emergency situations.

Using wireless communication is one of the ways to obtain information about the vehicle's environment, and, in particular, the status of other vehicles, such as their location, speed and other data. Vehicles can exchange information with other vehicles and inform them about their location, speed, acceleration, etc. Having this information gathered from other vehicles a vehicle can locate neighboring vehicles. Such exchanges of information about neighboring vehicles are constrained to vehicles within the range and messages can be interfered with, as in an urban environment.

On the other hand, vehicles can also benefit by using cameras as another source of information to monitor the road and nearby traffic. Vehicle tracking via image processing systems is done by mounting cameras on the vehicles which provide images to a processing system to recognize other vehicles. Depending on the cameras and image processing, vehicles at some distance can be detected and even properties of those vehicles, such as their speed, can be determined. This information could augment the information being exchanged among nearby vehicles and even propagated to other vehicles. However, if a vehicle is occluded or partially occluded, the cameras may not able to detect it and it would be out of the view. Wireless communications between vehicles could augment such vehicle identification.

Using cameras to capture elements of the surrounding environment and tracking the neighboring vehicles provides the technology with valuable information which can be used in many different situations and for many different applications. As noted, the main shortcoming in using cameras for tracking vehicles is that they can provide the information about the vehicles only in their sight and in lots of situations. On the other hand, vehicle-to-vehicle communication can provide driving assistance systems with more information about position, speed and directions of nearby vehicles regardless of their visibility. However wireless based methods also have some limitations. Not all the vehicles may be equipped with wireless communication facilities, messages may experience interference and there could be other objects, like pedestrians, animals, etc., which cannot report their status using wireless systems, although information about their location could be critical.

To overcome some of these shortcomings, we propose a new method of vehicle tracking which uses both technologies together to track the vehicles. In our vehicle tracking method, each vehicle sends a map request via wireless to other vehicles in range and based on their responses it updates its own information. We also assume that not all the vehicles are fully equipped and consider the implications.

We have implemented a Vehicular Ad-Hoc Network (VANET)-based vehicle tracking method for vehicles which receives the camera information from other vehicles and uses its own camera information to match the received information and to update its own information. This vehicle tracking method has been implemented and tested using the Vehicles in Network Simulation (Veins) which uses OMNet++ [1], (wireless network simulation tool) linked to SUMO [2] (a road network simulation tool) and a camera simulator which mimics camera operation which is mounted on a vehicle. Our tracking method has been tested in a city network based on Erlangen [3] and in highway network based on 401 highway in Ontario [4]. Our vehicle tracking method contributes to research in the following ways:

- Previous tracking methods have used either wireless communication or vision based systems to detect neighboring objects and to provide a view of the surrounding environment. In the proposed tracking system, both of these technologies have been used to overcome their respective limitations and provide more reliable and more accurate information about the objects around the vehicle.
- Our vehicle tracking method does not rely on other vehicles and it can work in the situation in which no vehicle around is equipped with wireless technology. In this case the system just uses its own information obtained from its cameras and a vision based tracking system. Generally, our system can work if all the vehicles are equipped with both camera and wireless communication, with just wireless or neither.
- Our system works well in specific traffic situations, such as an intersection or in low light situations, where other tracking methods cannot operate well.

This paper is structured as follows. We present related work on which this paper is based in Section II. In Section III, the vehicle tracking method is described. In Section IV the simulation environment is explained and in Section V, the results of a simulation of our vehicle tracking method are examined. Finally, Section VI provides some concluding remarks and future directions for this research.

II. Related Work

In this section, some of the previous work in the field of vehicle tracking are discussed. We also review simulation environments for vehicles on roads.

Using one or more cameras to detect and track neighboring vehicles is a common way to provide necessary information for many different intelligent transportation applications such as forward collision warning systems, travel management systems, etc. A vision based vehicle detection and tracking system was presented by B. Coifman [5], [6]. This tracking system was designed to operate under challenging conditions, such as various lighting conditions. In this vision based tracking system, instead of tracking an entire vehicle, vehicle features are tracked which makes the system less sensitive to the problem of partial visibility.

Another vision based vehicle tracking system was presented by M. Bertozzi which detects and tracks vehicles based on a monocular image sequence [7]. M. Betke has also introduced a vision based tracking system which recognizes and tracks multiple cars in hard real time from sequences of images [8]. A.f Alin, has presented a vision based tracking system which uses the street information and attractor-based adjustment of the probabilistic forward prediction in a Bayesian grid filter to track other vehicles [9].

