LCDs: Lane-Changing Aid System Based on Speed of Vehicles

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Received March 18, 2016; Revised April 23, 2016; Accepted April 25, 2016; Published June 30, 2016

** Extended from a Conference: Preliminary results of this paper were presented at the IEIE ICEIC 2016. This present paper has been accepted by the editorial board through the regular reviewing process that confirms the original contribution.*

***Abstract*:** Lane change is an important issue in microscopic traffic flow simulations and active safety. Overtaking and changing lanes are dangerous driving maneuvers. This approach presents a lane-changing system based on speed and a minimum gap between vehicles in a vehicular ad hoc network (VANET). This paper proposes a solution to ensure the safety of drivers while changing lanes on highways. Efficient routing protocols could play a crucial role in VANET applications, safeguarding both drivers and passengers, and thus, maintaining a safe on-road environment. This paper focuses on the development of an intelligent transportation system that provides timely, reliable information to drivers and the concerned authorities. A test bed is created for the techniques used in the proposed system, where analysis takes place in an on-board embedded system designed for vehicle navigation. The designed system was tested on a four-lane road in Neemrana, India. Successful simulations were conducted with real-time network parameters to maximize quality of service and performance using Simulation of Urban Mobility and Network Simulator 2 (NS-2). The system implementation, together with the findings, is presented in this paper. Illustrating the approach are results from simulation using NS-2.

***Keywords*:** GPS, RSU, Smart cities, V2V, V2I, VANET, ITS

1. Introduction

Taking the upcoming model of driverless cars and smart cities into consideration, it is very important to build up mobility models and algorithms for safe and efficient environments. With the introduction of the vehicular ad hoc network (VANET) in the field of intelligent transportation systems, a new area for research has evolved. A VANET is basically a subset of mobile ad hoc networks (MANETs), where all the vehicles behave as moving nodes. Vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications [1] play a very important role in this aspect. In the vehicle-to-infrastructure model, information about the traffic is collected at the roadside unit (RSU), is broadcast to the receiver vehicles, and is then sent to a central server for monitoring the vehicles. Fig. 1 shows the communication model for central monitoring of vehicles. The vehicles on the road communicate with each other, and then the information is sent to the RSUs. The RSUs exchange information with the central traffic-monitoring server via the Internet. The communication is bidirectional.

The road tracks are assigned with particular speed limits for different lanes, and the vehicles moving on them have to follow those particular speed limits. While moving in these lanes, vehicles can increase or decrease their speed and change lanes accordingly. Changing lanes will be possible only with a minimum gap between the vehicles set in the algorithm. But if any particular vehicle is not complying, the hardware-implemented on-board unit (OBU) in the vehicle will display a warning message to the driver to either change speed or change lanes. If the default vehicle does not follow the speed limit, then an emergency warning message will be broadcast to the vehicles and the RSUs within communications range of the vehicle in order to maintain a safe environment. Other vehicles also receive

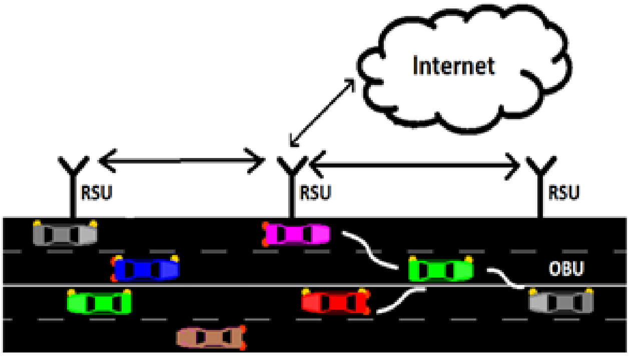

Fig. 1. Communication Model (Vehicle-RSU-Central Server).

