Research Article

IoT based rear-end collision avoidance system in highways

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Abstract
Rear-end vehicular collision due to illegally parked and unusually slow-moving vehicles on National Highways can be avoided if drivers can get alert messages and full information needed to make an objective judgment about what is ahead. A lot of work has been done on collision avoidance strategies using various networking techniques. IoT based solutions area recent research trend. The objective of this project is to develop an intelligent system that will identify illegally parked and the slow-moving vehicles on highways using the message queuing telemetry transport (MQTT) protocol that enables vehicles to exchange their real-time information, such as velocity and position, with the neighbouring vehicles through brokers (also called as servers). MQTT being a lightweight IoT protocol for machine to machine communication is useful for an effective data transfer between vehicles. An optimal algorithm has been developed to accurately identify every vehicle in the vicinity of the region of interest and to calculate both speed and position of the vehicle and transfer data from one vehicle to another vehicle. The new algorithm is implemented in a Raspberry Pi using a global positioning system (GPS) module. The results show that the collision avoidance system that uses MQTT protocol can accurately generate alert messages 90% of the time when there are only ten or less than ten vehicles which is also the case in most highways. Also, the system is easy to implement without requiring extra equipment. Hence the new technique can be used in various types of vehicles, especially cargo trucks and buses that use the highways frequently.

Keywords
Collision avoidance, Vehicle to vehicle (V2V), Message queuing telemetry transport (MQTT), Global positioning system (GPS) speed, Compass direction, Hall effect sensor, Rotations per minute (RPM).

1.Introduction
Road accidents on National Highways are multi-causal. Ideally, the factors responsible should be established through an objective assessment of the circumstance under which the road accident occurred. Head on collision constituted 18.7% followed by hit from back with 16.7% in road accidents in the country, according to the extant data reporting system of the Road Accidents in India-2017 report released by Ministry of Road Transport and Highways, Government of India [1]. The National Highways in India which constitutes just about 2% of the total road network carries 40% of the traffic, accounts for 30.4% of total road accidents and 36.0% of the total number of persons killed during 2017 [1].

The high collision rate is due to the fact that the vehicles are at high speeds and it is difficult for drivers to judge on what is ahead especially when there is an illegally parked vehicle or an unusually slow-moving vehicle on the highways. The solution is to duly notify and alert the drivers about what is ahead in advance thereby decreasing the chances of occurrence of potential accidents due to rear-end collisions. The objective of this work is to develop an IoT based system that can be implemented with ease in any vehicle to alert drivers when there is an illegally parked vehicle or an unusually slow-moving vehicle.

There are already many works done in this area, that alert the drivers using cooperative collision warning system (CCWS) with the help of vehicular adhoc networks (VANETs), wireless sensor networks (WSN), dedicated short range communication

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(DSRC) for vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications.

This work demonstrates how the problem of rear-end collision is overcome by using message queuing telemetry transport (MQTT) protocol in place of DSRC Protocol. The strength of using MQTT protocol for Internet of Things (IoT) is that the vehicles that are connected to each other using this protocol need not know each other to transfer messages between them. The MQTT protocol acts as a bridge between two vehicles which transfers the following data to each other, GPS Coordinates (Latitude and Longitude), speed and compass direction. With the help of these data, distance and relative velocity are calculated by every vehicle involved in the network. Based on the data obtained, various algorithms as shown in section 3 are executed and alert signals are issued to drivers to avoid any rear-end collision. The results show that vehicles can effectively avoid any rear end collision on highways with an illegally parked vehicle or a slow-moving vehicle on highways.

2.Literature review

Wang et al. [2] have designed an algorithm for vehicle collision detection at T-shaped intersections using location-based service (LBS) which integrates GPS, inertial measurement unit (IMU) and other vehicle sensors. Information transfer between vehicles is done using DSRC. Jiménez et al. [3] in their work employed a laser scanner for their forward collision warning system in a single carriageway road. Tian et al. [4] have used a DSRC for inter-vehicle communication and a trajectory modeling method to predict the vehicle behavior and vehicle path. Lee et al. [5] in their work have used laser scanners to collect information to predict path of the vehicles, time to collide and frontal overlap. Dinesh V. Jamthe and Dorle [6] have used VANETs to transmit speed and position information to other vehicles in the network to avoid collision. The position and speed of the vehicle is collected using the GPS and accelerometer. Sun et al. [7] have used a global satellite navigation system (GSNS) for GPS, electronic compass, lane information fusion with cubature Kalman filter (CKF) to estimate the relative distance, relative velocity and relative heading which are given as an input to the adaptive neuro fuzzy inference system (ANFIS) to predict collision. The velocity and direction of vehicles is communicated using WSN in the work by Sajib et al. [8]. Their approach includes additional road infrastructure to provide possible collision warnings to the vehicles on the highways.