A real time object tracking approach for the design of a video based freeway traffic monitoring system was proposed by B.Gloyer [10]. The tracking algorithm operates based on mapping the detected vehicles onto the real 3D scene. The proposed tracking algorithm makes an estimate of expected position of the vehicles as well as tracking all the vehicles on the road [10].

Other than using a camera to capture surrounding environment, wireless communication among vehicles can also provide the information for vehicle tracking systems.

S. Rezaei etc. introduced four different schemes for tracking neighboring vehicles with the use of wireless communications. Based on these schemes, each vehicle broadcasts its GPS position, speed and heading to other vehicles via wireless communication. In their first scheme, the sender broadcasts its information every 100ms and the receiver assumes that the sender remains constant until reception of the next message. The second scheme provides the receiver with a model estimator which estimates the position of the sender based on the model and the received information. In the third scheme, the sender uses a model estimator as well as the receiver. Finally, in the fourth scheme the sender repeats its message a few times within a short time window [11].

K. Shafiee introduced a routing protocol for vehicular ad hoc networks which uses a vehicle tracking method to position neighboring vehicles [12]. In this vehicle tracking method, vehicles send beacons reporting their position to other vehicles. Based on the information obtained from neighboring vehicles, each vehicle can calculate the density of vehicles in the network and select the adequate route to communicate via VANET.

A joint rate-power control algorithm for broadcast of self-information that provides vehicle tracking is presented by C. Huang [13]. This algorithm performs based on two modules, a rate control module which decide how frequently a vehicle should broadcast its information, and a power control module which determine how far the information should be broadcast.

Y. Fallh has introduced a cooperative tracking method for vehicles, which uses the state information of neighboring vehicles broadcast by themselves and provide an estimation of their locations on the road. The effect of different choices of rate and range of the transmission on such kinds of tracking system is analyzed [14].

The most significant problem of vision based vehicle tracking systems is that these systems do not have any information about the vehicles or other objects which are not in camera's field of vision, especially near intersections. Also, object detection with use of a camera depends on the lighting in each situation. In contrast, communication among vehicles can provide position information of the vehicles within communication range or even propagate that information. But vehicles out of range or without communications capability are not trackable. In contrast, cooperative vehicle tracking systems can be considered to overcome these problems. We have combined both vision based systems and wireless systems and introduced a new vehicle tracking method and tested it in a simulation environment.

Having a reliable simulation environment is a significant element in the development and evaluation of an intelligent transportation application. There has been a number of different simulation environments developed in this area.

D. Gruyer has presented a cooperative system simulation architecture developed within the interconnection of the sensors simulation platform SiVIC (“Simulateur Véhicule - Infrastructure - Capteurs”, Vehicle – Infrastructures - Sensors Simulator) and the prototyping platform RTMaps (Real Time Multisensor Advanced Prototyping Software) [15]. The SiVIC simulator is interfaced in real-time with the RTMaps software which allows prototyping and testing of ADAS (advanced driver assistance systems) and behavioral analysis applications in a simulated environment.

S. Eichler has presented a simulation environment which can be used to analyze the effect of real-time vehicle-to-vehicle warning message distribution applications on road traffic [16]. Three major components of this simulation are: the traffic simulator CARISMA, developed by BMW to simulate the traffic network; the network simulator NS2 to simulate mobile vehicle-to-vehicle network; and a comprehensive ad-hoc agent for vehicle-to-vehicle warning message propagation.

C. Sommer has developed a simulation framework that provides coupled network and road traffic simulation called Veins (vehicles in network simulation) [17]. For network simulation, OMNeT++, a simulation environment free for academic use, is implemented to model realistic communication patterns of VANET nodes and the traffic simulation is performed by the microscopic road traffic package, SUMO. Veins supports the active exchange of control and statistics data and also Veins provides a framework for the interaction between the network simulation and the road traffic micro-simulation. Both road traffic simulation and network simulation are bi-directionally coupled and simulations are performed on-line. This way, not only the influence of road traffic on network traffic can be modeled, but also vice versa. In particular, the influences of inter-vehicle communication (IVC) on road traffic can be modeled and complex interactions between both domains examined. We have used Veins as the basis of our current research.

