UNMANNED AERIAL VEHICLE-BASED TRAFFIC ANALYSIS: A METHODOLOGICAL FRAMEWORK FOR AUTOMATED MULTI-VEHICLE TRAJECTORY EXTRACTION

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ABSTRACT

The Unmanned Aerial Vehicles (UAVs) commonly referred to as drones, are considered as one of the most dynamic and multi-dimensional emerging technologies of the modern era. Recently, this technology has found multiple potential applications in the transportation field as well, ranging from traffic surveillance applications to traffic network analysis. However, in order to conduct a UAV-based traffic study, an extremely diligent planning and execution is required followed by an optimal data analysis and interpretation procedure. In this paper, however the main focus is on the processing and analysis of the UAV-acquired traffic footage. A detailed methodological framework for the automated UAV video processing is proposed in order to extract the trajectories of multiple vehicles at a particular road segment. Such trajectories can then be used either to extract various traffic parameters or to analyze traffic safety situation. The proposed framework provides a comprehensive guideline for an efficient processing and analysis of a UAV-based traffic study. It is classified into the following five components: (i) pre-processing, (ii) stabilization, (iii) geo-registration, (iv) vehicle detection and tracking, and (v) trajectory management. Up till now, most of the traffic-focused UAV studies have employed either manual or semi-automatic processing techniques. However, this paper comprises an in-depth description of the proposed automated framework followed by a field experiment conducted in the city of Sint-Truiden, Belgium. The future research will mainly focus on the extension of the applications of the proposed framework in the context of the UAV-based traffic monitoring and analysis.

Keywords: UAVs, Drones, Traffic Applications, Traffic Analysis, Video Analytics, Trajectories
INTRODUCTION

The continuous increase in number of motorized vehicles and the ever-increasing travel demands call for innovative and effective measures to be taken to tackle the challenges of high traffic volumes and congestion levels. With the limited yet expensive infrastructure expansion alternatives, transportation managers are only left with the option of ensuring an efficient and optimal use of the existing network. For this purpose, state-of-the-art intelligent traffic information systems are employed to monitor and analyze the traffic streams, particularly in emergency situations.

The efficient operational management of the network requires an accurate, timely and quick inflow of traffic data. Traffic data collection and its subsequent analysis has also been a critical element for the development and improvement of macroscopic as well as microscopic traffic simulation models. However, it is not easy to collect the traffic data for large spans of roadway networks as most of the data collection methods require a large fixed infrastructure or are labor intensive [1].

Over the years, the methods of collecting useful traffic data have evolved with the advancement in technology. The induction loops, overhead radar sensors and fixed video camera systems have been commonly used to monitor traffic status for a number of years. Although, such traditional devices provide accurate and useful data; the data collected is only measured at a particular point with generally no useful data about traffic flows over larger areas [2]. This results in a number of hidden points; since a high density of detectors are required to cover the whole network [1,3]. In such a dataset, the real root cause of the traffic congestion or any other incident remains unknown. Manual detections are made by the specially deployed personnel if some traffic information is required beyond the range of the installed cameras or sensors.

Apart from such traditional equipment, advanced ITS technologies such as vehicle-to-infrastructure(V2I), probe vehicles with GPS and other smartphone sensor technologies resulting in “big datasets” are also being used, especially for the extraction of vehicle trajectories. However, such data is not always easily converted to useful traffic information [4]. Also, the use of GPS technology might not be correct for studying the driver behavior since the drivers know they are being monitored [3,5].

Technological advances have recently provided an alternative to an inflexible fixed network of sensors or the labor intensive and potentially slow deployment of personnel [1]. The complex traffic situations can be fully observed with the help of wide field-of-view and non-intrusive sensors and cameras mounted on airborne systems. Initially, satellites and manned aircrafts were used for traffic data collection purposes e.g. [6], but a number of quality, cost and safety issues have proven these methods to be inefficient. Recently, unmanned aerial systems in the traffic monitoring, management, and control are starting to take center stage [2,7].

