Vehicle speed and volume measurement using V2I communication

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Abstract: Intelligent transport system (ITS) is the system that manages road traffic using information and communications technology. One of the most important part of ITS is the vehicle detection which provides vehicular data such as volume, density, and speed for the traffic management center. This paper proposes a vehicle detection method which measures volume and speed based on vehicle to infrastructure communication (V2I) and Global Positioning System (GPS). It can be implemented on roadway infrastructure with or without another type of vehicle detector such as loop detector.

Key–Words: Loop detector, Traffic data, GPS, Ad-hoc, V2V, V2I

1 Introduction

Today roadway is one of the most important transport systems all over the world. Development of ITS in order to solve traffic problems is the indispensable demand in many countries. ITS includes sensor, communication, and traffic control technologies. Vehicle detection and surveillance technologies are integral parts of ITS, since they gather some parts or all of the data that is used. In general, there are two vehicle detection methods: intrusive technology (neumatic road tube, inductive loop detectors, piezoelectric sensors) and non-intrusive technology (video image processor, microwave radar, infrared sensors, and ultrasonic sensors) [3]. Most vehicle detection today rely on inductive loop detectors because of their stability and accuracy in counting vehicle volume at real time. However, installation of these detector needs a lot of saw-cut on roadway surface, which makes them difficult to deploy and maintain. This work is much more expensive for roadway section which demands a large amount of loop detector. Moreover, this type of detector can provide traffic information only from vehicle to infrastructure and not vice versa, thus limiting the functionality of the system. Combining or replacing loop detector system with better vehicle detection technology is an essential issue for the future of ITS.

This paper proposes vehicle volume and speed measurement method using wireless communication channel between the roadside equipments and vehicles. In this solution several roadways and intersections are managed by the roadside equipments. Vehicles are equipped with GPS receiver and wireless communication device, to detect there geographical location and to provide ad-hoc network connectivity with the roadside equipment respectively. The roadside station collects data from vehicles to calculate the volume as well as speed at specified position on the roadway. The V2I system proposed in this paper is a two way data exchange between vehicles and roadside equipments. Consequently, besides providing traffic data, this system can be further developed for other information services such as Incident Notification, Vehicle Tracking or In-Car Internet Access.

This paper is organized as follow. Section 2 introduces the background of vehicle detection. Section 3 describes the method of measuring volume and speed of vehicles. The simulation results will be shown in Section 4. Finally, we conclude the paper and discuss possible future work in Section 5.

2 Background of vehicle detection

In general vehicle detection is done through an inductive loop detector consisting of three components: a loop, a loop extension cable and a detector [4]. Each loop detector is placed at a specified location on the roadway to measure vehicle volume and speed based on the occupancy time of vehicle on it. The collected traffic data is then sent to the central traffic computer via wired communication channel. In order to improve the vehicle detection technique for ITS, wireless communication has already been studied. The wireless communication used in ITS can be distributed into 2 types: vehicle to vehicle communication (V2V) and vehicle to infrastructure communication (V2I).
Some systems employing V2V and V2I to provide more services and functions for roadway security and management such as VETRAC [1] and COC [2] are being developed.

In this paper, to perform function of loop detector roadside equipments need to detect the position of vehicles periodically and then count number of vehicles passing a given position in a period.

3 Method description

In this proposed system, vehicles and fixed roadside equipments form an ad-hoc network which has no pre-arranged infrastructure. These vehicles which are considered as nodes in the network are mobile, so a vehicular ad-hoc network (VANET) is created. Each fixed roadside equipment called V2I station manages an area within its direct radio range. We assume the vehicle’s transmission range is enough for the connection to the V2I station, whenever they enter its range. In fact, the coverage range overlap between two V2I stations can lead to the wrong detection of vehicle. However, this problem can be fixed as described in the Section 3.4. Every query period $T_{query}$, V2I station broadcasts a query message to all vehicles in its range. Vehicles reply the query by a "Hello" message which contains their own information such as identification number (ID), location, sending date and speed. We assume every vehicle has a different ID. Vehicle speed parameter is given by the on-car speedometer. These vehicular data are used for volume and speed measurement.