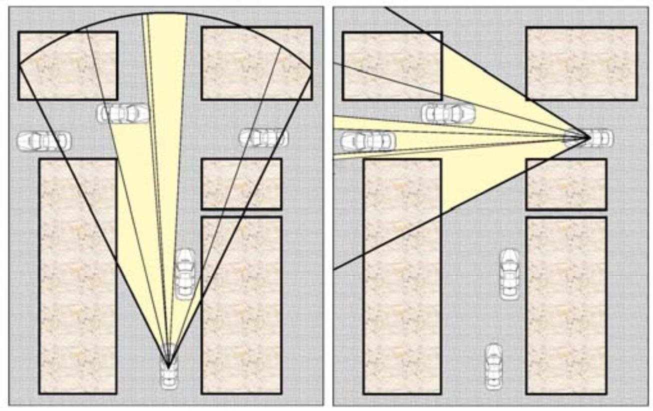
III. Vehicle Tracking Method

As noted, both vehicle-to-vehicle communications and using cameras for tracking vehicles both have plusses and limitations. Cooperative tracking methods can provide driving assistance systems with more information about vehicles. We present a new vehicle tracking method which integrates both camera based methods and wireless based methods to take the advantages of both kinds of systems. “Fig. 1” shows how sharing camera information can provide more accurate view of road for each vehicle.

Our tracking method uses camera technology integrated with wireless technology to provide information about neighboring vehicles. The camera captures the surrounding environment and the associated vision system provides the position, direction and speed of all the vehicles which are visible to the camera. In some situations, like reaching an intersection, it would be helpful if the system had information about other vehicles which are not in camera’s sight, e.g. the example in “Fig. 1”. To do so, wireless technology can be used.

Each subject vehicle (SV) will send a wireless message to neighboring vehicles (NV) in the surrounding area and request their position, speed and direction as well as their camera’s information about other vehicles’ position, speed and direction. Each NV sends the requested information along with a timestamp.

Fig. 1. In the right picture the vehicle can detect two other vehicles using its camera and in left picture another vehicle can detect two other vehicles by its camera. If these two vehicles share their camera views they can have a more complete view of road.



Each wireless message received by an SV contains the positions of detected vehicles by the sender and the position of the sender vehicle itself. Other than a list of detected vehicle positions, the message contains a timestamp which shows the time this list was created. The SV has its own list of the positions of detected vehicles and when it receives a wireless message, the SV processes the message and adds all the vehicles’ positions in that list to its own list. Each response message is of the following format:

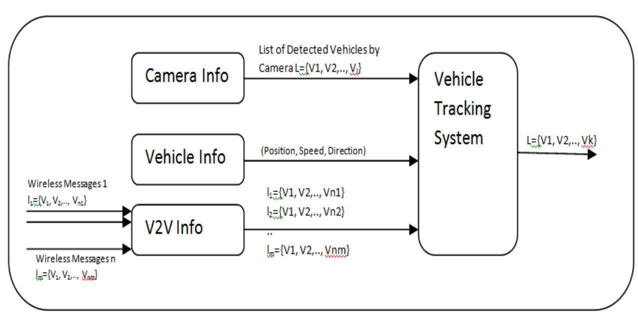
Response Message = (TimeStamp , ListOfVehicles)

ListOfVehicles = {$\text{Vehicle}_{\text{sender}}$, Vehicle_1, Vehicle_2, … , Vehicle_i, … , Vehicle_n}

Vehicle_i = (Position_i , Speed_i , Direction_i)

The first triple in the list represents the sender information and the next ones are the information about the vehicles detected by the sender’s camera.

Fig. 2. Tracking System Structure

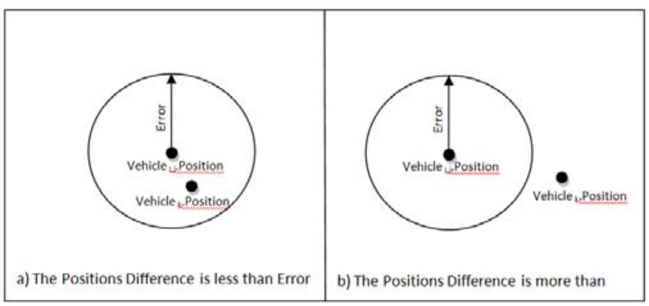


SV collects the responses within 2 seconds and ignores the messages received after that. When the SV receives the NVs' information, it matches the information to its own list of detected vehicles and creates a bigger view of surrounding environment. To do so, based on the estimation of vehicles' position, the system either finds the match for each vehicle in its own list provided by its camera, considering an acceptable error, or adds its "view" of vehicles as a new vehicle (See "Fig. 2"). The error is based on the time at which the request was sent, the timestamp of the received message, the vehicle speed and direction; it is calculated as follows:

For Each $ListOfVehicle_{si}.Vehicle_j$ from V2V $Message_{si}$
  $Error_{i,j}$ = (CurrentTime – $MessageTimeStamp_i$) * $Speed_{i,j}$
If There is no $Vehicle_k$ in $ListOfVehicle_{SV}$ where
  ($Vehicle_{i,j}$.Position – Error <=
  $Vehicle_k$.Position <= $Vehicle_{i,j}$.Position + Error)
Then Add $Vehicle_{i,j}$ to $ListOfVehicle_{SV}$

If the system can find each vehicle with same position in its list of vehicles or if it can find one with an error less than or equal to the Error calculated above, consider both the same vehicle and ignore it. But if it cannot find such a vehicle in its list, it adds the vehicle information to the list (See "Fig. 3").

Fig. 3. Vehicle Tracking System adds a new vehicle to the list if it is not already in the list within an error; Vehiclei,j in 3.a will not be added to the list while Vehiclei,j in 3.b will be added to the list



The more vehicles that can be detected by the system, the more accurate and reliable the tracking system can be.

Fig. 4. Map of Erlangen, Germany, as available from the OpenStreetMap project [17], [4].

Fig. 5. Map of 401 Highway, Canada, as available from the OpenStreetMap project [4]

We have tested our tracking method with an Erlangen city map ("Fig. 4") and a 401 Highway map ("Fig. 5") in Ontario in light traffic congestion and heavy traffic congestion and also specifically at intersections.

In order to evaluate our vehicle tracking method, we have used a simulator which consists of three main components; a vision simulator, a wireless communication simulator and a traffic simulator. The specification of these components and their connections is explained in next section.

IV. SIMULATION

We have used a simulation environment for inter-vehicle communication to test our vehicle tracking method. To model the communication pattern of VANET nodes, OMNeT++ using the MiXiM framework has been used. Road network simulation is done using Simulation of Urban Mobility (SUMO) package [3]. The Vehicle in Network Simulation (Veins) simulator has been used to link OMNeT++ with SUMO. Our vehicle tracking method is implemented as a custom module of OMNeT++. The tracking module uses a vision-based system integrated with wireless communication to simulate a real-time tracking system. In order to simulate our vehicle tracking system, we designed a vision simulator which mimics camera operations and provides the system with a simulated image of the surrounding environment. The vision simulator, wireless module and road network simulator are explained briefly in the following.

A. Vision Simulator

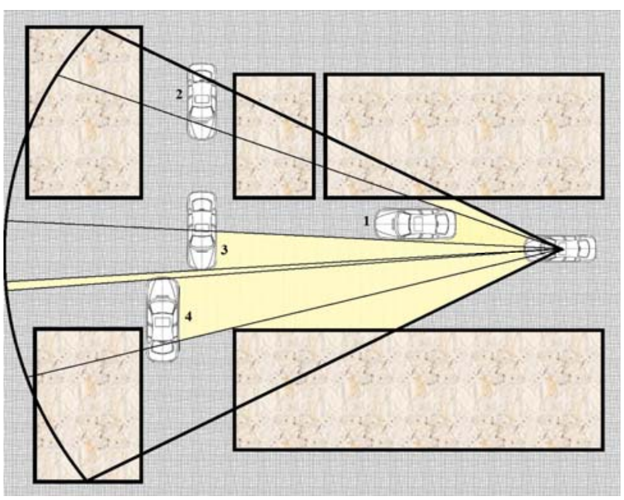
In order to simulate our vehicle tracking method we needed to have a vision module in our simulator which could act as a real camera installed in the vehicle. Computer vision algorithms provide a mathematical model of world based on the series of images captured by cameras. However while we are using a VANET and traffic simulator we already have access to 2D mathematical model of the world. Since we are not interested in the height of objects, a 2D model of the world works as a good approximation of what cameras in a vehicle can "see". We use this to determine which vehicle or obstacle in this model would be visible to each camera.

