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A Novel Bus Lane Enforcement System with Vehicular Sensor Networks

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Abstract

Bus lane enforcement system aims to monitor illegal utilization of bus lane by non-permitted vehicles (violator). However, Road-side system leads to considerable infrastructure cost while bus mounted system has limited surveillance coverage. In this paper, we consider an interesting problem in bus mounted system: how to improve the surveillance coverage of bus mounted system without additional infrastructure cost? In other words, we attempt to identify not only the violator immediately in front of the bus, bus also the violators not close to the bus, whose number plates cannot be read directly because of sight blocking of bus mounted cameras. With utilization of communication between bus and existing cameras around intersections, we propose a novel cooperative violator identification scheme, ***DoubleChecking****, with which violators can be sorted out from traffic flow with high accuracy. From theoretical analysis, DoubleChecking shows a good performance for violator identification, which demonstrates the effectiveness of the proposed scheme.*

Keywords

Bus lane enforcement system; violator identification; vehicular sensor networks; Intelligent Transportation System (ITS);

1. Introduction

In recent years, transportation authorities have paid much attention on increasing the capacity of public transit system. For instance, Bus Rapid Transit (BRT) has been proposed to support bus priority policy, but it is still cost prohibitive for many cities and inappropriate for many bus lines [5]. Alternatively, another low-cost approach is to build dedicated bus lanes in the road network of urban area. However, illegal utilization by non-permitted vehicles (*violator*) degrades considerable effectiveness of bus lanes [6]. Fortunately, recent advances in wireless communication and computer electronics have resulted in significant developments of intelligent transportation systems [1]. Especially, bus lane enforcement systems have been deployed in cities for violator identification.

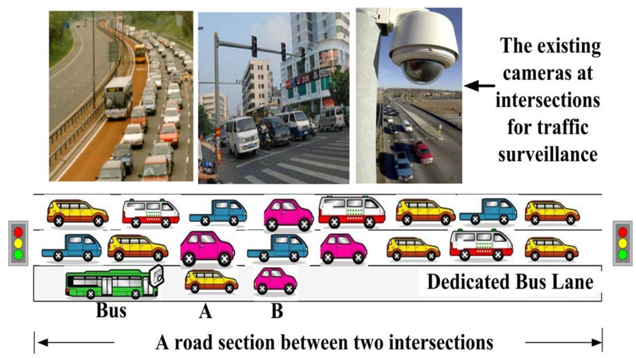

Figure 1. Application scenario of bus lane enforcement

A typical approach for violator identification is to use cameras and a key component in this system is the Number Plate Reader (NPR), by which the registration number of vehicle can be analyzed based on image processing. Basically, there are two kinds of bus lane enforcement system, one is road-side mounted system and the other is bus mounted system. In the road-side mounted system, the cameras can be installed on lampposts along the roads. The scalability, however, is a non-trivial issue which implies considerable infrastructure cost.

In this paper, we are interested in bus mounted system for violator identification, in which we need to handle the limited surveillance problem. We present ***DoubleChecking***, a cooperative approach for violator identification in bus lane enforcement system. Compared with existing works, DoubleChecking is designed to improve the surveillance coverage of bus mounted system without additional infrastructure cost (i.e. without deploying cameras on lampposts). To be more precise, we attempt to identify not only the violator immediately in front of the bus (The number plate can be read directly, e.g., vehicle *A* in Figure 1), bus also the violators not close to the bus (The bus cannot read the violator's number by bus mounted camera directly because of sight blocking, e.g., vehicle *B* in Figure 1). The main idea is to utilize the existing cameras around intersections to assist bus mounted system for violator identification. Originally, these existing cameras are not used for this purpose, but monitoring the intersection regions. Specifically, a cooperative violator identification scheme with probabilistic guarantee is adopted based on communication between bus and forward intersection cameras. Finally, violator vehicles can be sorted out with high probability. Overall, we mainly focus on new architecture of bus lane enforcement system and detailed image-processing problem is beyond the scope of this paper.

The remainder of the paper is organized as follows. Section 2 discusses the related work. Section 3 introduces the assumptions, model and problem statement. In Section 4, we present our DoubleChecking scheme for cooperative violator identification. Section 5 is the theoretical analysis part and Section 6 concludes the paper.

