Automation in Construction 72 (2016) 294–308

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

# Detecting and tracking vehicles in traffic by unmanned aerial vehicles

Liang Wang, Fangliang Chen, Huiming Yin *

*Department of Civil Engineering and Engineering Mechanics, Columbia University, 610 Seeley W. Mudd 500 West 120th Street, New York, NY 10027, USA*

A R T I C L E   I N F O

*Article history:*
Received 17 September 2015
Received in revised form 31 March 2016
Accepted 5 May 2016
Available online 25 May 2016

*Keywords:*
Unmanned aerial vehicle (UAV)
Vehicle detection
Vehicle tracking
Traffic data
Optical flow
Scale invariant feature transform (SIFT)

A B S T R A C T

Using unmanned aerial vehicles (UAV) as devices for traffic data collection exhibits many advantages in collecting traffic information. This paper introduces a new vehicle detecting and tracking system based on image data collected by UAV. This system uses consecutive frames to generate vehicle's dynamic information, such as positions and velocities. Four major modules have been developed: image registration, image feature extraction, vehicle shape detecting, and vehicle tracking. Some unique features have been introduced into this system to customize the vehicle and traffic flow and to jointly use them in multiple consecutive images to increase the system accuracy of detecting and tracking vehicles. Field tests demonstrate that the present system exhibits high accuracy in traffic information acquisition at different UAV altitudes with different view scopes, which can be used in future traffic monitoring and control in metropolitan areas.



## 1. Introduction

With the ongoing growth of our metropolitan road network, it is indispensable to have a comprehensive monitoring system for the complex transportation. However, there are many limitations based on the current monitoring systems. Firstly, the range of traditional road traffic monitoring is restricted to the sensor's distributions, such as induction loops, radar sensors and traffic cameras. According to the sparse distribution of the current traffic monitory system, there are many blind regions on a city road network. In certain cases such as emergency mitigation, it is required to temporarily supervise the detailed traffic situations at the "hotspots", such as the regions of traffic incidents, sources and/or destinations of traffic flow, and the emergency locations with damage of ground infrastructure [1], etc. Secondly, most traffic sensors are designed to collect traffic information on a fixed road section or with a limited road length. As a result, it is convenient to obtain traffic data at lane's level, including each lane's average speed, density and flow, but it is hard to obtain traffic data at vehicle's level based on these discretely distributed sensors, such as vehicle's trajectory data.

The vehicle's level data is the fundamental data for both intelligent transportation systems (ITS) and transportation management [2]. Therefore, a monitor method designed for traffic data at vehicle's level is of significance in transportation engineering. On the other hand, in the research of driving behaviors, a detailed and accurate vehicle trajectory data is also necessary. Driving behavior models capture drivers' tactical maneuvering decisions in different traffic conditions, which are essential components in microscopic traffic simulation systems. Due to the limited availability of detailed trajectory data, most models have not been validated rigorously [3]. Data availability has posed a significant obstacle to the advancement of driving behavior modeling. Therefore, a system for detecting and tracking vehicles based on UAVs can on one hand compensate the disadvantage in the existing transportation monitoring system, while on the other hand it can also fulfill the data requirements in the research of driving behaviors modeling.

As a useful and powerful aerial robot, UAVs have been playing important roles on data and image acquisition. For example, they have been widely used in the research of agriculture, geology, hydrology, cinematography, etc. [4–9]. Compared with traditional transportation sensors located on the ground or low angle cameras, UAVs exhibit many advantages, such as low cost, easy to deploy, high mobility, large view scope, uniform scale, etc. UAVs can record a load with different lengths by adjusting flying altitude to fulfill different research requirements. Compared with low angle cameras, the video recorded by UAVs has less influence on the block of vehicles in a lane, and could measure a vehicle's position more accurately from the top view [10]. However, UAVs are rarely applied in the transportation monitoring. One of the main reasons is the lacking of an effective and robust method to detect and track vehicles in UAV's image data.

Usually, the traffic data captured by UAV contains much complex information than those by traditional monitoring system. UAV's videos include not only the traditional data such as the traffic flow average speed, density and flow, but also each vehicle's level data, such as vehicle's trajectory data, lane change data and car following data on the road. In addition, the data from a frame of a UAV's video contains multiple vehicles and the frame frequency of the UAV's video is very high, thus the data size from the UAV's video is very large. Moreover, data from the UAV's

* Corresponding author. Tel.: +1 212 851 1648; fax: +1 212 854 6267.
*E-mail addresses:* lw2451@columbia.edu (L. Wang), fangliang.chen@columbia.edu (F. Chen), yin@civil.columbia.edu (H. Yin).

http://dx.doi.org/10.1016/j.autcon.2016.05.008

video contain the fundamental information of transportation research and management, and play an important role in several other fields of transportation science and engineering, including safety studies and capacity analysis [3,11,12]. Considering such features, the data collection, reduction and analysis can be considered as an important component in the big data analysis in transportation. It can also be extended to other civil engineering applications.

Compared with traditional traffic surveillance systems, detecting and tracking vehicles through the images captured by a UAV has specific challenges. First of all, the camera of a UAV surveillance platform changes frequently because the camera in a UAV may rotate, shift and roll during video recording. In addition, sudden shakes might also happen due to wind fluctuations, which can cause negative effects in the vehicle tracking. On the other hand, in driver behavior research models, such as car following and lane change models, each car's accurate trajectory data is needed. Missing car data and tracking error could affect the accuracy of the model parameters settings. Therefore, a high resolution of images is crucial for accurately calculating vehicle speed and lateral position of vehicles in the process of vehicle detecting and tracking.