All vehicles are modeled as rectangles and therefore can be presented by four points which are the corners of the rectangle. All buildings are modeled as a set of points which are the corners of the shape of the building. We assume a single camera in each vehicle (though in practice, it may be stereo cameras to determine depth information). All cameras are specified by the angles covered by each camera and the associated maximum distance over which they can accurately detect and position the objects.

Having shape and position of all buildings and vehicles and also the specification of each camera we present the following algorithm to determine all visible objects for each vehicle equipped with a camera:

1. Create a list of all observable objects, i.e., the vehicles or buildings which have at least one of their points in the observable area of the vehicle's camera.
2. For each vehicle, determine for each object in its list of observable objects the two points nearest to the camera position on a vehicle, that object will be defined by the line joining these two points.
3. For each object (represented as a line) in the list of observable objects, determine the other objects which are located completely or partially beyond it.
4. After running the previous steps for all objects of the list of observable objects, determine the visibility percentage of each object and any object with a visibility percentage less than 50% is removed from the list.

Fig. 6. Camera Simulator



"Fig. 6", illustrates how the camera simulator works; a vehicle with its camera area highlighted is shown in an urban setting with buildings and other vehicles. The vehicles which are beyond other vehicles or behind a building will be considered to be invisible to the camera. In "Fig. 6", vehicle1 is completely visible, vehicle2 is completely invisible, vehicle3 is partially visible but less than 50% (vehicle1 partially obscures vehicle 3) and so would be considered not visible to the camera, vehicle4 is visible and it is considered visible to the camera since more than 50% of it is visible.

This approach does not take into account the height (z axis) and creates a model in 2D. However, since most roads are relatively flat and buildings are higher than vehicles, identifying vehicles in 3D would be approximately the same as this approach. In other words, when a vehicle is positioned completely behind a building or another vehicle is consider invisible which is the same in real world and when it is partially behind another vehicle or building depending on how much of the vehicle is in view, it is considered visible or invisible which is almost the same in real world. Therefore, the camera simulator detects the vehicles relatively the same as a real camera.

B. *Wireless Module*

A multi-Channel IEEE 1609.4 and IEEE 802.11p Enhanced Distributed Channel Access (EDCA) model is implemented in Veins. This model encompasses the 80211.p DSRC PHY and MAC layers, including Access Categories for QoS, the Wave Short Message (WSM) handling, and beaconing WAVE service announcements, as well as multi channel operation, such as the periodic switching between the Control Channel (CCH) and Service Channels (SCHs) [18], [19].

The messages are transmitted with bitrate of 11Mbps and transmission power of 20mW on the Control Channel (CCH). We model path loss with path loss coefficient of 2.0 and shadowing with a mean signal attenuation of -89dB and standard deviation of 4dB.

C. *Road and Traffic Network Simulator*

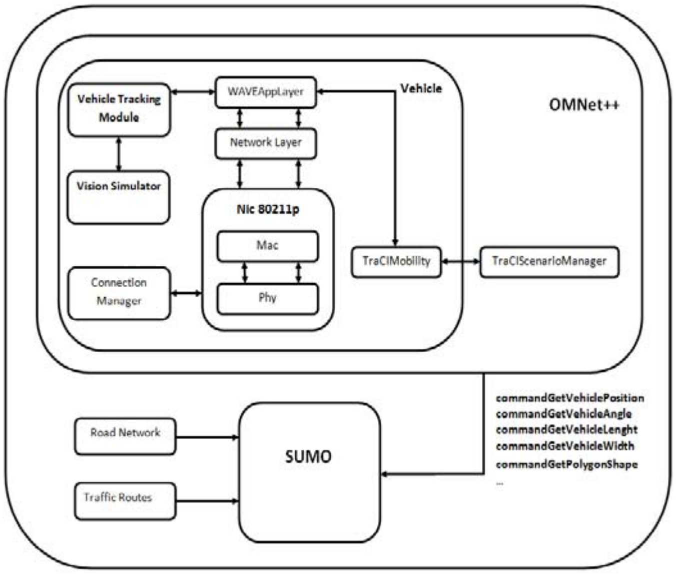
SUMO has been used to simulate of road and traffic network. There are API calls (known as commands) available in TraCIScenarioManager and TraCIMobility modules of Veins which each module can use to directly interact with running traffic simulation (SUMO). In order to design our vehicle tracking module, we have used some of these commands and also we have implemented additional commands which were not present in the original TraCIScenarioManager module or in TraCIMobility module. For this simulation we have implemented four commands which are described as follows:

- *commandGetVehiclePosition: this command returns real-time position of any vehicle from SUMO.*
- *commandGetVehicleAngle: this command returns the real- time direction of the vehicle.*
- *commandGetVehicleLength: this command returns the length of given vehicle.*
- *commandGetVehicleWidth: this command returns the width of given vehicle.*

Using these commands, the camera simulator can shape a rectangle for each vehicle and use it to identify the visible objects.