this information, which will influence their movements in a particular fashion. As soon as the number of the default vehicle's messages increases, the RSUs transmit the information to the nearest traffic monitoring system. This algorithm-based model use the concept of lane-changing with respect to speed with the help of information received from a global positioning system (GPS). Latitude and longitude are parsed, and the current position of the vehicle is checked with respect to the lane, and the speed of the vehicle is checked with respect to the lane's speed limit. If the vehicle is exceeding the allowed speed, the driver will be warned, first by an alarm and message on a liquid crystal display (LCD) for a certain time duration. The rest of this paper is organized as follows. Section II provides a brief description of the concept of a VANET and related work in this field. In Section III, the system design and problem formulation are discussed. Section IV defines the protocol. Section V shows the performance evaluation, taking a look at the applications of the GPS and the hardware implementation of the protocol, the traffic model generated with the help of Simulation of Urban Mobility (SUMO) and **mo**bility model generator for **ve**hicular networks (MOVE), followed by simulation of the VANET network in NS-2. Section VI concludes this paper and gives a glimpse of future work to be done on this model.

2. Related Work

The VANET is a vast area for research, which has opened the gates to new possibilities and better technology in the field of transportation in terms of both safety and efficiency. In a VANET, cars are defined as mobile nodes in a mobile ad hoc network, creating a mobile network [3]. Chiasserini et al. [2] discussed smart broadcasting of messages in a VANET. This helped improve efficiency and also security, to some extent.

Nayak [4] proposed a method to calculate the speed of the vehicle based on its position. Vehicles exchange information with the RSU, and the RSU sends it to a central monitoring server.

Kassem et al. [5] presented a paper that proposes a method of vehicle detection and speed estimation based on Radio Frequency. The main drawback is that a vehicle can change to any speed in case of a miss, which can cause an error in the accurate estimation of speed.

Shringar et al. [6] presented a paper that throws light on various technical applications, advantages, challenges, and issues in VANETs, and offered methods to improve the network system. That paper also discussed the techniques involved in secure message transmission, which will aid future work on data authentication.

Kausar et al. [7] proposed an approach for a collision avoidance system in VANETs based on lane changing using GPS-based hardware with transceivers for data exchange.

Zhou et al. [8] discussed lane changing and a safety warning system based on a virtual lane boundary. The safety system alerts the driver based on the width of the lane and the time required to cross it.

In other research [9, 10], authors discussed safe lane change–assistance systems for drivers with the help of cameras and proximity sensors. The basic terminology is to detect the presence of any vehicle in the blind spot, and to change lanes based on the speed and driving style of the driver.

Other authors [11, 12] proposed approaches to lane-change tracking and vehicle detection in a VANET with the help of cameras mounted on the vehicles. The basic process involved is for the camera to make a recording of the vehicle's surroundings, followed by image processing. Lane changing and vehicle tracking is done by using a Hough transform on the results of the processing image data.

Saboune and Arezoomand [13] discussed vehicle detection for safe lane changing. The authors proposed using cameras mounted on the vehicles to detect vehicles in the blind spot.

Cooperative lane-change models have been analyzed [14] where the authors described the requirements associated with optimal lane-change behavior, and then compared the existing lane change models based on these requirements in order to design a distributed cooperative lane-change assistant (D-CLCA) within the European Commission project called REDUCTION.

3. System Design and Problem Formulation

Driving behavior depends on many factors, such as situation, speed, fast lane changes, density of traffic, etc.

Therefore, driving recklessly will cause accidents and also affects traffic movement. Now, if the driver of a vehicle is at fault, and did not follow proper lane-changing protocol, and exceeds the speed limit, then quick actions are required to stop that vehicle.

So what is the solution to check speeding and the lane-changing mechanism of a vehicle to minimize the danger? In addition, how is it possible to send faster warning messages to neighbor vehicles about the situation? Can latency be minimized and the quality of service increased by using an appropriate routing algorithm?

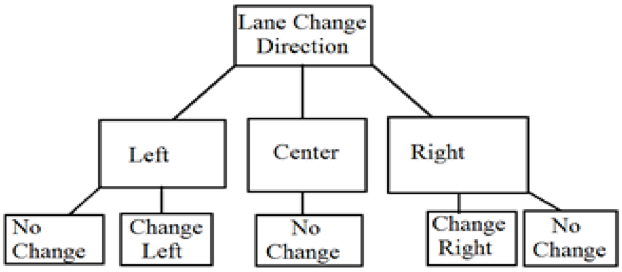

Fig. 2. Basic Lane Change Model.