Unmanned Aerial Vehicles (UAVs) commonly referred to as drones are considered to be one of the most dynamic and multi-dimensional technologies of the modern era. This technology is swiftly strengthening its presence in multiple applications, varying from commercial tasks such as parcel delivery, sports coverage etc. to research applications e.g. survey of inaccessible areas and crop fields. UAVs are predicted to be the most dynamic growth sector within aviation in the coming years [8].

As mentioned in [2,7], the UAVs recently are being used in the transportation field to monitor and analyze the traffic flow and safety conditions. These airborne imaging systems are mobile and most importantly provide high resolution traffic data relevant in both time and space [2]. The UAVs, without affecting the drivers’ behavior, can cover a large area in short times with a considerably lower cost than alternate solutions. The technology can be useful particularly in the transportation field to monitor and analyze the traffic flow and safety conditions. These airborne imaging systems are mobile and most importantly provide high resolution traffic data relevant in both time and space [2]. The UAVs, without affecting the drivers’ behavior, can cover a large area in short times with a considerably lower cost than alternate solutions. The technology can be useful particularly in...
areas where the fixed sensor infrastructure is either not available or is financially not feasible to install a high density of sensors along the area. The mobility and flexibility are the key assets of this technology.

Although attempts to collect traffic information from UAV-based images have been made in the past, their use in traffic studies is still at an early stage (2,3). The actually implemented applications of this technology are currently limited in numbers and are still in the research stages. Practically, UAVs still have some significant concerns and limitations that need to be addressed. The technical limitations i.e. limited battery time, weather constraints along with safety and privacy concerns are the biggest hindrances in making this technology more effective. However, the hardware limitations are expected to be reduced significantly in the coming years as the technology is progressing rapidly. Automated UAV flights and coordinated flights of a swarm of UAVs are already becoming a reality. Therefore, UAVS can be safely termed as a future-proof technology, especially with the widespread commercial availability and decreasing costs. It is forecasted that 600,000 commercial small UAVs (weights between .55 lbs. and 55 lbs.) could be over U.S. skies by 2020, implying new and improved applications of the technology (8).

However, the use of drone technology in traffic related studies involves a high level of planning and management precision (9). With an introduction of state laws regarding the use of UAVs, an extremely diligent planning and execution of a UAV flight is required as the consequences of a mismanged execution could be severe. For this purpose, we proposed a universal framework in (9) that serves as a guide for not only a safe and efficient execution of a UAV-based traffic study but also for the processing and analysis steps that follow the execution of a UAV flight.

In this paper, however the main focus is on the processing and analysis of the UAV-acquired traffic footage. A detailed methodological framework for the automated UAV video processing is proposed in order to extract the trajectories of multiple vehicles at a particular road segment. Such trajectories can then be used either to extract various traffic parameters or to analyze the traffic safety situation. Up till now, most of the traffic-focused UAV studies have employed either manual or semi-automatic processing techniques. However, this paper comprises an in-depth description of the proposed automated framework followed by a field experiment conducted in the city of Sint-Truiden, Belgium. With the significant increase in the number of UAV studies expected in the coming years, this automated systematic framework could become a useful resource for future research studies.

This paper is organized as follows: first of all, the relevant studies that have been carried out regarding the applications of UAVs in the domain of transportation(traffic) are briefly discussed. This is followed by a detailed description of the proposed framework. To support the proposed framework, an experiment along with its results are presented. Finally, the paper is briefly concluded along with some discussion regarding the proposed future developments and applications of the framework.