"Fig. 7" shows the simulator components and flow of information between these components as well as our vehicle tracking module in relation to other modules in the simulator.

Fig. 7. Simulator Components Integration



V. EVALUATION

We evaluated our vehicle tracking system under different situations when different percentages of vehicles are equipped with wireless communication or both camera and wireless (our presented vehicle tracking system). Each subject vehicle (SV) sends a map request every 100 seconds through a wireless message to neighboring vehicles (NV) in range and asks for their information about other vehicles in their cameras' sight. When NVs which have wireless technologies receive the map request message they send the information about their positions along with the positions of the vehicles identified through their cameras. In the case that they do not have a camera, they just send their own positions. The SV collects all the information within two seconds and ignores the messages received after two seconds. Then the SV combines the collected information with its own information provided by its camera to form a better view of the road and vehicles on it.

We calculated the number of messages transferred between vehicles and the number of tracked vehicles assuming different adoption rates (number of equipped vehicles) in six different traffic road simulation scenarios; light traffic on highway (150 vehicles traveling on the roads), heavy traffic on highway(300 vehicles), light traffic in urban area (90 vehicles), heavy traffic in urban area (180 vehicles, light traffic at intersections (76 vehicles) and heavy traffic at intersections (160 vehicles).

The adoption rate could be different based on the proportion of the vehicles which are: a) not equipped with tracking technologies; b) are only equipped with wireless communication technologies and no camera; c) are equipped with our presented tracking system and d) use both camera and wireless technologies to track neighboring vehicles. When 100% of the vehicles are not equipped, 0% are equipped with wireless technology and 0% with wireless and camera technologies, the adoption rate is denoted as 100%-0%-0%. On the other words, the first number shows the proportion of the vehicles which are not equipped, the second number shows the proportion of the vehicles which only use wireless technology to track other vehicles and the third number shows the proportion of the vehicles that use our integrated tracking system. Therefore, a 33%-33%-33% adoption rate means that 33% of all vehicles traveling on the road are not equipment with any technology, 33% of the vehicles are equipped with wireless technology, and 33% of the vehicles are equipped with our tracking system (wireless and camera).

"Fig. 8" illustrates the normalized[1] average number of tracked vehicles for different adoption rates in the different scenarios for highway with heavy and light traffic. The results show, as expected, that by increasing the adoption rate, the number of tracked vehicles increases and overall number of tracked vehicles in our tracking method is much more than just the wireless based method.

Fig. 8. Normalized number of tracked vehicles in different tracking methods with various adoption rates in a highway heavy and light traffic; error bars show the range of one standard deviation.

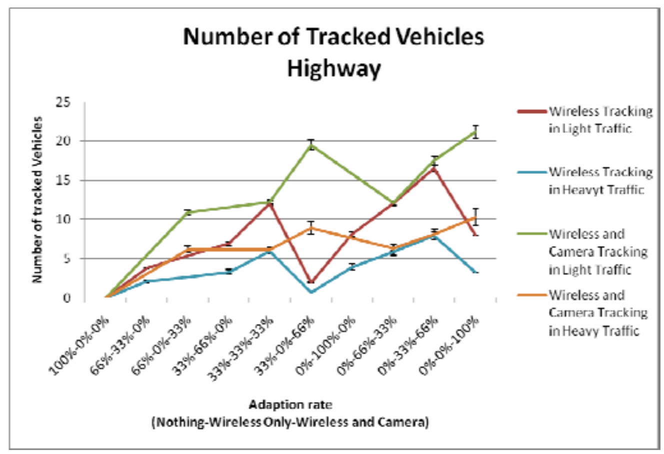
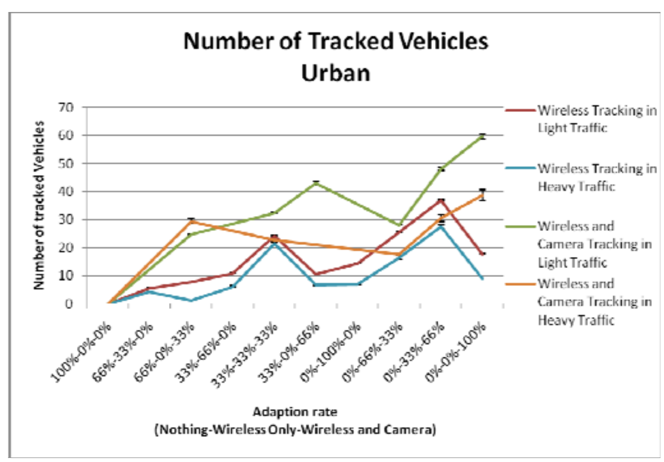


