

19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016,
Istanbul, Turkey

UAV-Based Traffic Analysis: A Universal Guiding Framework Based on Literature Survey

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Abstract

The Unmanned Aerial Vehicles (UAVs) commonly also known 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 applications in the transportation field as well; ranging from the traffic surveillance applications to the traffic network analysis for the overall improvement of the traffic flow and safety conditions. 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. This paper presents a universal guiding framework for ensuring a safe and efficient execution of a UAV-based study. It also explores the analysis steps that follow the execution of a drone flight. The framework based on the existing studies, is classified into the following seven components: (i) scope definition, (ii) flight planning, (iii) flight implementation, (iv) data acquisition, (v) data processing and analysis, (vi) data interpretation and (vii) optimized traffic application. The proposed framework provides a comprehensive guideline for an efficient conduction and completion of a drone-based traffic study. It gives an overview of the management in the context of the hardware and the software entities involved in the process. In this paper, an extensive yet systematic review of the existing traffic-related UAV studies is presented by moulding them in a step-by-step framework. With the significant increase in the number of UAV studies expected in the coming years, this literature review could become a useful resource for future researchers. The future research will mainly focus on the practical applications of the proposed guiding framework of the UAV-based traffic monitoring and analysis study.

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Peer-review under responsibility of the Scientific Committee of EWGT2016.

Keywords: UAVs; Drones; Traffic Applications; Traffic Analysis; Guiding Framework

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1. 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 infrastructural expansion alternatives, the 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 the macroscopic as well as the 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 (Coifman *et al.*, 2006).

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; however, the data collected is only measured at a particular point with generally no useful data about traffic flows over space (Puri,2005). This results in a number of hidden points as a high density of detectors are required to cover the whole network (Coifman,2006; Barmponakis *et al.*,2016). 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. However, such data is not always easily converted to useful traffic data (Vlahogianni.,2015). Also, the use of GPS technology might not be correct for studying the driver behavior since the drivers know they are being monitored (Salvo *et al.*,2014¹; Barmponakis *et al.*, 2016).

The technological advances have recently enabled an alternative to an inflexible fixed network of sensors or the labor intensive and potentially slow deployment of personnel (Coifman *et al.*,2006). 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 surveillance purposes, 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 (Kanistras *et al.*,2013; Puri, 2005).

The Unmanned Aerial Vehicles (UAVs) commonly also known 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 fields of the human life, 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 of the world aerospace market this decade (PR Newswire, 2011).

As mentioned by Kanistras *et al.* (2013) and Puri (2005), 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 (Puri,2005). The UAVs cover a large area in short times with an extreme low cost. The lower cost can also be achieved, since all the equipment is reusable to a different point of interest (Barmponakis *et al.*, 2016).

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 (Barmponakis *et al.*,2016; Puri,2005). The actual applications of this technology are currently limited in numbers but are still in the research stages. Nevertheless, this technology is progressing rapidly and can be safely termed as a future-proof technology with the widespread commercial availability and decreasing costs. It is forecasted by the aviation authority that 30,000 drones could be over U.S. skies by 2020, implying new and improved applications of the technology.

However, the use of drone technology in traffic related studies involves a high level of planning and management precision. 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 mismanaged execution could be pretty severe. For this purpose, we aim to propose a universal framework 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, we re-organize the existing UAV-based traffic studies into a step-by-step framework. Such a detailed framework may prove to be helpful for various traffic related UAV studies such as traffic surveillance, network traffic analysis and behavioural studies. It may also serve as a foundation for more advanced studies involving swarms of UAVs. Up till now, there have been general survey studies (Puri,2005; Kanistras *et al.*,2013) regarding the research applications of UAVs in the field of transportation, but there has been no such detailed framework based on the existing literature.

This paper is organized as follows: first of all, the relevant survey studies that have been carried out regarding the applications of UAVs in traffic field are briefly discussed in the section 2. This is followed by a detailed description of the proposed framework based on the existing literature (section 3). Finally, the section 4 comprises of the brief discussion of the framework along with the conclusions and the proposed future developments of the framework.