RELATED WORK

As mentioned earlier, UAVs are increasingly being employed for multiple purposes. According to the literature, UAVs are widely being researched for traffic surveillance and network evaluation applications (1,10,11). Various types of UAS are being used or tested to measure traffic related data at several universities (2). The authors in (2,7) discuss and summarize the research carried out all over the world in the domain of UAV based traffic surveillance and analysis. This is followed by a systematic categorization of the relevant research based on the
research objective, methodology, platform used and the place of research. Also, the authors mention a number of advantages along with the barriers that the UAVs have to overcome in order to be successfully employed for civil applications like traffic monitoring and surveillance operations.

Some researchers have tried to propose a workflow or an outline for the conduction of the UAV based studies. In (9), the authors present a universal guiding framework for ensuring a safe and efficient execution of a traffic-related UAV study. The authors re-organize the existing UAV-based traffic studies and the available software platforms into a step-by-step framework. The systematic framework includes a detailed description for all the aspects of conducting an efficient traffic-related UAV study. Similarly, the authors in (12) develop a UAV system specifically focused on driving-behavior monitoring to prevent accidents. Based on an application-specific outline or workflow, the authors propose a methodology for real-time vehicle tracking using image processing, and vehicle risk modelling through statistical analysis.

The main focus of this particular work, however is on the evaluation of the drivers’ behavior by developing a risk analysis model.

Recently, many researchers have attempted to make use of UAV-acquired traffic videos to conduct various traffic analysis studies. In (13), the authors analyze the gap-acceptance of vehicles entering a major road in an urban intersection with the help of UAV videos. The same authors in (5) use UAV-acquired traffic videos to determine various traffic parameters (flow, velocity etc.) and then compare them with the theoretical macro simulation models. Also, in (3), a UAV-based traffic experiment is conducted over a low-volume intersection in order to extract various kinematic parameters including the estimation of vehicle trajectories. However, all of the studies mentioned up till now have employed either manual or semi-automatic processing methods. Some studies that propose an automated video analysis include (12,14,15,16,17). The authors attempt to make use of fast and robust computer vision-based object detection and tracking techniques for the processing of aerial traffic videos.

A lot of research has been conducted for the extraction and application of vehicle trajectories for traffic analysis purposes. Researchers have employed Global Positioning System (GPS) and smartphone technology in order to extract trajectories of vehicles (18,19,20,21). Apart from these big data sources, computer vision technology using fixed camera systems has also been researched widely for the trajectory extraction and traffic analysis applications. The researchers in (22,23,24,25) apply image processing techniques to fixed-camera traffic videos to extract and analyze the trajectory data. Also, an extensive trajectory dataset (NGSIM) has also been developed using video analytic techniques (26). However, all this research has been using the fixed camera videos. Some researchers have attempted to employ UAV videos to extract vehicle trajectories (3, 14,16, 27). The authors in (16) present an especially effective methodology on the automatic extraction of the vehicle trajectories, however in their approach the user initially has to manually select the vehicle to be tracked.

THE PROPOSED FRAMEWORK

This paper proposes a detailed framework for the automatic extraction of multi-vehicle trajectories on a particular stretch of road via UAV-acquired data. A step-by-step methodology is presented for the optimal application of a UAV in the domain of transportation engineering and management. This framework categorizes the whole process into a number of stages, thereby resulting in a systematic and efficient conduction of a UAV-based traffic study. The proposed framework aimed broadly for traffic analysis and surveillance applications, is classified into the following five components: (i) pre-processing, (ii) stabilization, (iii) geo-registration, (iv) vehicle
detection and tracking, and (v) trajectory management. Figure 1 illustrates the steps involved in the processing and analysis of a drone or a UAV-acquired video for a traffic related study.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{The proposed framework for the automated UAV video processing and analysis}
\end{figure}

The proposed framework employs a combination of software packages in order to ensure an optimal processing and analysis of the traffic related UAV videos. Apart from some video editing tools, the major portion of the implementation has been done in MATLAB and C++ (OpenCV Library).

In the following sub-sections, the different elements of the proposed framework are discussed in detail. This is followed by an experiment and its results to demonstrate the working and efficiency of the proposed framework.

