Road Traffic Congestion Monitoring and Measurement using Active RFID and GSM Technology

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Abstract: In this paper, we present an intelligent Traffic Congestion Monitoring & Measurement System called TrafficMonitor to monitor and measure the road traffic congestions using probe vehicle. The concept of probe vehicle has come up in recent times for collecting real time traffic data. Our system provides an easy platform to analyze the traffic movement and congestion pattern. TrafficMonitor is a rapidly deployable, cost-effective and easily maintainable traffic congestion monitoring & measurement system that combines active RFID (based on IEEE 802.15.4 protocol, 2.4 GHz ISM band) and GSM technologies. The congestion detection algorithm is based upon calculation of vehicular speed over a stretch of road and the average waiting time of vehicles at road-crossing. Besides providing a complete description of our system and the concepts developed, the paper also provides a comprehensive description of on-road test results to support our concepts. We also provide a detailed description of all the field trials conducted, various traffic data gathered and finally the conclusions derived from such data. Government agencies, especially traffic control department, may use this system for real-time congestion monitoring by installing the system with probe vehicles. Road research organizations and NGOs may use this for studying and analyzing traffic mobility and congestion patterns.

Keywords: Probe vehicle, Active RFID, GSM

I. INTRODUCTION

Road traffic congestion detection and management has been a challenge and several countries have come up with new concepts and ideas to detect congestion. Today, number of vehicles is increasing at an alarming rate and improvement of road infrastructure, which has its limitation, has not been able to ease the problem. Over the decade, many innovative concepts and technologies have been developed in relation to collecting real time traffic data and use it for gaining knowledge regarding the various aspects of traffic flow. Both quantitative and qualitative information can be collected using such techniques. The quantitative data include: a) average lane velocity b) queue length c) trip time d) waiting time, etc. The qualitative data include, for example, detecting and characterizing congestions at various site of incidents.

All the above data can be used as a suitable parameter for determining the nature of traffic flow. For example, trip time is the average time taken by a vehicle to travel across a stretch of lane or from one junction to another and link travel time is the total time to travel from a given source to a given destination. In [3], Chen, et al. make use of probe vehicle technique to show that link travel time is not equal to the sum of all the determined trip times.

In this paper we present a comprehensive system called TrafficMonitor to detect, monitor and measure congestion over a given stretch of lane and arrive at various conclusions like:

a) Period of slowest traffic movement: Time period during slowest traffic movement can be recorded.
b) Average Lane Velocity: This parameter can be used to detect the level of congestion (high, medium, low) and the nature of traffic at different hours of day.
c) Average Waiting Time: This parameter can be used to detect the waiting time at a given junction at different hours of day.

II. RELATED WORKS

Several researches have been conducted using probe vehicle technique that is used to collect traffic data in real-time in order to determine the nature of traffic. Most of the probe vehicle techniques are used for determining the link travel time [3, 4] where they make use of GPS technology. But the major problem with GPS is that the accuracy of a typical GPS receiver is about 10 meters. This makes it difficult to pin-point a crossing for the purpose of congestion measurement. Secondly, it has been noticed that GPS sends erroneous velocity data even when the vehicle is stationary.
Other notable ITS probe vehicle technique includes[5]:

a) Sign-post based Automatic Vehicle Location (AVL)

b) Automatic Vehicle Identification (AVI).


d) Cellular Geo-location.

Our system TrafficMonitor makes use of RFID enabled probe vehicles to monitor traffic and detect congestion. Several technologies have been proposed for congestion detection, such as the inductive loop, magnetometer, Infrared, acoustic, ultrasonic, visual camera, radar etc [5,6,7,8,9]. These techniques suffer from a common disadvantage - high implementation cost and maintenance cost.