2. Related Work

As mentioned earlier that the UAVs are increasingly being employed for multiple purposes. According to the literature, the UAVs are widely being researched for traffic surveillance and network evaluation applications (Coifman,2006; Puri *et al.*,2007; Heintz *et al.*,2007, etc.). Various types of UAVS are being used or tested to measure traffic related data at several universities (Puri,2005). A few literature survey studies have been conducted to summarize the research work carried out around the world regarding UAV-based traffic applications.

Puri (2005) discusses and summarizes the research carried out all over the world until 2005 in the domain of UAV based traffic surveillance and analysis. The author initially covers some of the research work on-going at various universities such as University of Florida, Ohio State University, Linköping University, Georgia tech etc. 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 author mentions 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. Similarly, Kanistras *et al.*(2013) adopt the same approach as Puri (2005) by conducting a literature survey of the applications of the unmanned aerial vehicles for traffic monitoring and management. However, the authors only focus on the research that has been carried out in this perspective within a specified period i.e. between 2005 and 2012. The relevant research conducted during this period is also systematically arranged as per the approach employed in the previous research of Puri.

Some researchers have tried to propose a workflow or an outline for the conduction of the UAV based studies. Eisenbeiss (2009) proposes a workflow for UAV photogrammetric studies particularly for archeological and environmental applications. The author enlists and discusses the different modules of the proposed workflow i.e. flight planning, image acquisition and processing of UAV images. A particular focus is on the improvement of the UAV flight planning and control systems, eventually ensuring the quality of the acquired data. On the other hand, Zheng *et al.* (2015) develop a UAV system specifically for 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 and the development of a risk analysis model.

3. Framework

In this paper, we re-organize the existing UAV-based traffic studies and the available software platforms into a step-by-step framework. This framework categorizes the whole process into a number of stages, resulting in a systematic and efficient conduction of any drone-based study. The framework based on the existing studies, is classified into the following seven components: (i) scope definition, (ii) flight planning, (iii) flight implementation, (iv) data acquisition, (v) data processing and analysis, (vi) data interpretation and (vii) optimized traffic application. Figure 1 below illustrates the steps involved in conducting a drone or a UAV platform based traffic related study. We discuss each step on the basis of the existing relevant studies with a particular focus on the studies that employ small, low altitude (<150m) multirotor UAVs for the traffic related applications. Also, a special consideration is given to the data analysis techniques that have been used to detect and track different vehicles in the existing relevant studies.

Figure 1 below illustrates the steps involved in conducting a drone or a UAV platform based traffic related study. As the figure suggests that the whole process can be divided into two main blocks i.e. the drone block and the processing (software) block. The output of the scope definition step is fed consequently into the two blocks as shown below:

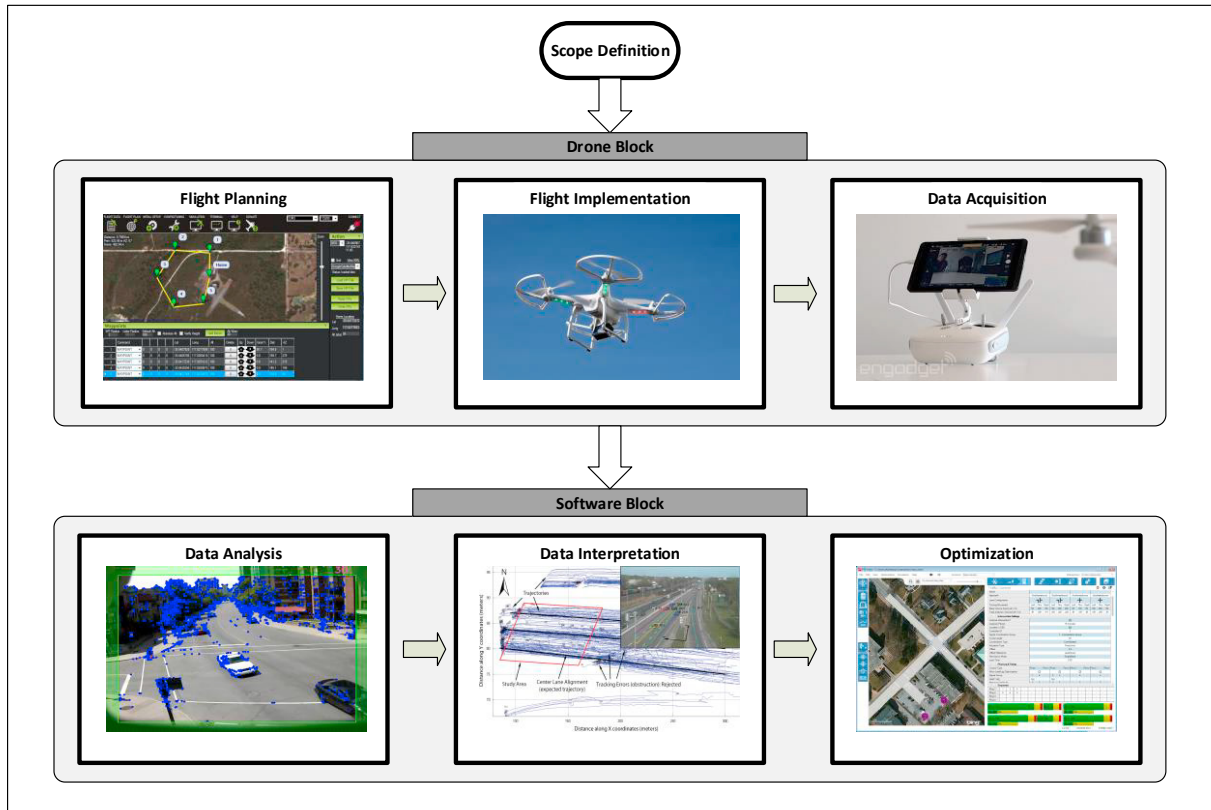


Figure 1. The Proposed Framework

3.1. Scope Definition

The first module of our proposed framework involves the definition of the scope of the study to be conducted. This is a critical step in any project as all the latter steps are dependent on it. Therefore, a clear problem statement with fixed and definite project objectives must be defined during this step. As mentioned by Eisenbeiss (2009), the attributes of the workflow modules are generated in the first module in which the project parameters like object type, output data, camera sensor, type of model helicopter and flight restrictions are designated. These parameters can vary from one application to another. Based on the literature review of project scope development (AASHTO,2010), we present a 3-step process in the context of a UAV based traffic study as shown in the figure 2:



Figure 2. The Scope Definition Module

First of all, the main objectives of the study are defined and a specific focus is established with respect to the expected results of the study. The objectives of the project may include an implementation of a traffic policy program to improve traffic flow or to reduce the traffic conflicts. This can be achieved with the help of the drivers' lane change behaviors and traffic pattern studies e.g. Salvo et al. (2014²) use a UAV video to analyze the gap-acceptance in an urban intersection. After the establishment of the objective, the network elements to be monitored and analyzed are selected. This can be an intersection, a roadway segment, a ramp or a combination of them. In the Performance measures step, the parameters to be determined for the study are selected such as traffic volume, pedestrian volume,

number of lane changes, vehicle classification, velocities, acceleration/deceleration, number of conflicts etc. The type of traffic parameters to be derived from the UAV videos also define the type of UAV flight to be conducted e.g. Barmounakis *et al.* (2016) extract the vehicle trajectories across the different legs of the intersection by just making the UAV hover (constant altitude, zero velocity) above an intersection.

3.2. Flight Planning Stage

The Flight Planning Stage involves the preparation for the implementation of the actual UAV flight for the collection of the required data. With the significant increase in the number of UAVs, state laws are now being formulated and implemented all over the world to avoid major mishaps. In this situation, the UAV flight planning step has become even more important. This implies that an in-depth flight planning, based on the project parameters or scope is essential (Eisenbeiss,2009). Based on the literature survey of the traffic related UAV studies, the whole process of the UAV flight planning may be classified into three main categories; safety, environment and route planning aspects, as shown in the figure 3.