1. Preprocessing

The first step of the proposed framework is the pre-processing of the traffic video acquired via a UAV. This step is critical as all the subsequent steps are directly dependent on it. Various sub-steps can be included in the pre-processing phase of the proposed framework in order to prepare the UAV-acquired traffic videos for the actual processing and analysis procedures.

The pre-processing procedure of the UAV videos may be grouped under three categories i.e.: (i) Video Trimming, (ii) Image Rectification and (iii) Region-of-Interest Masking stages.

First of all, the UAV videos are trimmed to extract the useful part of the videos. This is done by excluding the parts of videos which are not useful for the traffic analysis such as the UAV take-off and landing portions of the recorded videos. After extracting the useful part of the UAV videos, the next step is the image rectification process. In this step, a special attention is given to the type and quality of the acquired images. The types of image rectification processes used are majorly dependent on the type of hardware (i.e. UAV and the camera) employed. Image distortions such as fish-eye effect and darkened-edges effect caused by the type and settings of lens used are removed or minimized in order to make the video ready for the processing and analysis phase. The main target of the step is to make each and every pixel of the image to be
useful for processing.

The next step of the pre-processing phase of the proposed framework is the masking of the irrelevant parts of the images. This process is particularly of significance for studies that target an automatic detection and tracking of vehicles or other road users via computer vision algorithms. Only the regions-of-interest such as specific lanes in a particular direction are kept in focus while all other areas are masked in the frame. This is done in order to make the image processing or computer vision algorithms more efficient as it extracts only the required data. Additionally, the computational power and the processing time are optimized as well.

2. Stabilization

The UAVs have advanced significantly over the last few years. The state-of-the-art hardware parts including the 3-axis camera-mount gimbals have drastically improved the level of stability of the recorded videos. However, the videos acquired via a UAV or a drone still have a certain amount of shakiness. This may be due to a number of reasons which can be either external such as the pressure applied by the wind gusts or can be internal i.e. the vibrations of the platform caused by the rotors and other mechanical parts. Therefore, a reliable stabilization procedure is necessary in order to minimize the effects of the UAV instability, as even a minor camera vibration can result in major movement in the imagery. The stabilization process also significantly simplifies and improves the efficiency of the latter processes of the proposed framework, specifically the vehicle detection and tracking.

As mentioned earlier, the use of a 3-axis camera-mount gimbal is critical to achieve the maximum possible stability in UAV videos during the flight. Further, these videos are processed during the post-recording phase as well to maximize the level of stability. For this purpose, a number of stabilization methods and softwares are available which can reduce the effects of small camera movements. A simple, yet laborious method usually employed e.g. in (3), to ensure the stability is by tracking an established ground control point or any other stationary object whose coordinates are known, throughout the length of the recorded video. This object is then regarded as a reference point and the difference between the coordinates of this object for consecutive frames is applied to the coordinates of all other objects. This technique, although effective, requires a frame-by-frame manual tracking as well as the prior knowledge of the exact coordinates of the reference object.

This paper, however, specifically focuses on using the automated techniques for the processing of the UAV-based traffic videos. Therefore, a point feature matching approach is employed in order to counter the instability and shakiness in the UAV videos. This Mathwork’s stabilization approach, as illustrated in Figure 2, first of all converts the two consecutive frames into grayscale to increase the computation speed. Following this, the corner points of features in both the images are determined and matched with each other by using the concept of sum of the squared differences (SSD). To maintain a degree of uniqueness in the matching points and to keep only the valid inliers, the RANSAC (Random Sampling and Consensus) algorithm is used. These points are then used to compute an affine transformation matrix which is a 3x3 matrix used to correct the geometric distortions in the image. The affine transformation matrix performs the transformation based on the scale, rotation and translation parameters. This transformation matrix is then warped to all the frames in order to remove the distortion caused by the instability of the UAV platform.
3. Geo-Registration

The geo-registration procedure of the UAV-acquired images involves the assigning of real world distances and coordinates to the image coordinates. The pixel coordinates are converted into real-world coordinates for the better applicability of the produced trajectory data. The geo-referenced calibrated trajectories can be directly used and integrated with various GIS applications as well. This process also enables the user to visualize and estimate various traffic parameters by generating the data in an actual scale.