Li et al. [9] have used a Zigbee based WSN to exchange traffic information between vehicles. The transmission distance for Zigbee is 10m and hence vehicles with this range from a WSN. Krishnan et al. [10] have used sensors fixed at the rear-end of the vehicles that collect information on the speed and distance of the oncoming vehicles.

The DSRC communicates [11] with vehicles or road side infra-structures using on-board units (OBU). The vehicle has to perform vehicle to vehicle (V2V) as well as a vehicle to infrastructure (V2I) communications to transmit all traffic information. This is a tedious process as it creates a heavy workload on the sender's side. Adding equipment to the vehicle for implementing DSRC would increase the overall cost of the vehicle. Hence the MQTT, a lightweight protocol for IoT is used in this study, for V2V message transfer to generate accurate alert messages.

3.Methodology
3.1Rear-end collision avoidance system
Figure 1 shows the overall process of the rear-end collision avoidance system where V1 is a parked or a slow-moving vehicle on the highways. Vehicle V2 approaches V1. Vehicle V1 transfers its GPS position, speed and the compass direction to vehicle V2. If both V1 and V2 are travelling in different directions the message is ignored. If both vehicles are travelling in the same direction, vehicle V2 calculates the relative velocity and the distance between the vehicles. When the distance between the vehicles is reducing and V2 is approaching V1 an alert message is generated and the users are alerted.

3.2Implementation of MQTT protocol
Vehicle V1 is connected to another vehicle V2 via broker over the internet. The publisher sends messages to brokers. Broker forwards messages to subscribers requesting for messages. There is no limit on the number of vehicles that can be connected at the same time.

Assume V1 as a publisher and V2 as a subscriber. Consider that V1 is moving ahead of V2. V2 does not know that V1 is ahead. V1 transfers the following parameters to V2 via broker: (i) GPS Coordinates (Latitude and Longitude) of V1 (ii) Speed of V1 and (iii) Compass direction of V1.
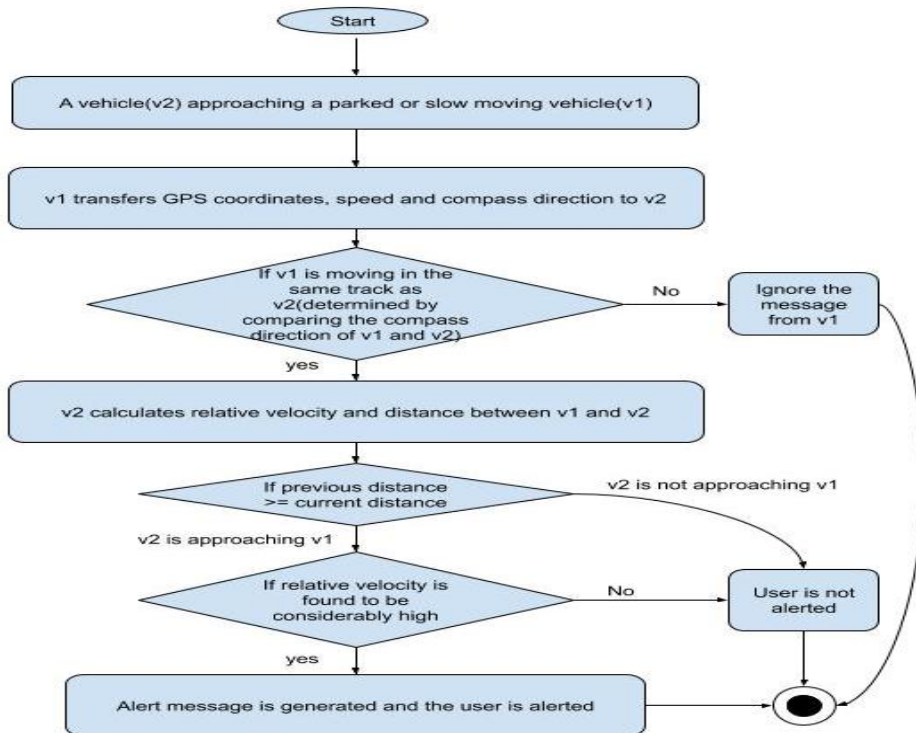
Figure 1 Rear-end collision avoidance system