2. Related Work

Recently, a new infrastructure named Vehicular Sensor Network (VSN) has attracted tremendous interests from both government and academic. VSN is a network of mobile sensors equipped on vehicles, such as taxis and buses[1],which can be used for urban sensing, such as traffic monitoring[3][4]. VSNs facilitate collection of surveillance data over a wider area than the fixed infrastructure [2]. Meanwhile, unlike traditional wireless sensor networks, vehicular sensors are typically not affected by strict energy constraints and vehicles can be equipped with powerful processing units and wireless transmitters. Actually, the work presented in this paper still falls into vehicular sensor networks domain and the bus mounted cameras can be regarded as sensors.

Four bus lane enforcement projects have been carried out in United Kingdom: one in Birmingham and the other three in London[6][7][8]. The Birmingham Bus Lane Enforcement System depends on video camera and image processing equipment mounted on buses or along the roadside. The camera digitally takes photos for the vehicles in the bus lane twenty meters ahead of it and transmits the numbers of those vehicles to an E-display screen at the end of the bus lane. With this system, the bus lane offences decreased by 60% and average bus journey times decreased by 32% in Birmingham [8][9]. The Bus Lane Violation Detection & Deterrent (BLVDD) in Heathrow is very similar to the roadside mounted system in Birmingham, which is installed on a highway to the airport [10]. The other two systems in London area rely on SVHS video cassette recorder rather than digital images to generate redundant information, with which more accurate violator identification can be expected[7]. Work in [11][12] studied the bus lanes enforcement with intermittent priority, in which the author proposed a cost effective approach to increase bus transit system speed and reliability without creating excessive delays to private vehicles.

3. Scenario, Model and Problem Statement

3.1 Scenario and road section model

Actually, lots of buses are already equipped with various electronic devices by bus companies, such as GPS, storage device, wireless transmitter, etc. Besides that, we assume that two forward facing cameras (color and monochrome) and image processing unit are available on each bus. With a GPS system, a bus can determine whether or not it is in a bus lane and therefore whether or not to open the two bus mounted cameras [6]. At the same time, the existing static surveillance system around the intersections (including similar devices mentioned above) can be utilized to assist the bus mounted system for violator identification without additional infrastructure cost. Especially, a color camera provides a wide context view in front of the bus and a monochrome camera shows a close up view of the vehicle's number plate. An infra-red illuminator enables operation in poor lighting conditions. With an image processing unit, the registration number of vehicle can be analyzed. Due to sight blocking of bus mounted monochrome camera, it just could read the number of violator immediately in front of the bus. For the violators not close to the bus, only limited attribute information can be obtained by the wide context view of the bus mounted color camera, such as vehicle type, color, etc. However, the existing static cameras around intersections are capable of reading all the information of vehicles because of good viewpoint (high position, good orientation, as shown in Figure 1). In addition, with wired/wireless communications[16][17], information can be exchanged between intersections or between buses and intersections to support cooperative violator identification.

In this work, we use a typical road section: a road section has three lanes and one of them is the dedicated bus lane (as illustrated in Figure 1). Meanwhile, we assume heavy traffic on the two public lanes and light traffic on the bus lane (It is not worth and necessary for public vehicle to be a violator if all lanes have similar traffic).

3.2 Problem statement

In this work, we discuss the violator identification problem based on *one-one* model, i.e., a standard case unit includes one road section and one bus running on this road section. Accordingly, in each run of simulation, we only focus on one standard case unit. *Specifically, we consider the following problem: It is known that we have a bus mounted system and an existing intersection system as introduced in Section 3.1, for a standard case unit, how to sort out a suspicious vehicle (to be the violator) set **S** by cooperative violator identification?*

First, we introduce some definitions as follows.

Definition 1 (*Maximum photographic distance*):

The definition is mainly used for *bus mounted* cameras, which have a limited field of vision. That is, they only can generate high quality images for limited distance in front of the bus. This parameter is named as *maximum photographic distance*, denoted as ***mpd***. How to regulate the orientation of camera for capturing image and how to deal with the image processing are beyond the scope of this paper, related work can be found in [13][14].

Definition 2 (*Accuracy ratio, AR*):

For a standard case unit, we get a *suspicious vehicle set **S*** by cooperative violator identification. The *accuracy ratio* (*AR*) is defined as the proportion of *real* violator in the set ***S***:

$$AR = \frac{|S'|}{|S|} \quad (1)$$

where |S| and |S'| are the sizes of suspicious vehicle set ***S*** and the real violator vehicle set ***S′***, respectively. The metric indicates the effectiveness of bus lane enforcement system. In addition, we define another vehicle set ***S′′=S-S′***, which includes the vehicles which are in the suspicious vehicle set but are not the real violators.