3.1 Roadway design

Roadway system which are to be simulated consist of links and connectors which are identified by their ID numbers. Connector is used to connect two links. One roadway may have only one link (One-Way Street) or two links (2-Ways Street). Link refers to one side of roadway where vehicles move in the same direction which is also link direction. One link may have many lanes. Lane is a defined area on the link which generally allows only one type of vehicle to move. Lanes on a link are numbered by integers starting from 1. Lane 1 is the rightmost lane in the link direction (see figure 1). We define nodes (way point), identified by successive integers starting from 1, along the imaginary central line of a link in its direction. Nodes are chosen in such a way that the shape of imaginary line that joins them is most similar to the shape of link and the distance between nodes is greater than average vehicle length (5 m).

Loop detectors are placed on specific lanes inside the coverage range of V2I stations. We also define emulated detectors, which are identified by different ID numbers and coordinates, located at the same location of loop detectors. The proposed solution aims to calculate vehicle volume and speed through emulated detectors. The results are then compared to those provided by loop detectors.

3.2 Query period

This section discuss about the value of the query period $T_{query}$. To ensure the vehicular data updating, $T_{query}$ must be longer than the transmission delay. We first estimate the transmission delay.

We assume the exchange message size does not exceed 50 Bytes or 400 bits. If the communication follows the wireless local area network standard 802.11 [6] at bit rate of 11Mbps, the transmission delay for each message is $\frac{400}{11} = 36(\mu s)$. This delay increases if there are more than one vehicle communicating with the V2I station at the same time. In the case radius of V2I station range is R=100 m, the coverage area is $\pi \cdot R^2 = 31400(m^2)$, and we assume the average space size for a vehicle is 3.5 m of width (equal to lane width) and 5 m of length. The maximum number of vehicles present in this area is $N = \frac{31400}{3.5 \cdot 5} = 1794$. So the maximum transmission delay is $D = 1794 \cdot 36 \cdot 10^{-6} \approx 0.065(s)$.

In addition, in order not to miss any arriving vehicle within the query period, the V2I station need to receive vehicle’s "Hello" message before that vehicle arrive to the emulated detector. So the query period must be shorter than the time interval which vehicle needs to cover d (Distance between the Emulated detector and range border of V2I station) (see figure 2). In this paper, we select $T_{query} = 0.1$ seconds which is higher than the maximum transmission delay. In this case, the distance d must be longer than $T_{query} \cdot (\text{Maximum vehicle speed})=0.1(s) \cdot 36(m/s)=3.6(m)$. All emulated detectors are consequently distributed within the smaller effective area of radius (R-d) comparing with the real radio range. To obtain an effective area as wide as possible, $T_{query}$ must not be too long.
3.3 Offline data processing

Each V2I station stores parameters of nodes, links, and emulated detectors in its coverage range in separated following data tables:

- Node_table = \{X_node, Y_node, node ID, link ID, lane width, number of lane\}
- Station_table = \{Node_table\}, X_station, Y_station, station ID, transmission range
- Detector_table = \{X_detector, Y_detector, detector ID, link ID, lane number\}

They are also called offline data. Location parameter is defined as a 2 dimensions coordinate (X,Y). Lane and link parameters in Node_table as well as Detector_table refer to the link and lane where node and emulated detector are located. For example, Node_table = \{20.5,69.2, 5, 3, 3.5, 2\} refers to a node 5 located at coordinate \{X=20.5,Y=69.2\} on the link 3 which has 2 lanes of 3.5m width.

3.4 Online data processing

Every \( T_{query} \) the V2I station receives updated vehicular data called online data by querying all vehicles in its transmission range. This vehicle data is then stored in form of following data table:

- Vehicle_table = \{ X_vehicle, Y_vehicle, vehicle ID, transmitted time, speed, station ID \}

In addition, to solve the problem of wrong detection caused by the overlapping zone between V2I stations, we remove the data of vehicles in this zone based on their distance to the station and the non-overlapping transmission range. After update vehicular data, the V2I station starts its calculation process which can be divided into 3 sub-processes: link checking, lane checking, speed and volume measurement. The first two sub-processes check the lane and link where the vehicles are located. The third one counts vehicles that have passed emulated detectors within \( T_{query} \). Speed is measured based on values collected from "Hello" messages.