Publisher V1 sends the above data to the broker along with a particular topic. Broker forwards the message to subscribers requesting for messages with the same topic name. If the topic names published and subscribed are different than the message published to the broker is either discarded or stored temporarily until any other subscriber requests for the message stored with the same topic name.

Subscriber V2 also calculates certain parameters such as: (i) GPS Coordinates (Latitude and Longitude) of V2 (ii) Speed of V2 and (iii) Compass direction of V2. Apart from the parameters above-calculated, V2 also calculates distance and the relative velocity between V1 and V2 using GPS coordinates and speed of both V1 and V2 respectively. Distance and relative velocity are calculated by V2 only after receiving V1 parameters.

3.3Determination of GPS coordinates
The GPS coordinates are retrieved using GPS module connected to the vehicles V1 and V2. It contains time, position and fix related data, such as the time and the rate at which the message is generated. An example of GPS message string is $GPGGA, 172814.0,3723.46587704, N, 12202.26957864, W, 2,6,1.2,18.893, M, -25.669, M, 2.0,0031×4F

This is an example of NMEA 0183 message. NMEA is a specification that refers to the National Marine Electronics Association. This standardized format is used in communication between marine electronic equipment's. All marine electronics equipment's and computers communicate using this standard. The GPS receiver also uses this specification.

3.4Calculation of speed
Hall Effect sensors [12] are used for calculation of speed. Hall Effect sensors are sensors which produce an electrical signal at its output when it comes in contact with a magnetic field. The analogue value of the electrical signal at the output of the sensor is a function of the strength of the magnetic field. Hall sensors are used for the measurement of speed, position and distance in cars and in other automotive industry-based products. A pulse signal is produced whenever the magnet passes the sensor. The fluctuation of the analog voltage from HIGH to LOW or from 3.1V (approx.) to 0V produces this signal. The changes of state from HIGH to LOW is used to calculate a variable called "pulse".

The main thing that we need to do here is to figure out how long does it take to the wheel making one complete rotation. One complete rotation means, as the wheel spins, the magnet will move out of its initial position (at the hall effect sensor) and come

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back to that same spot after one complete cycle. That will be considered as the value of "1 pulse" in the code. A variable "elapse" in seconds gives the time it takes to get 1 pulse. The speed of wheel rotation and the variable are inversely proportional (i.e.) when speed is high, the elapse is small and vice versa.

3.5 Calculation of distance and velocity between two vehicles

The distance between the two vehicles is calculated using their latitude and longitude positions with the Haversine formula [13, 14]:

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi1.\cos\varphi2.\sin^2(\Delta\lambda/2) \quad (1)$$
$$c = 2.\text{atan2}(\sqrt{a}, \sqrt{(1-a)}) \quad (2)$$
$$d = R.c \quad (3)$$

Where φ in is latitude, λ is longitude, or is the earth's radius (mean radius = 6,371km); note that angles should be in radians.

After receiving speed data from the publisher, subscriber's vehicle calculates relative velocity based on two different circumstances.

If a publisher is moving towards subscriber, velocity is the sum of the speed of the publisher and subscriber.
Relative_velocity = absolute_value (Speed(p) + Speed(s))
If publisher and subscriber are moving in the same direction, the velocity is the difference between the speed of the publisher and subscriber.
Relative_velocity = absolute_value (Speed(p) - Speed(s))
Where,
Speed(p) = Speed of the publisher
Speed(s) = Speed of subscriber
An absolute value of relative velocity is calculated since the direction of motion of a vehicle is determined using compass readings. So, negative values of relative velocity are not required.

3.6 Collision detection

This paper focuses on only rear-end collisions as they are major contributors to the total number of collisions.
There are two situations when a rear-end collision can take place
❖ The vehicle is illegally parked on roadside.
❖ The vehicle is slowly moving compared to other vehicles.
If a vehicle is under any one of the above situations, to avoid rear-end collision vehicles coming at the back of it should be appropriately notified.

Detection of vehicles travelling in the same track
Vehicles travelling on the same track are detected based on their compass readings. The publisher is a vehicle which is either parked or slowly moving. Now the publisher has to send messages to the subscriber which is travelling in the same track and approaching the publisher. It should be duly noted that vehicles moving in front of the publisher and have overtaken publisher should not accept the message transferred by the publisher.
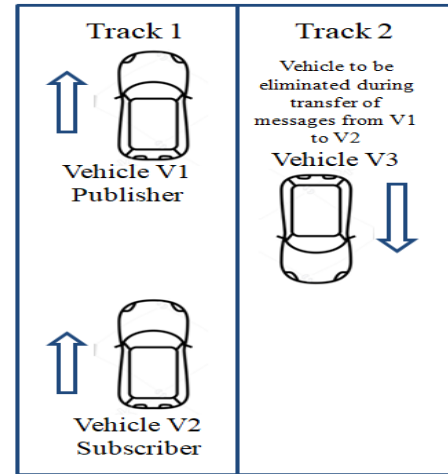

Figure 2 Detect vehicles in the same track

According to the *Figure 2*, vehicle 1 (V1) is a publisher and vehicle 2 (V2) is a subscriber. V1 and V2 are travelling on track 1. Vehicle 3 (V3), which is travelling in the opposite direction to that of V1 and V2 (in track 2), should not receive any message transferred by V1 in track1. To avoid V3 from receiving messages, vehicles travelling in track1 alone should be detected. The following is the algorithm used to eliminate vehicles in track 2.

Algorithm for eliminating vehicles in the opposite direction:
Assume that compass readings (V1) have been transmitted to V2 by V1.
"Flag" is used to denote whether a vehicle is moving in the forward direction or in the reverse direction.
❖ If flag=0, then the vehicle is moving in a forward direction
❖ If flag=1, then the vehicle is moving in reverse direction
❖ If (compass readings(V1) =compass Readings(V2)) and ((flag(V1) = 0 and flag(V2) = 0) or (flag(V1) = 1 and flag(V2) = 1), then V1 and V2 are travelling in the same track.

❖ If (compass readings(V1) not equal to compass Readings(V2)) and (flag(V1) =1 and flag(V2) = 0), then V1 and V2 are travelling in the same track

For other possible conditions of V1 and V2 vehicles are travelling in different tracks.

Detection of vehicles approaching Publisher
Messages transmitted by the publisher should be accepted only by approaching vehicles from behind and not by those which have already gone in front of the publisher or just overtaken publisher.

Considering track 1 in *Figure 2*, V2 is approaching V1. In order to detect V2, it is assumed that GPS coordinates of V1 are transmitted to V2 before executing the algorithm shown below.

Algorithm for detecting approaching vehicles:
❖ Distance between GPS coordinates (V1) and GPS coordinates (V2) is calculated using the Haversine formula [12, 13].
❖ If (Previous distance >= Current Distance), then V2 is approaching V1 otherwise V2 is not approaching V1.
Previous Distance denotes the previously calculated distance between the GPS coordinates of V1 and V2. Current Distance denotes the current distance between the GPS coordinates of V1 and V2.

Detection of parked or slow-moving publisher and alerting the driver accordingly
A publisher can be detected whether it is either moving slowly or parked beside the road by a subscriber using Relative velocity parameter.

In *Figure 2*, V1 is either parked or slowly moving. In order to detect whether V1 is parked or moving slowly, assume that the speed of V1 is transmitted to V2 before executing the algorithm mentioned below.

Algorithm for detecting slow-moving or parked vehicle:
❖ The relative velocity between V1 and V2 is calculated using the formula given in Section 3.5.
❖ If ((flag(V1) = 0 and flag(V2) = 0) and (Relative velocity > 20 and speed(V2)>= 40)), then the driver should be alerted
❖ If ((flag(V1) = 1 and flag(V2) = 0) and (Relative velocity) > = speed(V2)), then the driver should be alerted
In order to achieve the expected outcome of rear-end collision avoidance, all the three algorithms

implemented separately are combined to develop a collision avoidance system.