Some approaches to vehicle detecting and tracking based on a UAV system have been proposed in the literature [13]. Based on the recognition methods applied in the researches, a vehicle recognition method can be categorized into optical flow and feature extraction-matching methods. The optical flow method has many advantages in tracking and detecting moving objects in consecutive frames, such as autonomous robot navigation and surveillance of large facilities. Optical flow can capture the moving objects in a video, but the movement is the sum of the motion of both the camera and the vehicles. It is essential to identify and separate the camera's motion from the vehicle's motion. Rodríguez-Canosa, et al. [8] developed a real-time method to detect and track moving objects from UAVs. This method introduces an artificial optical flow by estimating the camera's motion, compares it with the real optical flow directly calculated from the video, and then calculate the motions of objects. Xu et al. [14] introduced a vehicle detecting and tracking method for low angle camera video. The cellular neural network was used to subtract the background and to refine the detection results with optical flow. Farnebäck and Nordberg [15] constructed a polynomial expansion to approximate the movement between two consecutive frames at the pixel level. Based on the optical flow field constructed, the vehicle's motion could be calculated.

The feature extraction-matching method has been widely used in photogrammetry and computer vision. The working process consists of extracting features of interest from two or more images of the same object and matching these features in adjacent images [16]. In the photo-based research, generally these methods search the vehicle-like features in one or two photos, and then refine the detection results through classification and representation based on the predefined database. The vehicle-like features include a vehicle's edges, shapes, feature points, colors, gradients, etc. Zhao and Nevatia [17] figured out the important car features from a captured photo based on human experience in psychological tests, and then used the boundary of the car, front windshield and the shadow as car features in car recognition. Kaâniche et al. [18] presented a vision system for traffic surveillance with a fixed-wing UAV. The method analyzed the corner and edge information in a frame, and the Dempster–Shafer theory was used in the process of verification to increase the accuracy of vehicle detection. Kim and Malik [19] introduced a new vehicle detection method, which combines photos of multiple cameras and generates a 3D-model of vehicles. This vehicle detection and description algorithm was based on a probabilistic line feature grouping, and it could increase the computing speed and reliability. Gleason et al. [20], introduced a multiple features extraction and classification method for vehicle detection. The vehicle features, such as histogram of oriented gradients, edge orientation, and color were applied to increase the detecting accuracy. Leifloff [21] presented an approach for vehicle detection from optical satellite images, where an improved Haar-like feature was used in the method. Vehicle queues were detected using a line features extraction technique in the analysis. Tuermeret al. [22] applied the features of histogram of oriented gradients, Haar-like features and local binary patterns in the vehicle detection, where a sophisticated blob detector was used for vehicle detection. Leitloff et al. [23] developed a vehicle detection method that relies on an extended set of Haar-like feature operators. The support vector machine was used in the process of classification and refine vehicle detection results.

In general, because of the limited information available in one photo, the photo-based vehicle recognition method could only obtain a vehicle's static information, like position or gap between vehicles, but it is impossible to get the dynamic information, such as speed and acceleration of vehicles. However, the video based feature extraction-matching method focuses on the relationship and connection among the matched feature points, rather than their characteristics. Therefore, the video based feature extraction-matching method exhibits many advantages for vehicle tracking compared with the photo-based vehicle recognition method. Cao et al. [24] introduced a new framework of multi-motion layer analysis to detect and track moving vehicles in a UAV's video. The Kanade–Lucas–Tomasi (KLT) feature was selected in the vehicle motion and background motion layers. The new method is more effective and robust in the application. Cao et al. [25] applied a histogram orientation gradient (HOG) feature on vehicle detection. All HOG features are combined to establish the final feature vector to train a linear SVM classifier for vehicle classification. Lingua et al. [16] analyzed the advantages of a scale invariant feature transform (SIFT) operator for the feature extraction-matching method in the UAV systems, and developed an auto-adaptive version of the SIFT operator used in the UAV's photogrammetry field. Many researchers have also used the feature extraction-matching method for vehicle tracking. Some studies used the vehicle image as a feature [23,26] or the matched feature points [27–29] to track a vehicle's motion on the road.

Overall, detecting and tracking vehicles in traffic by UAV videos and photos has been attracting increasing attentions among transportation research community. However, many problems have not been solved yet. Firstly, the accuracy of vehicle recognition is low. Normally, the detecting accuracy of the existing technology is lower than 90% [20,22,23,30], and the driver's detail trajectory data cannot be obtained [31,32]. Moreover, traffic information, such as road, traffic flow and driver behavior features, have not been included in these methods [13,27,33]. Overall, a well-developed vehicle detecting and tracking method for actual transportation application has not been developed yet.

This paper introduces a new method attempting to address these problems. It combines many features in different optical methods into an integrated system, which consists of four modules as follows: image registration, image feature extraction, vehicle shape detecting, and vehicle tracking. Complementary advantages of different optical methods considerably improve the accuracy by this method. In addition, vehicle and traffic flow features and the corresponding specifications have been implemented in the system. In what follows, Section 2 will introduce the experiments with the UAV; Section 3 will present the methodology of vehicle detection and tracking in traffic. Section 4 will demonstrate the numerical results based on the experimental data for the vehicle detection and tracking. Finally, some conclusions of this work are provided in Section 5.

## 2. Experiments

A UAV traffic monitoring system has been set up to study traffic information, which consists of a quadrocopter, a camera mount, an image transfer system, and a camera as shown in Fig. 1a, while the camera mount and the camera are enlarged in Fig. 1b.

The quadrocopter used in the experiments of this paper is the DJI Phantom 2. It includes motors, battery, electronic parts, and the connection port for the camera mount. The core control part of the UAV is the flight control unit, which is a lightweight multi-rotor control platform