3.5 Link checking

In this check, the V2I station searches all nodes in its range to find the closest one to the vehicle to detect the link of that vehicle. It compares location of the vehicle with every two successive nodes on a corresponding links. The figure 3 shows the link checking example of a vehicle. We here assume that \( A_1 \) and \( A_2 \) are two successive nodes on the link A. M is a vehicle in the same V2I station area containing link A. Coordinates of these three nodes are respectively given by: \( M(x_1, y_1); A_1(x_{A_1}, y_{A_1}); A_2(x_{A_2}, y_{A_2}). \)

![Figure 3: Localization of vehicle M](image)

To determine whether M is on the segment \( A_1A_2 \) of link A, we first determine the coordinate of H which is a projection of M on the line \( A_1A_2 \). The condition \( \overrightarrow{MH} \perp \overrightarrow{A_1A_2} \) can be mathematical represented by

\[
x_{MH} * x_{A_1A_2} = y_{MH} * y_{A_1A_2} \quad (1)
\]

Moreover, H is also on the line \( A_1A_2 \) leading to:

\[
x_{A_2H} * y_{A_1A_2} = y_{A_2H} * x_{A_1A_2} \quad (2)
\]

where

\[
x_{A_iA_{i+1}} = (x_{A_{i+1}} - x_{A_i}) \quad (3)
\]

\[
y_{A_iA_{i+1}} = (y_{A_{i+1}} - y_{A_i}) \quad (4)
\]

Resolving two equations (1) and (2), we obtain the coordinate of \( H(x_H, y_H). \)

The two following conditions ensures that vehicle M is on segment \( A_1A_2 \) of link A:
H is between $A_1$ and $A_2$;

Distance from M to the line $A_1A_2$ ($d_{MH}$) is less than link width.

The distance $d_{MH}$ is given by:

$$d_{MH} = \sqrt{(x_{MH})^2 + (y_{MH})^2} \quad (5)$$

This process is represented in the figure 4.

![Figure 4: Link checking algorithm](https://via.placeholder.com/150)

### 3.6 Lane checking

According to the node definition in part 3.1, $A_1A_2$ becomes the central line of the link A. So it will divide link A to 2 parts: left side and right side along link direction. The left side contains high number lanes and lower number lanes are on the right side. To determine the lane for a vehicle, we rely on the link side where vehicle is located and also on the comparison between MH and lane width. The link side of vehicle can be found by analyzing $(\alpha - \beta)$ which is the angle difference between 2 vectors $\overrightarrow{A_1M}$ and $\overrightarrow{A_1A_2}$. Where $\alpha$ is the angle between $\overrightarrow{A_1M}$ and horizontal axis given by:

$$\tan(\alpha) = \frac{y_{A_1M}}{x_{A_1M}} \quad (6)$$

$\beta$ is the angle between $\overrightarrow{A_1A_2}$ and horizontal axis given by:

$$\tan(\beta) = \frac{y_{A_1A_2}}{x_{A_1A_2}} \quad (7)$$

Lane number of the vehicle is calculated for two cases. If $(\alpha - \beta) \geq 0$, the vehicle is located on the left side of $A_1A_2$ (see figure 3). Depending on the number of lanes (numlane) on the link is odd or even, lane number of vehicle is given by equations (8) and (9) respectively.

$$Lane = \frac{numlane + 1}{2} + \left[ \frac{d_{MH}}{lane\_width} \right] \quad (8)$$

$$Lane = \frac{numlane}{2} + \left[ \frac{d_{MH}}{lane\_width} - \frac{1}{2} \right] + 1 \quad (9)$$

Otherwise, if $(\alpha - \beta) < 0$ the vehicle is located on the right side and we have also two sub cases given by odd case (10) and even case (11).

$$Lane = \frac{numlane + 1}{2} - \left[ \frac{d_{MH}}{lane\_width} \right] \quad (10)$$

$$Lane = \frac{numlane}{2} - \left[ \frac{d_{MH}}{lane\_width} - \frac{1}{2} \right] + 1 \quad (11)$$

In the equations from (8) to (11), operator $[\ ]$ is used to round off value to nearest integer value.

### 3.7 Speed and volume measurement

After adding link and lane parameters to Vehicle table, the V2I station will check whether the vehicles have passed the emulated detector on the same lane. The checking result is then added also to Vehicle table. The ID of the emulated detector is contained in "detector ID" parameter, and the passing status ("YES" or "NO") of vehicle is stored in "passing status" parameter.

![Figure 5: Wrong detection case 1](https://via.placeholder.com/150)

In the figures 5, 6, 7, each link A and B contains an emulated detector D1, D2 respectively. A and B connect with each other at an intersection. Two successive positions of vehicle M which is always on link A: M(t) and M(t-1) are captured at t and (t-1). If M is
located right at the intersection, the V2I station may
detect incorrectly whether it is on link A or B. In the
first case, the V2I station detects incorrectly that M(t)
passes the detector D2 on link B although it is on link
A.