Fig. 9. Normalized number of tracked vehicles in different tracking methods with various adoption rates in the city of Erlangen with heavy and light traffic; error bars show the range of one standard deviation



[1] The normalized average of tracked vehicles was computed by dividing the actual average of tracked vehicles by the total number of vehicles and multiplied by 100.

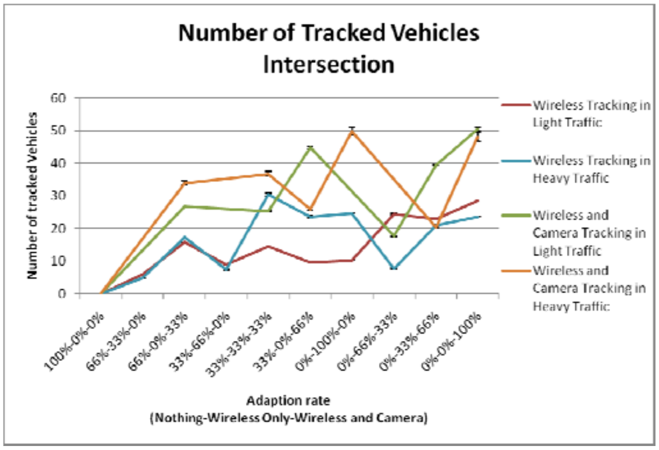


Fig. 10. Normalized number of tracked vehicles in different tracking methods with various adoption rates at intersections with heavy and light traffic; error bars show the range of one standard deviation

The normalized number of tracked vehicles in both tracking methods using various adoption rates in an urban area is shown in "Fig. 9". The number of tracked vehicles in the wireless based tracking method and the integrated tracking method using different adoption rates at intersections with heavy traffic and light traffic is shown in "Fig. 10".

The number of vehicles which could be recognized and tracked only with camera only depends on the number of the vehicles in camera's sight of view. The average numbers of the vehicles tracked only with cameras in different scenarios are shown in TABLE I.

TABLE I. AVERAGE NUMBER OF TRACKED VEHICLES WITH CAMERA ONLY

	Number of Tracked vehicles
Highway Heavy Traffic	1.68
Highway Light Traffic	1.77
Urban Heavy Traffic	3.87
Urban Light Traffic	2.80
Intersection Heavy Traffic	2.68
Intersection Light Traffic	1.08

The results show that using the proposed vehicle tracking method can have significant impact on number of tracked vehicles, especially at intersections where cameras' sights are limited. In these scenarios, even with low adoption rates, a vehicle can recognize a large number of neighboring vehicles. Integrating a vision based system and wireless technologies is an effective approach to track a larger number of the vehicles on the road and provide a better view of the surrounding environment. This, in turn, can provide safer and more reliable intelligent transportation applications.

The other factor which should be considered is the number of messages transferred between vehicles in order to provide requested information. "Fig. 11" shows the average number of transferred wireless messages between vehicles for tracking requests with considering various adoption rates in highway scenarios; the average number of transferred messages per request for an urban area is shown in "Fig. 12" and for intersection scenarios in "Fig. 13".