In order to geo-register the UAV-acquired mono-vision 2D imagery, first of all, various UAV-acquired video frames are used to create a mosaic image using the Scale-Invariant Feature Transformation (SIFT) matching algorithm. This image is then assigned a coordinate system (mostly Cartesian) and is calibrated according to a specific scale with the help of any GIS tool. This leads to the point correspondence step in which a number of points on the calibrated UAV image are compared to the referenced (or Google) map of that particular area. This process results in the generation of two sets of coordinate data; the image coordinates and the corresponding real-world coordinates. The point- correspondence data is then processed using the RANSAC algorithm in order to compute the homography matrix. This 3x3 matrix allows the transformation of 2D planar image into 3D coordinates by using the assumptions of pin-hole camera model. This model based on certain assumptions enables the projection of a 3D object onto the 2D image plane. The coefficients of the matrix \( H \) can then be used to convert a set of 2D image coordinates \((x_i, y_i)\) into the real-world coordinates \((x_w, y_w, z_w)\) as shown in the equations (1, 2, 3, 4).

\[
\begin{bmatrix}
    x_w \\
    y_w \\
    z_w
\end{bmatrix}
= \begin{bmatrix}
    h_{11} & h_{12} & h_{13} \\
    h_{21} & h_{22} & h_{23} \\
    h_{31} & h_{32} & h_{33}
\end{bmatrix}
\begin{bmatrix}
    x_i \\
    y_i \\
    1
\end{bmatrix}
\]  

(1)

\[
z_w = h_{31} x_i + h_{32} y_i + h_{33}
\]  

(2)

\[
x_w = (h_{11} x_i + h_{12} y_i + h_{13}) / z_w
\]  

(3)

\[
y_w = (h_{21} x_i + h_{22} y_i + h_{23}) / z_w
\]  

(4)
4. Vehicle Detection & Tracking

After the Geo-Referencing or calibration of the images to the desired coordinate system, the detection and tracking of different road users is carried out. This process is the pivotal step in any video analytics-based traffic study as the principal results are all based on the efficiency and accuracy of this process. The main aim of any vehicle detection and tracking method employed is to produce consistent tracks of detected vehicles while minimizing the number of false or missed tracks.

The efficiency of the vehicle detection and tracking depends on the method employed. The vehicle detection and tracking processes being used in existing studies can be broadly classified into two categories: (i) Semi-Automatic and (ii) Automatic techniques (9). The semi-automatic techniques (3,5,13) produce accurate results, however they are laborious and require certain steps to be performed manually. On the other hand, automatic techniques, though having some limitations, are gaining popularity as they provide quick results with minimum manpower involved.

In the proposed framework, the automatic detection and tracking of vehicles is the most complex step as it involves a series of computer vision algorithms in order to efficiently detect and track the different types of vehicles on a particular road segment. This process requires the development of a robust and reliable algorithm to produce accurate results. For this purpose, a detection and tracking algorithm is developed using the OpenCV library in C++. The stabilized UAV video is used as input into the system. First of all, the input video is passed through optical flow tracking algorithm (28,29), in which the direction and speed of the moving pixels are estimated from one frame to another by utilizing the concept of weighted-least squares. The Lucas-Kanade optical flow algorithm tracks the corner points of all the significant features throughout the video. The output of optical flow process is then used as an input for the background subtraction algorithm. Background subtraction (BS) is a commonly used technique (especially for static videos) in which the moving objects are detected by subtracting the current image from the reference background image. It is worth mentioning here that the main reason of implementing optical flow before background subtraction is to improve its accuracy for the UAV videos having dynamic backgrounds and some instability. Once the moving objects are separated from the background, the neighboring moving pixels (blobs) in the foreground are identified as vehicles and are tracked through each frame. A particular consideration is also given in the algorithm to counter the inaccuracies caused due to losing and re-initialization of tracks. The Figure 3 shows a simplified schematic diagram for the vehicle detection and tracking process.