4. DoubleChecking: Cooperative Violator Identification for Bus Lane Enforcement

4.1 Methodology

On one hand, some attribute information of vehicles, which are in *mpd* of the bus, can be identified based on image processing. Typically, attribute information includes vehicle type, color, brand, length, taxi or private vehicle, etc. To be general, in the paper, we assume that vehicle type and color information can be obtained. Meanwhile, the number of vehicle immediately in front of the bus can be obtained by monochrome camera. In addition, the bus can estimate the relative locations of violators in the whole traffic flow by GPS. All related information can be transmitted from bus to the forward intersection's processing unit by wireless communication, such as DSRC.

On the other hand, a road section is connected with two intersections. With utilization of cameras at two intersections, for a given unidirectional traffic flow, we can construct two *vehicle sequences* based on their timestamps of entering/exiting the road section, respectively (Accordingly, two *indexes* will be assigned to each vehicle in both entering/exiting sequences and large index corresponds to large timestamp). Basically, the two indexes of a vehicle should not have considerable change in two sequences due to the heavy traffic on the public lanes, which is similar with FIFO. However, for an *exceptional vehicle* which is with large index in entering sequence while small index in exiting sequence (I.e., compared with other vehicles, it took less time to travel through the road section), it has higher probability to have illegally utilized the bus lane as a violator.

SCHEME-**DOUBLECHECKING**:

// For a given bus *b* and road section with length *l* in standard case unit

1. For a bus *b*, the bus mounted cameras take photographs for the violators (denoted as v_i) in its maximum photographic distance. For each violator v_i, with utilization of GPS and speed estimator, the bus can calculate the time instant T_i, at which v_i will arrive at the forward intersection (corresponding to parameter T_{begin} at the intersection). Other information can be also analyzed by image processing, such as vehicle type, color. Especially, the number plate can be read if the violator is immediate in front of the bus (denoted as v'). Then, All the related information, e.g. (v_i, *type*, *color*), will be transmitted to the forward intersection's processing unit by wireless communication.
2. For the forward intersection of bus *b*, currently there are two time-related parameters: T_{begin} and T_{end}. If the intersection receives a new time instant T_j from bus *b* and T_j is earlier than T_{begin}, then T_{begin} will be updated by T_j. T_{end} is the time instant, at which v' will arrive at the forward intersection.
3. The traffic flow between [T_{begin}, T_{end}] will be examined for violator identification. The exceptional vehicles in this traffic flow will be sorted out based on Definition 3, which constitute a vehicle set, denoted as S^0. (**First Checking Process**)
4. For each vehicle in set S^0, it will be added into final ***suspicious vehicle set S*** if it has same (*type*, *color*) combination provided by bus *b*. (**Second Checking Process**)

Figure 2. The DoubleChecking scheme

Finally, with cooperation between intersections and buses, a fraction of traffic flow can be selected based on the location information of violators provided by bus. Then, the exceptional vehicles in this targeted traffic flow will be examined by utilizing more information sent from the bus, such as vehicle type and color, etc.

4.2 DoubleChecking scheme

We first give the definition of exceptional vehicle.

Definition 3 (*Exceptional vehicle*):

For a given threshold δ, the vehicle *v* will be regarded as an exceptional vehicle if and only if:

$$v.eni - v.exi \geq \delta$$

where *v.eni* and *v.exi* are the two indexes of *v* in the entering and exiting sequences, respectively. Actually, here we are only interested in the exceptional vehicles which have less travelling time costs than others. The threshold δ is an empirical parameter based on traffic flow model, which indicates how sensitive for the DoubleChecking scheme to define exceptional vehicles.

Based on the discussion in Section 4.1, we propose ***DoubleChecking***, a novel cooperative violator identification scheme for Bus Lane Enforcement, as shown in Figure 2. In addition, we admit there are still exceptional vehicles or violators which cannot be monitored by buses because of limited *mpd* of bus mounted cameras. Actually, with increase of bus density, we may enable the communication and cooperation between buses, which will further improve the surveillance coverage of bus lane enforcement system. Meanwhile, the model used in this paper can also be extended so that the bus may monitor the violators behind it. Then, according scheme can be designed based on DoubleChecking. We state this part as our future work.

5. Performance Evaluation

5.1 Theoretical analysis

In this section, we carried out a theoretical analysis about expectation of accuracy ratio. For a standard case unit, we have the following parameters:

N: Number of vehicles in the whole traffic flow;

α: The proportion of exceptional vehicle in the traffic flow (not including the real violator), this parameter is related to the parameter δ;

n: Number of real violators in suspicious vehicle set ***S***;

tp: Number of vehicle types;

clr: Number of vehicle colors;

β: The proportion of traffic flow used for violator identification by DoubleChecking. Actually, this parameter is related to the parameters T_{begin} and T_{end} (Step 3 in Figure 2).