Existing models

In basic lane-change models, a vehicle in its lane tries to change lanes by moving either left or right. If the gap in the selected lane is acceptable, the lane change is allowed; otherwise, the vehicle remains in its current lane. The basic lane change model is shown in Fig. 2.

Classification of lane change models

Classification of lane change models is done based on the type of lane change execution. Hence, there exist two types of lane change.

(1) Mandatory Lane Change (MLC): This sort of change is fundamental (i.e., a driver must change lanes to take a predetermined route). Suppose a driver needs to make a right turn at the next intersection; then, the driver changes to the required lane, which is considered a mandatory lane change.

(2) Discretionary Lane Change (DLC): This type of lane change happens when a driver changes lanes in order to avoid traffic or avoid following behind a slow-moving truck, in an attempt to maintain the desired speed. This type of lane change is not mandatory, and the driver changes lanes if he/she perceives better driving conditions in the adjacent lane.

Most of the existing models distinguish lane changes as either discretionary or mandatory. This separation implies there are no compromises between mandatory and discretionary considerations.

Also, in order to implement DLC and MLC models, rules for drivers under MLC conditions need to be mentioned. Though this point is generally not observed, only judgment-based heuristic rules are used, which are often generally defined by the distance from the point where the MLC is to be applied. Like decision- and judgement-based lane changing models, there also exist other models, like gap-acceptance and general acceleration–based lane changing models.

(1) Merging Models: If the gap in the target lane is not acceptable, then the subject vehicle forces the other vehicle to decelerate until the gap between them is sufficient. This process is called forced merging. At any instance in this process, drivers are assumed to (a) be monitoring and sensing the traffic environment, evaluating the condition of the target lane to decide if the driver has an intention to merge in front of the vehicle in the lane, and (b) be trying to establish communication with the lagging vehicle so as to understand the driver's intention.

(2) Cooperative Merging: However, in congested traffic conditions, acceptable gaps may not be available, and so, other mechanisms for lane changing are needed. This type of merging happens based on courtesy, or in situations in which drivers try to force merge into a target lane, which in turn slows down the lagging vehicles.

Fig. 3. Ali3d3 Board Used in the Hardware.

5. Proposed System (Speed-based algorithm)

The proposed system uses an Ali3d3 board as the primary hardware for the implemented VANET. It comprises a 500 MHz AMD Geode LX800 central processing unit with two network interface cards, and it also interfaces with a Unex DCMA86P2 mini-PCI card using an ath5k driver when connected to an ordinary WiFi network card using an ath9k driver. The ath5k driver can be changed for this wireless card in order to use the IEEE 802.11p protocol, as the Atheros AR5414 wireless chipset of the DCMA86P2 wireless card supports radio operation in dedicated short-range communications (DSRC) of 5.85GHz - 5.92GHz with seven available bands of 10MHz. The system board peripheral also connects a Long Term Evolution (LTE) module and two antennas used for WiFi and IEEE 802.11p. An external GPS module is used to acquire location information, and an OBU-to-RS232 interpreter collects information about the status of the vehicle. An STN1110 module is used to transmit vehicle status information to the surrounding vehicles with a Bluetooth interface.

The protocol was developed to implement efficient lane changing based on the speed of the vehicle for the sake of safety and an efficient environment in a VANET. This section discusses the Speed based lane change algorithm to study the behavior of vehicles with its implementation, and later on, Section VI implements the algorithm in the hardware module and the appropriate routing protocol, with the mobility model generation checked with the help of SUMO-MOVE and simulation of the algorithm in NS-2.

Definition 1 (Road Segment): A road segment is denoted by R, where $R=\{s(x,y), e(x,y),l,v_l\}$. Here s and e are the starting and end points of the lane, respectively, with (x,y) as the location (x=latitude, y=longitude). l is the number of lanes (five according to the scenario). v_l#is the permitted speed in the lane. The length of the road segment and the width of the lanes can be estimated with the help of the location of *s* and *e*.

Definition 2 (Road Network): Road network is a graph Rn=(j,s). Here, j is the set of all road segment junctions, and s is the set of all road segments.

Parameters:

Assume there are three lanes, Li={L1, L2, L3}, with speed limits (Vi)={V1, V2, V3}, respectively, and a tolerance of 10%.

LBi is the lane buffer ID, which will help in storing the ID of the previous lane in which the vehicle was moving.

Vli and Vui are the lower and upper limits of lane Li. (Each lane has its own upper and lower limit.) The vehicles at the start point initiate the entire path-planning process for travelling in various lanes, L1, L2 and L3, at different speeds, Si={S1, S2, S3}, (the speed of the vehicles).

The GPS will monitor LBi, and helps to locate the ID of the last lane, the current position, and the speed to be stored in a buffer of the monitoring system.

Now, suppose that a vehicle is travelling at speed Sest in lane L3 having upper and lower speed limits at a particular point. The GPS-based monitor system will check the speed of this vehicle against the lane speed limits and send an alert message to the driver to either reduce or increase speed or to change lanes, if driving at the wrong speed. The system continuously monitors the driving style of the vehicle for a particular time, t. If the vehicle changes lanes or reduces speed within time t, the monitoring system gives an OK status to the driver and to the RSU.

A. Speed-based lane change model algorithm

Taking the above assumptions and definitions into consideration, the algorithm is as follows:

Position Verification:

Obtain the values of S_{est}, V_{li}, V_{ui}, w.r.t. L_i

Pos-label

if ($S_{est}<V_{ui}$) **AND** ($S_{est}>V_{li}$)
then
*Alarm Status: **OFF;***
Display **"Speed Under Limit";**
Display S_{est} to the driver**;**
elsif ($S_{est}>V_{ui}$)
Display **"Reduce speed or Change Lane";**
Alarm Status: **ON**;
Timer **ON** ;
Check for **Deceleration/lane change subroutines**;
Update System Variables;
Timer ends;
GPSR based forwarding of the warning message to **RSU** and nearby **vehicles;**
goto ***Pos-label***

elseif($Sest<V_{li}$)
Display **"Accelerate or Change to a Lower Lane."**
If(S_{est} == 0)
Update **Engine State = OFF**
if (Engine State == OFF)
then Display "Vehicle not in motion"; //At the base station
else
Display "Vehicle in motion**";** **//**At the base station
Alarm Status: **ON**;
Timer **ON**;
Check **Acceleration/lane change subroutines;**
Timer ends;
GPSR-based message forwarding to **RSU** and surrounding vehicles;
goto ***pos-label***
Deceleration/Acceleration:
1. **if** ($S_{est}<V_{li}$)
Warning issue: "**Accelerate"**
Check and update S_{est}
Check ***min***$_{gap}$
goto *Position Verification*
2. **if** ($S_{est}>V_{ui}$)
Warning issue: **"Decelerate"**
Check and update for S_{est}
Check ***min***$_{gap}$
goto *Position Verification*
Lane Change:
1. **if** ($S_{est}<V_{li}$) **OR** ($S_{est}>V_{ui}$)
Check ***min***$_{gap}$
If (***min***$_{gap}$ condition not satisfied)
Display **"Lane changing not allowed"**
Else
Display **"Lane changing allowed"**
Update LB_i
goto *Position Verification*

5. Performance Evaluation

This section discusses the workings of the on-board navigation unit and the simulation of the algorithm using NS-2.

A. OBU- GPS–enabled monitoring system

The GPS with respect to the moving vehicles receives the data packets from the satellites and feeds them to the microcontroller. The microcontroller further parses the required data, stores the lane information in the Lane ID buffer, and checks it with the thresholds set. In case of a

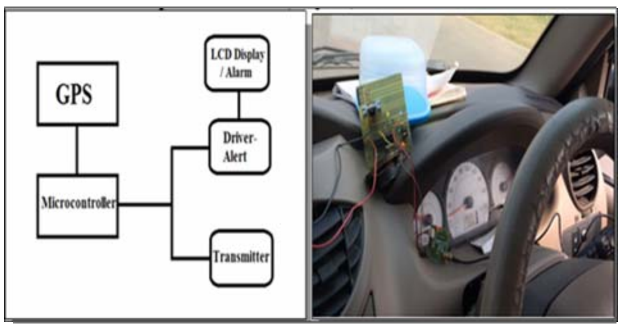

Fig. 4. Block Diagram and Implementation of the Hardware Circuit.

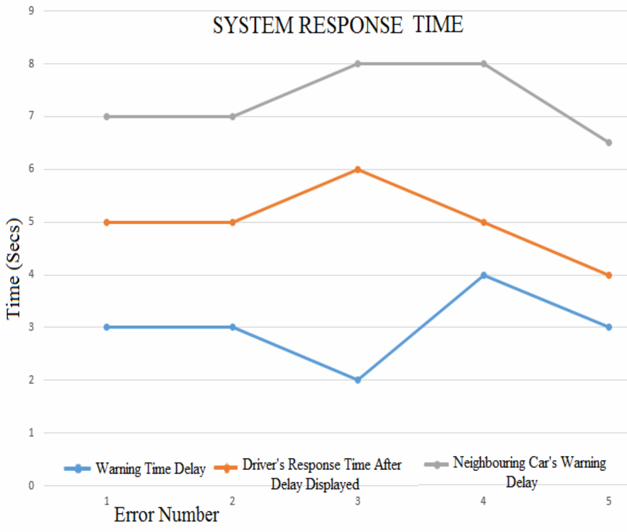

Fig. 5. Graph Showing Response Time in Real Test Bed.

Table 2. Data format from the GPS and OBU modules

	Data	Units
GPS module	Latitude	Degree (Up to 4 phces of decimal)
	Longitude	Degree (Up to 4 phces of decimal)
	Speed	m/s (Up to 4 phces of decimal)
	Direction	Degrees
OBU module	Average speed	kmph
	Maximun speed	kmph
	Acceleration	m^2/s

mismatch, the microcontroller alerts the driver three times. The block diagram and implementation of the OBU described above is shown in Fig. 4.

The hardware of this model comprises an embedded system with a Peripheral Interface Controller (PIC) microcontroller interfaced with a GPS receiver at 9600 bps, an LCD, an alarm and a radio module for broadcasting warning messages alerting the driver.

Fig. 5 shows the response rate of the system in the real test bed. The graph shows the delay after the driver has committed an error in lane speed, the driver's response time after the warning has been issued, and the time taken for the warning message to reach the neighbouring vehicles in five instances. The following are the parameters for the on-board GPS-based system.

B. SUMO with MOVE and NS-2

The mobility model describing the scenario is shown in Fig. 6. A specific highway segment in Neemrana, India, that has a four-lane road was chosen. The model was implemented there, and the simulation results recorded. Fig. 6 shows a roadmap of the segment in Neemrana. The four-lane road shown in the picture has different speed limits assigned to each track.

The entire scenario was simulated in NS-2, and the algorithm was implemented. The results are described and explained in the next section.

SUMO-MOVE provides the .tcl and sumo.tr file that

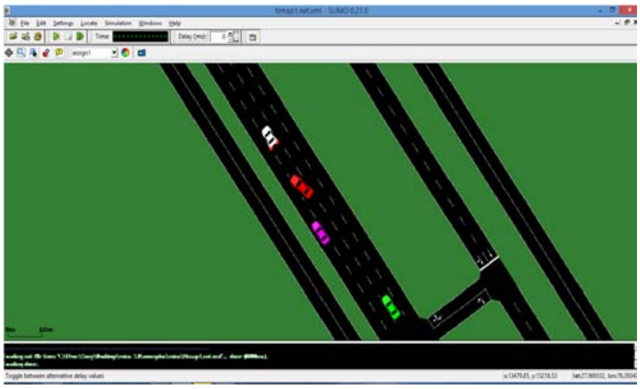

Fig. 6. Scenario.

Fig. 7. *min*$_{gap}$ and Speed Estimation–based Lane Changing.

are the requirements for simulation in NS-2. The above scenario was then imported into NS-2, and the algorithm implemented in it. The simulation results of the implemented protocol can be seen in Fig. 7. In NS-2, the nodes -> 1,2,3,4 are the four vehicles on four different tracks generated with the help of SUMO. In Fig. 7, vehicle No. 2 shifts lanes based on a speed change. Initially, it starts from the first lane and then shifts to the third lane, based on the protocol. The **mingap** estimation is also shown in Fig. 7.

C. Efficiency Analysis

The algorithm was checked in the test bed of a flyover on Highway NH-8 in Neemrana, Rajasthan, India, and generated a smart flow of vehicles in real time. A small range transceiver (TRX) was used, along with the hardware OBU system in the car plying the four-lane highway. A long-range TRX was used as an RSU to receive road segment information and update congestion status. The lane assistance protocol was checked and sent warning messages about faulty-driving vehicles to other vehicles using OBU and TRX (short range), and the effectiveness of the system was verified. The system is efficient at remote monitoring of traffic. Congestion alerts and speeding can also be checked with the given OBU system in the vehicles. The alert message was sent by the TRX to approaching vehicles so they could avoid the congestion and take an alternate route. This increases efficiency and reduces travel delays. The functionality of the OBU implementing the speed-based algorithm was checked. Four cars were used, each driving in different

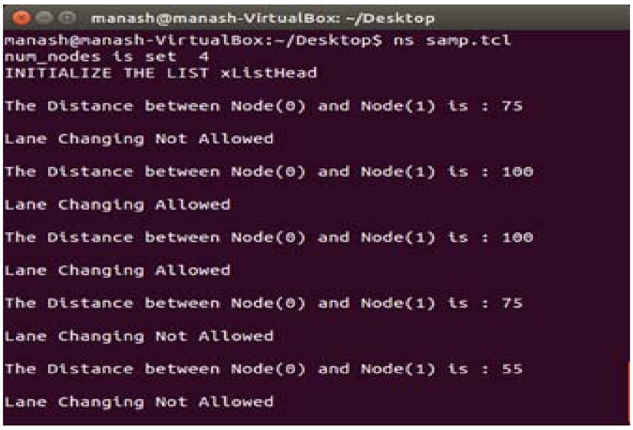

Fig. 8. Simulation Results in the Terminal for Lane Change Allowance.

lanes. The first case found that all drivers maintained constant lane speeds, maintaining a proper gap amongst themselves. The OBU gives the real-time speed and a “Lane OK” message to the drivers where there is proper lane-wise driving. This scenario was run three times in a day to test the efficiency of the system. On the next test (without the speed-based algorithm), four cars were deployed with different drivers. During this test, three out of four drivers were negligent in terms of maintaining the permitted speed for their lanes. The third time, car No. 4 did not follow the lane-change rules and exceeded the speed limit in various road segments. With the protocol, the chances of reckless driving were reduced, but in the same test without the use of the speed-based algorithm, reckless driving occurred in almost every case.The existing lane-change assistance–based models have some limitations.

3.2 Conclusion and Future Work

The speed-based lane change protocol implemented within the on-board system plays a very important role in a VANET. The use of a GPS-based system is more reliable, as it is more accurate and the data provided are real-time data. Thus, the proposed system is more reliable and efficient in terms of safety and accuracy. This paper explains the protocol and the first-level implementation of the algorithm with the help of SUMO-MOVE, NS-2, and some field trials with the hardware prototype. Furthermore, different packet-forwarding strategies will be used for different connection states. By transmitting information like location and speed, etc. from the hardware, there may be cases where the data can be manipulated. The protocol will be improved in such a way that it takes care of these issues.

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