![Schematic Diagram](image)

**FIGURE 3.** The schematic diagram of the vehicle detection and tracking process
5. Trajectory Management

The final step of the proposed framework for an optimal processing and analysis of the UAV traffic videos is the management of the extracted trajectories of the vehicles of interest. The tracks or the trajectories extracted automatically during the vehicle detection and tracking step have to be dealt-with in an effective manner such that they can be stored and then retrieved for further traffic analysis.

In the proposed framework, each coordinate of the vehicle detected and tracked in the area of study is automatically written and saved to a text (.txt) file. This text file containing the coordinates of each vehicle for every frame of the UAV video enables the user to sort and process the data in order to extract various traffic parameters such as vehicle’s velocity, average velocity, acceleration, traffic flow etc. This sorted data can then be used to generate various charts and graphical displays of the extracted vehicle trajectories in order to study the drivers’ behavior and to track unusual activities (incidents).

EXPERIMENTS & RESULTS

To test the proposed framework for the automated traffic analysis via a UAV-acquired footage, a series of flights were conducted over an urban intersection near the city of Sint-Truiden in Belgium. The equipment used for the flights was the Argus-One (from Argus-Vision) which is a high-end octocopter UAV, capable of a 9 minute flight while carrying 3 kilograms of weight. Panasonic Lumix GH4 DSLM camera was attached with the UAV to obtain a high resolution (4K Resolution@ 25fps) traffic footage. In addition to this, a live-feed transmission (first-person-view) system was also attached with the UAV for real-time monitoring of the camera angles. This particular UAV requires simultaneous operation by the pilot and the camera operator. Despite of a relatively lower flight time, this particular UAV was employed as it provides a high quality and stable video data which was necessary to initially develop and test the proposed methodology. Figure 4 below shows the Argus-one UAV in standby mode and in flight respectively.

FIGURE 4. The argus-one UAV; ready for take-off (left-side) and in-flight (right-side)

The experiment was conducted on a Friday afternoon (16:30 to 18:00 hours) to capture the evening rush hour. The weather was mostly clear while the wind level was gentle as well (18km/hour, Beaufort scale 3). The location as shown in Figure 5 is an intersection joining the national highways N80 and N718 with speed limits of 120km/hour and 90km/hour respectively. The selected 4-legged intersection for the experiment leads from the city of Hasselt into the center and suburbs of Sint-Truiden, with 2 lanes in each direction. The UAV was hovered (constant altitude, zero velocity) above the intersection at the heights of 80m and 60m. Due to the availability of
backup battery packs, a series of flights were conducted, resulting in a 14-minute useful traffic video after excluding the take-off and landing maneuvers.

FIGURE 5. The studied 4-leg intersection; Google earth satellite image (left-side) and image from the UAV (right-side)

As mentioned earlier, a combination of various softwares including MATLAB and C++ (OpenCV library) was used to develop an algorithm for the different steps of the proposed framework. The aim was to make every step of the framework automated with quick outcomes. The UAV video processing and the results generation was done on an Intel® Core™ i5-4210M CPU@2.60GHz, with 4GB RAM and Windows 8.1 (64 bits). The UAV video was stabilized according to the proposed methodology explained in the previous sections. The images were then scaled as per actual distances and a Cartesian coordinate axis was assigned having origin at the center of the intersection.

The trajectories of multiple vehicles crossing the intersection under observation were extracted using the developed computer vision algorithm. Figure 6 depicts the trajectories of 2 sample vehicles and their corresponding speed profiles. In addition, the figures 6(c) and (f) illustrate the space-time diagrams of platoon of vehicles while approaching and crossing the intersection at different times during the UAV flights.

A number of interpretations can be made from the trajectories and speed profiles illustrated in Figure 6. It can be observed from graphs in Figure 6(b) and (c) that all the vehicles in the Platoon-1 including the sample vehicle-1, show an increasing speed trend which implies that the traffic signal just turned green at the instant. Initially, the sample vehicle moved slowly while approaching the center of the intersection as it was moving in a group of vehicles (platoon-1) with small headways. As the vehicle entered and crossed the intersection, the speed kept on increasing uniformly. The mean speed of the sample vehicle while approaching and maneuvering through the intersection was measured to be 26 km/hour with a maximum of 32 km/hour (Figure 6(b)). As the accuracy of the calibration process was ensured by several measurements at site and then verification with Google Maps, therefore the values estimated did not have significant errors.

Similarly, another group of vehicles (platoon-2) approaching and crossing the intersection under observation was also analyzed. The graphs in the Figure 6(d), (e) and (f) illustrate the drivers’ behavior while approaching a signalized intersection. It is clearly evident from the trajectories that the each driver decelerated in his own particular manner in order to stop at the traffic signal. Some trajectories show a smooth transition to a stationary position (e.g. car 7) while others have a steep curve (car 1) implying a strong deceleration (Figure 6(f)). Additionally, the behavior of a right-turning vehicle (car 8) can also be observed. The slope of the car 8’s trajectory suggests that the vehicle had to reduce its speed in order to safely execute
the turning maneuver. Such diagrams can be also effectively used to monitor and study the unusual trajectories leading to traffic incidents.

**FIGURE 6.** The automatically extracted trajectories (a) Trajectory of Sample Vehicle-1 along x-y axis, (b) Speed Profile of Sample Vehicle-1, (c) x-t Trajectories of Platoon-1, (d) Trajectory of Sample Vehicle-2 along x-t axes, (e) Speed Profile of Sample Vehicle-2, (f) x-t Trajectories of Platoon-2
DISCUSSION & CONCLUSION

In this paper, an extensive yet systematic methodological framework is presented for the optimal application of a drone or UAV in the domain of transportation engineering and management. A step-by-step methodology elaborates the processes involved in the automatic extraction of the trajectories of multiple vehicles on a particular stretch of road using UAV-acquired data. Most of the existing traffic related UAV studies generally have employed semi-automatic processing and analysis methods, however, this paper particularly emphasizes on the automation of all the steps included in the framework. The ultimate goal of this research is to develop a system that produces useful traffic data in a short time.

The proposed framework is supported by a field experiment conducted in the city of Sint-Truiden, Belgium over an urban intersection. A series of trajectories were extracted and illustrated graphically using the proposed methodological framework. The results generated depict the overall applicability of the system. Apart from it, such a systematic framework may prove to be helpful for future traffic-related UAV studies as well by streamlining the processes involved. It may also serve as comprehensive guide for the automated and quick extraction of multi-vehicle trajectories from the UAV-acquired data.

Although, the methodology employed and the consequent results generated show a reasonably good performance, the vehicle detection and tracking algorithms need to be more robust and accurate in all types of conditions. The fully automated vehicle detection and tracking, though ideal for real time applications, has its own limitations as well. A number of errors can arise due to various reasons such as partial occlusions, objects in close proximity, false detections etc. A certain amount of noise appears in the produced data which has to be dealt-with accordingly. Additionally, the video stabilization process also plays an important role in improving the overall efficiency of the detection and tracking system.

The future research will mainly focus on the extension of the applications of the proposed framework in the context of the UAV-based traffic monitoring and analysis. Further, more specific and detailed UAV-based traffic-oriented studies will be carried out. Additionally, the proposed framework will also be extended to implement real-time processing and analysis of the UAV-acquired data.

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