Accordingly, the number of exceptional vehicles in the targeted traffic flow is $N\times\alpha\times\beta$, which is denoted as ***m***. Now, we tend to calculate $E(|\boldsymbol{S}|)$ and $E(|AR|)$, first we have:

$$E(|\boldsymbol{S}|)= E(|\boldsymbol{S}'|+ |\boldsymbol{S}''|)= E(|\boldsymbol{S}'|)+E(|\boldsymbol{S}''|)=n+ E(|\boldsymbol{S}''|)$$

$$E(|\boldsymbol{S}''|)=P(|\boldsymbol{S}''|=1)\times 1+P(|\boldsymbol{S}''|=2)\times 2+ \ldots +P(|\boldsymbol{S}''|=i)\times i \ldots + P(|\boldsymbol{S}''|=m)\times m$$

Here, $|\boldsymbol{S}''|=i$ means there are i out of m exceptional vehicles in the suspicious vehicle set ***S***. $P(|\boldsymbol{S}''|=i)$ is the probability that the incident $|\boldsymbol{S}''|=i$ happens. For given numbers of color ***clr*** and vehicle type ***tp***, there are totally ***tp×clr*** combinations (In our work, we simply assume that each vehicles randomly chooses its type and color). Then, we have:

$$P(|\boldsymbol{S}''|=i) =P(A_1)\times P(B_1|A_1) +\ldots+ P(A_j)\times P(B_j|A_j) + \ldots+ P(A_i)\times P(B_i|A_i)$$

where incident A_j means i exceptional vehicles occupy j color×type combinations and incident B_j means that for each of j color×type combinations in A_j, there exists real violator in the suspicious vehicle set ***S***, which has the same combinations.

Theorem 1: The probability that incident A_j happens is:

$$P(A_j)=\frac{C_{clr\times tp}^{j}\times j^i - C_{clr\times tp}^{j-1}\times (j-1)^i}{(clr\times tp)^i} \quad (2)$$

Here, the number of j-combinations (each of size j) from a set with $clr\times tp$ elements (size $clr\times tp$) is defined as:

$$C_{clr\times tp}^{j}=\frac{(clr\times tp)!}{j!\times(clr\times tp-j)!}$$

Meanwhile, it is easy to calculate:

$$P(B_j\mid A_j)=1-\sum_{x=1}^{j}(-1)^{x-1}C_j^x\left(\frac{clr\times tp-x}{clr\times tp}\right)^i$$

Then we have:

$$E(|S''|)=\sum_{i=1}^{m}P(|S''|=i)\times i$$

$$=\sum_{i=1}^{m}\left(\sum_{j=1}^{i}P(A_j)\times P(B_j\mid A_j)\right)\times i$$

$$=\sum_{i=1}^{m}\left(\sum_{j=1}^{i}\begin{array}{c}\left(\dfrac{C_{clr\times tp}^{j}\times j^i - C_{clr\times tp}^{j-1}\times (j-1)^i}{(clr\times tp)^i}\right)\\ \times\left(1-\displaystyle\sum_{x=1}^{j}(-1)^{x-1}C_j^x\left(\frac{clr\times tp-x}{clr\times tp}\right)^i\right)\end{array}\right)\times i$$

$$E(AR)=\frac{E(|S'|)}{E(|S|)}=\frac{n}{n+E(|S''|)}$$

$$=\frac{n}{n+\displaystyle\sum_{i=1}^{m}\left(\sum_{j=1}^{i}\begin{array}{c}\left(\dfrac{C_{clr\times tp}^{j}\times j^i - C_{clr\times tp}^{j-1}\times (j-1)^i}{(clr\times tp)^i}\right)\\ \times\left(1-\displaystyle\sum_{x=1}^{j}(-1)^{x-1}C_j^x\left(\frac{clr\times tp-x}{clr\times tp}\right)^i\right)\end{array}\right)\times i} \quad (3)$$

We use a practical case unit as an example and the empirical parameter setting is as follows: there are totally 200 (***N***) vehicles in this case, in which 5% (***α***) are exceptional vehicles. Specially, 10% (***β***) of whole traffic flow is used for violator identification and the bus reports three (***n***) vehicles as violators during travelling the road section in this case. The cameras can differentiate five (***tp***) vehicle types and five (***clr***) colors. Then, we calculated Equation (3) with values mentioned above and $E(AR)$ is about 97%, which shows that high accuracy ratio can be expected by using DoubleChecking scheme. More testing cases need to be analyzed and we state it as our future work, which is currently in progress in our lab.

6. Conclusion

We present a new scheme Doublechecking for bus lane enforcement system, which is designed to identify the violators in a cooperative manner. Compared with previous works, we tend to improve surveillance coverage of bus mounted system without additional infrastructure cost. To be more precise, we aim to identify not only the violator immediately in front of the bus, bus also the violators not close to the bus (The bus cannot read the violator's number directly because of sight blocking). With DoubleChecking scheme, the violators can be sorted out with high accuracy from traffic flow by the cooperation between bus mounted cameras and the existing cameras around intersections. From theoretical analysis, DoubleChecking shows a good performance for violator identification, which demonstrates the feasibility of our scheme.

Several issues remain to be addressed further. Our future work includes building a prototype system in Shanghai and testing our DoubleChecking scheme on this prototype. We hope the implementation experience helps us further to understand the efficiency of DoubleChecking. Second, DoubleChecking is a baseline scheme which can serve as guideline when deploying such an application in city urban area, how to design a more sophisticated violator identification scheme is also our future work (As discussed in Section 4.2, the model can be extended that the violators behind the bus can also be monitored. Meanwhile, we can enable the communication and cooperation between buses, which will further improve the surveillance coverage of bus lane enforcement system).

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References

[1] U. Lee, E. Magistretti, M. Gerla, P. Bellavista, and A. Corradi, "Dissemination and harvesting of urban data using vehicular sensor platforms," IEEE Transactions on Vehicular Technology, Vol. 58, 2009, pp. 882-901.

[2] Xu Li, H.Huang, et al. VStore: Towards Cooperative Storage in Vehicular Sensor Networks for Mobile Surveillance, IEEE WCNC, 2009.

[3] Xu Li, Wei Shu, et al. Performance Evaluation of Vehicle-based Mobile Sensor Networks for Traffic Monitoring. IEEE Transactions on Vehicular Technology, Volume 58, Issue 4, May 2009 Page(s):1647 – 1653.

[4] Xu Li, et al. Traffic Data Processing in Vehicular Sensor Networks, Intl. Conf. of ICCCN, 2008.

[5] A.R.Girard. Hybrid supervisory control for real-time embedded bus rapid transit applications. IEEE Transactions on Vehicular Technology, Vol 54, Issue 5, pp.1684 - 1696, 2005.

[6] Trevor Ellis. Deterring Bus Lane Bandits. Traffic Technology International Annual Review, 1998.

[7] D.Turner, P.Monger. The Bus Lane Enforcement Cameras Project: The London Area Scheme. Traffic Engineering & Control, Vol. 38, 1997, 529 - 539.

[8] S.Lewis, The Bus Lane Enforcement Cameras Handbook (Provisional), PSDB Publication No. 17/96, Home Office, St Albans, UK, 1996.

[9] A.Wiggins, "Birmingham Bus Lane Enforcement System", Conference on Road Transport Information & Control, IEE Conference Publication No. 454, 1998.

[10] G.Hill. Bus Lane Violation Detection/Deterrent BLVDD. BAA Heathrow, 1998.

[11] M.D.Eichler. Bus Lanes with Intermittent Priority: Assessment and Design" Masters of City Planning Thesis, Department of City and Regional Planning, University of California, Berkeley.

[12] M.D.Eichler. Bus lanes with intermittent priority: Screening formulae and an evaluation. working paper UCB-ITS-VWP-2005-2, UC Berkeley Center for Future Urban Transport.

[13] S.Greenhill, S.Venkatesh. Distributed Query Processing for Mobile Surveillance, ACM Multimedia 2007.

[14] S.Greenhill, S.Venkatesh. Virtual Observers in a Mobile Surveillance System, ACM Multimedia 2006.

[15] Michel Sede, Xu Li, Da Li and Min-You Wu. BLER: Routing in Large-Scale Buses Ad Hoc Networks. Intl. Conf. of WCNC, 2008.

[16] P.Zhou, X.Wang, and R.R. Rao. Asymptotic Capacity of Infrastructure Wireless Mesh Networks, IEEE Trans on Mobile Computing, Vol. 7, No.8, pp. 1011-1024, Aug. 2008.

[17] B.S.Manoj, P.Zhou, and R.R. Rao. Dynamic Adaptation of CSMA/CA MAC Protocol for Wide Area Wireless Mesh Networks. Elsevier's Computer Communications Journal. Vol. 31, No.8, pp. 1627-1637, May 2008.