4.Results and discussion
The collision avoidance system presented in this paper is implemented using RaspberryPi modules fitted with sensors. The programs are written in python.

Since the vehicles are connected to the internet and MQTT protocol is used for data transfer among vehicles, the system alerts the vehicles on any slow-moving vehicle or illegally parked vehicle in its path along the highways. All the vehicles on the highways forms an Internet of Things (IoT) which helps a vehicle to locate and identify any vehicle on the same track in the same direction.

The following different scenarios are tested and alarm signals are generated successfully.
- Two vehicles moving in the same direction
  - Both vehicles are moving considerably at an equal speed. (At high speed as well as low speed).
  - One vehicle is moving comparatively slower than the other vehicle.
  - Both vehicles are not moving (Zero velocity).
- Two vehicles moving in the opposite direction to each other. (Irrespective of the speed with which both the vehicles are moving).

The collision avoidance system is tested on highways where the number of vehicles is less than the city roads. The results proved that the system works well with 80% collision avoidance on highways when there are about 20 vehicles for data transfer. Accuracy increases to 90% when there are less than ten vehicles in the vicinity.
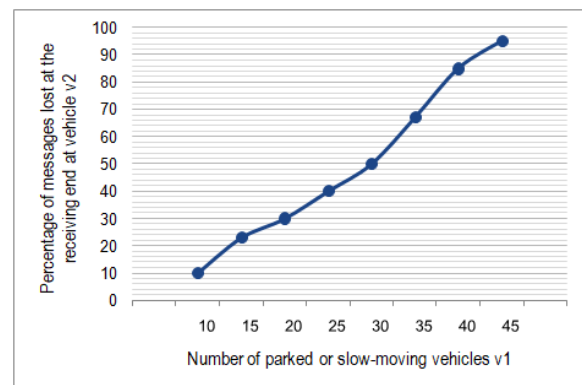

Figure 3 Message loss against the number of vehicles on highways

Figure 3 shows the number of messages lost by the approaching vehicle v2. The result clearly shows that the percentage of messages lost increases as the number of vehicles increases. This demonstrates that the MQTT protocol can be used on highways where there are fewer vehicles when compared with the city limits.
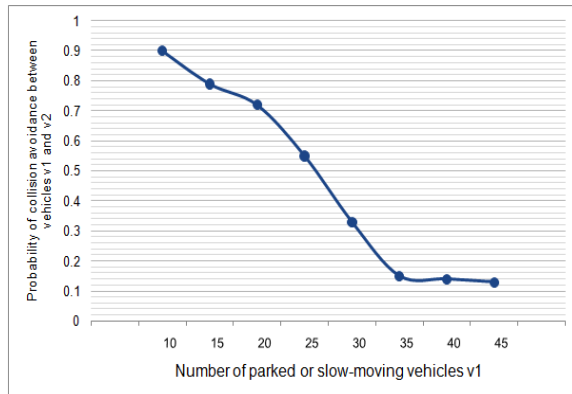

Figure 4 Probability of collision avoidance against the number of vehicles on highways

Figure 4 shows the success of the collision avoidance system with respect to the number of vehicles that are parked or slow moving. The graph is a clear indication that when the number of vehicles is less the probability of generating accurate alert messages is high. This is because the number of messages lost between the vehicles is less with fewer vehicles.

5.Conclusion and future work

This work uses MQTT protocol to exchange information between vehicles to identify illegally parked and slow-moving vehicles on highways. The results show that the collision avoidance system can accurately generate alert messages 90% of the time when there are ten or less than ten vehicles which is the case on highways. However, a drawback of this work is the occasional poor signal received from GPS satellites. But that can be overcome by using Kalman Filter. This application will not affect the accuracy of results even if the strength of the signal received by the GPS receiver is poor. The MQTT protocol-based approach is thus proved to be accurate and can be implemented in all kinds of vehicles, especially cargo trucks and busses that use the highways frequently to ensure safety. Further, special regions or lanes can be marked for vehicles to park or move slowly on highways. Alert messages can be either enabled or disabled when vehicles are nearing these regions to reduce false alarms.

Conflicts of interest
The authors have no conflicts of interest to declare.

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