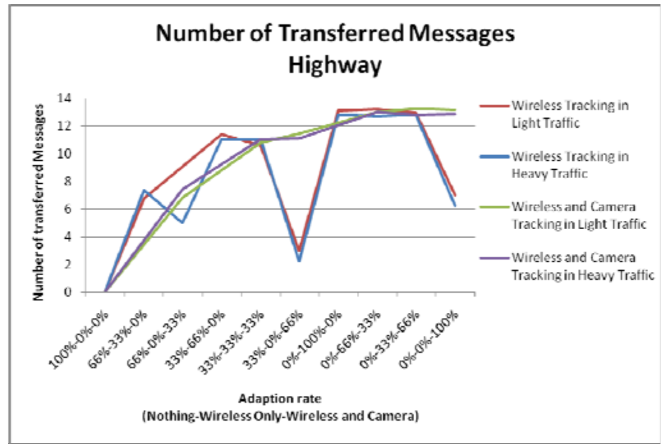


Fig. 11. Number of transferred messages for tracking requests in highway

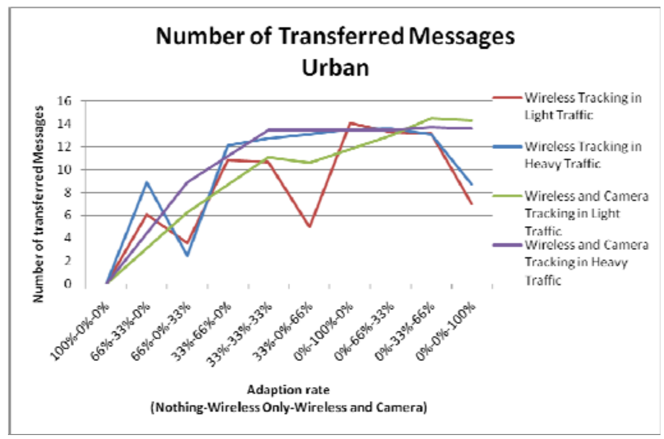


Fig. 12. Number of transferred messages for tracking requests in urban area

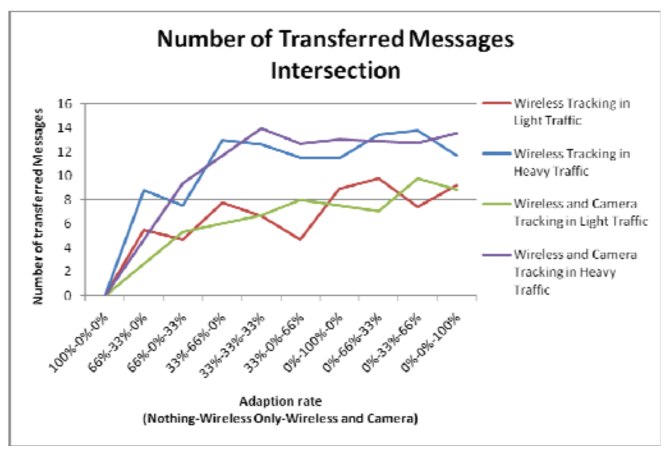


Fig. 13. Number of transferred messages for a tracking request at intersection

Though the numbers of transferred messages in both systems are almost the same, the sizes of messages are different since the amount of transferred information is different. Each tracked vehicle location data contains latitude and longitude which is represented as a float variable with 4 bytes. Therefore, for each tracked vehicle 8 bytes is added to the size of the wireless message. So in the wireless tracking system, the size of each message is approximately 8 bytes because it just includes just one vehicle's location information. The average size of each message in the integrated wireless-camera tracking system can be calculated based on the average number of tracked vehicles with cameras plus its own location information (See TABLE II).

TABLE II. AVERAGE SIZE OF EACH MESSAGE IN INTEGRATED WIRELESS-CAMERA TRACKING SYSTEM

	Average Size of Each Message (Bytes)
Highway Heavy Traffic	21.47
Highway Light Traffic	22.13
Urban Heavy Traffic	38.93
Urban Light Traffic	30.36
Intersection Heavy Traffic	29.48
Intersection Light Traffic	16.61

Overall, the size of the messages in an integrated wireless-camera tracking system is larger than the size of the messages in wireless-only tracking system. The communication system's bitrate is 11Mbps, so the overall impact is not so big as to influence the overall performance of the system. Generally, the integrated camera-wireless vehicle tracking system has shown great potential in increasing efficiency and accuracy in vehicle tracking applications.

VI. CONCLUSION

We introduced, implemented and evaluated a vehicle tracking system which integrates a vision based tracking system with wireless based tracking system. The approach seems to have the benefits of both technologies while avoiding their disadvantages. We evaluated the system via simulation and it shows potential for improving performance of intelligent driving assistance systems making use of information about the surrounding vehicles' locations. The results show that the system can perform well even if a small percentage of the vehicles are equipped.

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