III. PROPOSED SCHEME

We have developed an intelligent Traffic Congestion Monitoring & Measurement System called TrafficMonitor to monitor and measure the road traffic congestions and provide an easy platform to analyze the traffic movement and congestion pattern. TrafficMonitor is a rapidly deployable, cost-effective and easily maintainable traffic congestion monitoring & measurement system that combines active RFID (based on IEEE 802.15.4 protocol, 2.4 GHz ISM band) and GSM technologies. Complete with the necessary hardware, firmware and software components, the system’s strength lies in its portability and reliable wireless data communication. The ‘unit system’ of Traffic Monitor can measure the congestion of a single stretch of road. It consists of

- One active RFID tag to be kept in the probe vehicle
- One wireless router (R) and one wireless coordinator (C) (both acting as RFID readers) to be installed at the road side, around 200mt apart ,for calculating average trip time to cross the two road-side units, average waiting time of vehicles at that stretch of the road and sending the measurement to the central monitoring station
- Two GSM modems (one with coordinator and the other with central monitoring station) for wireless data transmission between gateway and software monitoring system
- Monitoring station software for real-time visualization of traffic congestion and report generation. The software is also capable of supporting multiple unit system instances simultaneously.

The system can also be connected wirelessly with Variable Message Sign (VMS) to divert the traffic upon automatic detection of congestion on a stretch of a road.

A. System overview

The system will use roadside active wireless devices to collect signals from active RFID tags attached to the probe vehicle. The goal is to implement a system that would trace the travel time of probe vehicle as it passes the roadside devices, create an average trip time. The figure below shows the overall system architecture. Suppose we want to measure congestion across the stretch between J1 and J2. “C” and “R” are Wireless Gateway and Wireless Router installed at the roadside. The vehicle marked in red is our probe vehicle which carries active RFID device.

![System diagram](image)

The salient features of our scheme are as follows:

- We collect the trip time (across the stretch between the coordinator and the router) and hence, calculate the speed of the probe vehicle across the stretch for which we want to measure congestion.
- If the vehicle waits near the junction J1 we calculate its total waiting time.
- Congestion level is measured based on the calculated speed and depicted in the software at the central station (marked as “CA” in the diagram) with respect to pre-configured values.
- If the lane velocity is normal but the vehicle waits longer than the red signal time, a site of incident is detected.

B. Device Details

We are using active RFID devices (tags, routers and gateway/ coordinators) from PervCom Consulting Pvt. Ltd [11]. All the wireless devices namely, tags, routers and coordinators from PervCom are IEEE802.15.4 compliant low-power and short-range RF devices operating on 2.4 GHz frequency band. Tags emit radio signals that can be captured by devices like routers or coordinators. Routers are capable of capturing tag data and relay the captured data to either coordinator or another router in its range. Coordinators have a serial interface through which external GSM/ GPRS devices can be interfaced.

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with it to make it a dual-radio device, one is 2.4 GHz radio interface and the other is GSM/GPRS interface. The coordinator receives data from either router or tag using its 2.4 GHz RF interface and can communicate with remote server using its GSM/GPRS interface. The GSM/GPRS modem of WaveCom is used for our testing and this module operates at 115200-baud rate.

The core of PervCom’s RFID devices is **CC2430-Based ZigBee RF module.** This module is low power, 802.15.4 compliant with data rate of up to 250 kbps and max range of 100 meters. All the RFID devices have an EPROM of 128 KB which the user can use to program the device. Below are some of the real life snapshots of each of the devices used in this scheme.

A) Tag:  
B) Router:  
C) Co-ordinator:  
D) GPRS/GSM modem and accessories:  

**C. Placement of Devices**

- A tag should be placed in each of the probe vehicles.
- The co-ordinator should preferably be placed near the junction and the router 100 meters away from it (the vehicles should move from router towards co-ordinator as shown in the figure above).
- The co-ordinators are connected to a GSM/GPRS modem with the help of a serial cable and hence can send SMS to the remote station/central admin.
- The central admin is nothing but a computer system which is similarly connected to a GSM/GPRS modem.
- The co-ordinator has an internal clock integrated within it, and is capable of recording timestamps (the absolute time of occurrence) of events.

**D. Congestion & Incident Detection Phase**

The figure below shows the step by step data flow amongst various hardware devices and how the congestion detection algorithm actually works.