Figure 6: Wrong detection case 2

Figure 7: Wrong detection case 3

In the second and third case, V2I station incor-
rectly inferences that M(t-1) passes D2 on link B. We
can correct these wrong detections for two cases. If
the "Detector ID" of M(t) is the same as M(t-1), we’ll
correct the "passing status" of M(t) and M(t-1) as dis-
cussed above. Otherwise, if M(t-1) did not pass a de-
tector $D_i$, which is also between two positions of M(t-
1) and M(t), M(t) passed $D_i$.

By using the proposed method, we can have vol-
ume and speed data of vehicles at any position of any
roadway lane in the transmission range of V2I station,
with the condition of GPS error less than lane width
(3.5 m) because we identify vehicle’s location at lane
level.

4 Evaluation of method

The proposed solution is implemented in VISSIM
4.30 (microscopic, behaviour-based multi-purpose
traffic simulation program developed by PTV AG
Germany) [5] on Windows platform using Visual Ba-
sic language.

Table 1: Simulation parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total simulation time (s)</td>
<td>600</td>
</tr>
<tr>
<td>Query period (s)</td>
<td>0.1</td>
</tr>
<tr>
<td>Lane width (m)</td>
<td>3.5</td>
</tr>
<tr>
<td>Loop detector size (m)</td>
<td>2.1 x 5</td>
</tr>
<tr>
<td>Vehicle length (m)</td>
<td>5</td>
</tr>
<tr>
<td>Transmission range (m)</td>
<td>50 &amp; 100</td>
</tr>
<tr>
<td>Maximum vehicle speed (m/s)</td>
<td>36</td>
</tr>
<tr>
<td>Input volume A (vehicle/h)</td>
<td>200</td>
</tr>
<tr>
<td>Input volume B (vehicle/h)</td>
<td>500</td>
</tr>
<tr>
<td>Input volume C (vehicle/h)</td>
<td>50</td>
</tr>
<tr>
<td>Input volume D (vehicle/h)</td>
<td>629</td>
</tr>
<tr>
<td>Input volume E (vehicle/h)</td>
<td>758</td>
</tr>
<tr>
<td>Pedestrian volume (people/h)</td>
<td>200</td>
</tr>
</tbody>
</table>

Each input at A, B, C, E has 1 lane; input at D has
2 lanes. Between the intersection and the traffic circle,
there is a two ways pedestrian crossing. A 50m radio
range V2I station covers the traffic circle area and the
100m one manages the intersection area. Six loop detectors from D1 to D6 are distributed within the coverage area of these two V2I stations to detect direct volume and speed of vehicles. In addition, volume and speed of vehicles are also indirectly calculated using V2I communication. Vehicles are set to move through this roadway network at maximum speed up to 36 m/s with static routing decision. Pedestrian is given the priority at the cross walk. The simulation is run for 600 seconds. Direct traffic data from loop detectors as well as indirect data from the V2I stations are collected every 30 seconds. The simulation parameters are shown in Table 1.

Figure 9 represents the comparison of speed data measured by the loop detector D3 and the V2I station. Figure 10 represents speed data of D4. Horizontal axis is 20 periods of 30 second each, during the 600 seconds simulation. We can see that, the difference of speed data in two collecting methods increases when vehicle speed decreases. This is because V2I station calculates the average vehicle speed at the end of query period while loop detector collects speed data whenever the vehicle occupies it. So the V2I based speed is smoother than the loop detector one.

Figure 11,12 are histograms of volume comparison which are measured by detector D3, D4 and the
V2I station. Here also horizontal axis is 20 periods of 30 seconds each. These results show the precision of the V2I based volume measuring method compared with loop detector based method. However, there is difference at some periods. The reason is also loop detector and V2I station don’t measure vehicle volume at the same time. Therefore, V2I station registers vehicle to the volume of next 30 seconds period while loop detector registers the vehicle to the volume of current period. However, the total volume does not change. For example in figure 12, D4 detects 2 vehicles at the time step 17 and 3 vehicles at the time step 18. While V2I station detects 3 vehicles at the time step 17, but 2 vehicles at the time step 18. The sum of detected vehicles during these two periods is always 5.

5 Conclusion

The traffic data measuring method based on V2I communication and GPS is quite a new method which can be used for future ITS. This method can be applied to urban or highway traffic conditions where there is a high demand of vehicular data. In this paper, we assume that all vehicles are equipped with GPS receiver which is not possible always. In the future work, we reduce number of vehicles equipped with GPS and apply approximate method to evaluate vehicular data.

References:


