Alexandria Engineering Journal (2016) **55**, 513–523

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

Traffic density determination and its applications using smartphone

Al-Sayed Ahmed Al-Sobky [a,*,1], **Ragab M. Mousa** [b,2]

[a] *Public Works Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt*
[b] *ASCE Associate Member, Faculty of Engineering, Cairo University, Egypt*

Received 29 September 2015; accepted 5 December 2015
Available online 2 January 2016

KEYWORDS

Smartphone;
GPS;
Traffic flow;
Density;
Travel speed;
Time synchronization

Abstract Smartphone is progressively becoming a dominant platform for many transportation applications. This paper introduces a new application for using smartphones to measure traffic density and speed. The proposed system consists of two smartphones and two cars, with observer to count vehicles between the two cars. This count is utilized with tracking data to give "measured" density and "measured" speed. The travel speed and manual traffic counts were used to derive "calculated" density. Measured density was validated against calculated one, and statistical *t*-test confirmed that the mean difference between two densities is not significant at 5% level. Calculated flow rates were also comparable to actual counts, with an average error of 8.2%. The proposed system was then applied to measure density on 6 of October Elevated Road in Egypt, and the level of service was determined accordingly on 15 road sections studied on this road. Furthermore, actual speed-density data were fitted using exponential model with *R*2 of 0.85. Advantages of proposed system qualify it for potential applications in developing countries where available resources limit installation of more costly systems. The application of proposed system is limited to daytime, uninterrupted flow conditions, and traffic streams with less percentage of heavy vehicles.

1. Introduction

Traffic density is a fundamental macroscopic characteristic of traffic flow, and is used in assessing traffic performance from the point of view of users and system operators. It is also employed as the primary control variable in freeway control and surveillance systems. The difficulty in measuring density inhibited its general use until the early 1960s, when presence-type detectors were introduced [1]. Density is also an important measure of the quality of traffic flow, as it is a measure of the proximity of other vehicles, a factor which influences freedom to maneuver and the psychological comfort of drivers

---

[*] Corresponding author.
E-mail addresses: Assobky@eng.asu.edu.eg (A.-S.A Al-Sobky), ragabmousa@yahoo.com (R.M. Mousa).

[1] Currently with Senior Transportation Engineer, Dar Al-Handasah, Cairo Office.

[2] Currently with Expert, Ministry of Transport and Communications, Sultanate of Oman.

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.12.010
1110-0168

[2]. For these reasons, the Highway Capacity Manual [3] used the traffic density as the primary measure of level of service (LOS) for uninterrupted flow situations.

The measurement and analysis of density characteristics are of particular interest from a historical perspective. The stages of development of density analysis were controlled primarily by measurement techniques. Before the 1950s only photographic techniques were employed. By the early 1960s, three approaches were being undertaken in parallel: calculation of density from input–output counts, calculation of density from measured speed and flow, and measurement of percent occupancy [1]. Video filming has also been used for estimating macroscopic density where exists an elevated vantage point from which the highway section under study can be observed [4]. Recent researches have been directed to automatic extraction of traffic density characteristics from video images using detection and tracking techniques [5,6]. Other non-intrusive systems have also been used to estimate traffic density. These are highlighted in the following paragraphs.

Photographic techniques were first employed, which revealed the importance and significance of density. However, they required considerable planning and time-consuming analysis, and could not be analyzed in real time. One of the first studies reported in the literature was published in 1928 and was an aerial photographic study of traffic density along the Baltimore–Washington highway [7]. Extensive aerial photographic studies were undertaken in the early 1960s in several cities in USA [8], and resulted in the development of density contour maps.

The input–output count technique is a rather straightforward approach in concept in which an initial count is made of the number of vehicles along the roadway between two count stations, and over time the number of vehicles entering the section is continuously added and the number of vehicles leaving the section is continuously subtracted from the initial count. The problem in this approach is that section density is calculated on the basis of the difference between two large numbers (input and output counts), and detector errors (even minor) cannot be tolerated without frequent re-initialization [1]. A unique input–output count algorithm for determining density was developed by the Port of New York Authority in the 1960s in the Lincoln and Holland Tunnels [9]. Similar input–output technique was executed using automatic Metro Count devices at the beginning and end of a road section [10].

A third technique is to calculate density from speed and flow measurements. This calculation technique requires two detectors, count and speed or two closely spaced detectors with software to convert elapsed travel time to speed. The density can then be calculated as the division of flow by speed. One problem with this approach is that it uses the time-mean-speed at this measurement station instead of the space-mean-speed [1].

The most significant advance in the measurement and analysis of density, however, was due to the development of presence-type detectors and the processing of signal pulses to compute percent occupancy in the early 1960s [11]. Occupancy is defined as the proportion of time that a detector is "occupied," or covered, by a vehicle in a defined time period. The lengths of the average vehicle and the detector are needed to compute occupancy [2]. The widespread use of presence-type detectors and percent occupancy calculations has led to numerous new applications.

Although the inductive loop technique used for density measurement is not affected by weather and light conditions, it suffers from high installation and maintenance costs [12,13]. In order to overcome this limitation, vehicle tracking using image processing techniques has been adopted in traffic monitoring systems to give traffic parameters including traffic count, speed, density, vehicle classification, and incident detection [12,13]. Nowadays, detection and tracking of moving objects are becoming more essential to traffic engineers. Although all detector technologies and particular devices have certain limitations and/or capabilities, only microwave radar, active infrared, and video image processing (VIP) systems are capable of supporting multiple lane and multiple detection zone applications [14]. In comparison with all other technologies, VIP system is considered the best in terms of installation, maintenance, and future upgrade. Moreover, this technology allows users to check visually the results by watching videos previously recorded [5].

The VIP system requires higher mounting camera position allowing for better angle and wider view of lanes on the road. Lower mounting heights would not provide effective images as some vehicles may hide behind others. In this case, the video image processing recognizes overlapped vehicles as single objects [15]. There are also concerns regarding accuracy of VIP results when processing video images with lane changes, light variation, shadows, vibration due to wind, and/or trucks that obscure full view of vehicles [5].

The Global Positioning System (GPS) receivers have been used in many applications such as spot speed and travel speed measurements. In one of these applications, field measurements were used to analyze the location error of moving GPS receivers [16]. This error was reported to vary from 2 m in an open square to 15 m in wide streets with four story houses on both sides. The location error was analyzed into two components; longitudinal and orthogonal errors. The orthogonal (or lateral) error component constituted the major part of the total error in location. A similar study was conducted using smartphones to measure the vehicle speeds. The speed determined using smartphones was validated using radar measurements and achieved acceptable accuracy [17].

This paper presents an approach for utilization of Smartphone in measuring temporal and spatial macroscopic traffic density on road network. This approach is tested on a simple road section and then applied to a longer road corridor. In this approach, traffic density is measured using available features of handy smartphones including GPS sensor and mobile applications. Traffic data utilized in the proposed application are collected using two smartphones; each one is provided in a moving test car. In addition, the vehicles between the two test cars are counted by an observer sitting in the lag car. Measured traffic density is verified by other means to check the reliability of the proposed application. A comparison is also established between the measured and calculated densities from measured flow and travel speed. Results, applications, and general findings are presented throughout this paper.

2. Proposed technique

The proposed system consists of two moving cars, namely, lead and lag cars. Each car is provided with a Smartphone, with synchronized timing of both smartphones. Both cars move in the traffic flow within variable distance from each other according to traffic condition in such a way to maintain the lead car visible to the lag one. The observer in the lag car