1. Tags continuously broadcast RF beacons.
2. When the probe vehicle containing the tag passes across the router, the later senses the tag beacons.
3. The router then forwards this data to its associated coordinator.
4. The co-ordinator starts a timer.
5. When this same vehicle goes ahead and comes under the range of coordinator, the coordinator intercepts the beacons sent by the tag.
6. Now, the co-ordinator stops the timer calculates the trip time of the tag (vehicle) and sends this information to the central station in form of SMS.
7. The central stations extracts required information, calculates the lane speed and based on the pre-configured speed levels deduces the level of congestion.
8. If the vehicle still remains under the coordinator, the co-ordinator senses the tag and periodically updates the central admin.
9. The central admin calculates the waiting time until the tag remains at the vicinity of the coordinator.
10. The central station determines any anomaly in vehicle movement or site of incident based on the waiting time, speed and red signal time for that junction.

**E. Calculating the trip time and lane velocity**

The coordinator calculates the vehicular trip time \( T_t = t_2 - t_1 \). The coordinator sends this trip time and tag id to the central admin in form of SMS. The central admin consists of running SMS reader software. The software parses the received SMS, extracts the trip time, tag id and its current location (that is, under which coordinator it is currently located). From the trip time the lane speed can calculated as \( v = T_t / d \) where \( d \) is the distance between the router and the coordinator. The central station is pre-configured (based on user’s conception of congestion level) with three levels of congestion viz. low, medium and high. From, the speed calculated we arrive at the congestion level of that stretch of lane.
F. Calculating the vehicle waiting time

Now, suppose the vehicle (tag) is still under the coordinator and the coordinator is still receiving tag beacons. The coordinator continuously sends special SMSs informing the central station of its (tags) current location. The central station keeps a timer on until the tag moves out of the range of the coordinator. From the total waiting time we easily infer anomalous traffic movement (if any).

Suppose the total waiting time is $T_w$ and the red signal time for that junction is $T_R$ (say). If $T_w \approx T_R$ then the vehicle was waiting under red light condition. If $T_w >> T_R$ then an incident has occurred ahead which has made the vehicle to wait under the coordinator for a considerable amount of time.

G. Observation at the Central Station

At the remote control station, there will be a computer for running road-map based congestion visualization software, which will allow the traffic department to view the congestion level at different crossings in near-real time using different color schemes for easy comprehension. It is also possible to use this real-time congestion data for taking congestion control decisions like re-routing the traffic (sending rerouting messages / congestion data from control stations to VMS installed at the congested crossings) or changing the existing signalling pattern and so on.

The visualization clearly shows the level of congestion on all the four roads (based on trip time), and a tag (E1) waiting under coordinator for 120 seconds.

IV. FIELD TRIALS AND DATA COLLECTION

We conducted field trials and collected traffic data for three major parts of the city of Calcutta. These three junctions suffer a major congestion and traffic delays and thus we had collected data to study traffic flow patterns with respect to speed and average signal waiting time using probe vehicle technique.

V. RESULTS

a) Readings and Graphs

The figure below shows the graph of time (hour of day) against average velocity (kmph). Average velocity was calculated based on duration of 3 hours. The graph shows the three day readings in three different colours.

From the above graph following inferences can be drawn:

1. We can easily extract the maximum and the minimum speed attained by the probe vehicle during the time (from 13:00 hours to 16:00 hours) of the day at a glance.
2. The maximum speed attained is about 40 kmph on the Lenin Sarani (9th March, 2011) while the minimum speed was about 3 kmph at CR Avenue (16th March, 2011).
3. Looking at a glance one can easily see that all road speed vary from 15 kmph to 25 kmph.
4. There was normal traffic flow from 2.30 P.M to 3.30 P.M while there were slower traffic movements before 2.30 P.M.

The figure below shows the graph of time (hour of day) against average waiting time (seconds). Waiting time was calculated based on duration of 3 hours. The graph shows the three day readings in three different colours.
VI. CONCLUSION

The way of detecting traffic congestion and measuring the level of congestion as well as the site of incident is a completely new idea based on probe vehicle technique with the help of active RFID technology. It is able to overcome the disadvantages of most of the other technologies. Most of the other technologies like inductive loop besides being an intrusive way of detecting congestion are costly to deploy and maintain. Even video cameras are costly and detecting congestion requires intelligent image processing techniques/softwares which again require skilled personnel with adequate software background or knowledge.

We have taken great steps towards what we had earlier proposed in [1] - like taking into consideration average waiting time and detecting the site of incident. Thus we have been able to measure congestion more accurately and easily. We have been able to support our concept with field trials and validated our test results using stop watch.

VII. REFERENCES