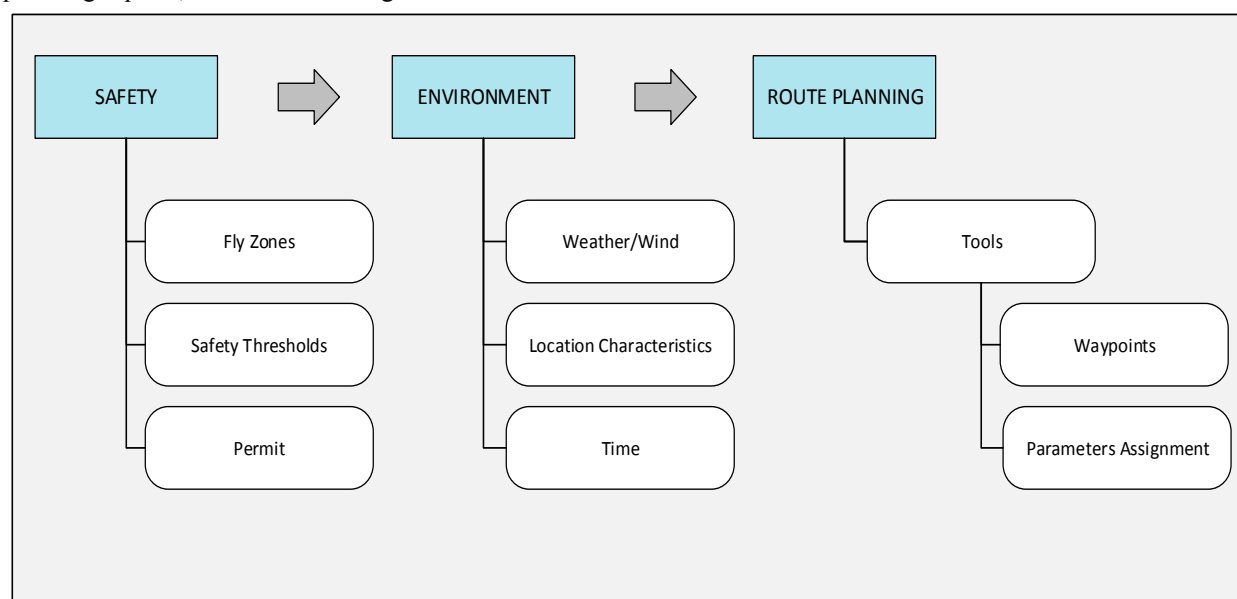


Figure 3. The Flight Planning Steps

These three categories include all the aspects that are critical for ensuring a successful UAV flight operation. First of all, the flying zone category of the study area must be evaluated with the help of the local flying zone maps. Also, a safe distance has to be maintained from the active airfields and from other sensitive installations. Based on the relevant flying zone, safety thresholds and other project characteristics, the flight parameters may be selected during the flight planning process (Eisenbeiss,2009). This is followed by an acquisition of a flight permit from the concerned department. This process has become easier with the development of UAV flight management platforms which automate a number of steps involved in ensuring safety and attaining flight permits. Idronect and UniflyUTMS are examples of such platforms from Belgium.

The location characteristics i.e. infrastructural environment and extents of the built-up area in the study zone must also be considered in quest for an optimal set of flight parameters. Apart from the spatial planning for the UAV flight, a temporal planning is also necessary. This requires a special deliberation towards the weather and wind conditions in the area of study along with the optimal selection for the time of the day. For example, Salvo *et al.* (2014¹) conduct their UAV flight at noon as the shadows are minimal during this time of the day, ultimately resulting in an easier and higher quality analysis of the videos. Also, the interference effects of electromagnetic emissions (Yochim, 2010) and the status of GPS satellites especially in case of an automated UAV flight must also be considered during the planning phase.

With the advancement in the technology, UAV flight planning tools have been developed that enable a more systematic and automated flight operation. Using such tools, the users can mark the waypoints along the desired path. The users can plan and upload the exact route of the flight to the UAV for an automated flight. Mission Planner and UgCS ground station are examples of such softwares. However, a backup certified pilot in line of sight (LOS) is compulsory even for automated UAV flights in the civilian domain due to security and insurance constraints. (Eisenbeiss,2009).

3.3. Flight Implementation Stage

During the flight implementation Stage, the UAV actually flies over an area of interest as per the planned flight path/route. This flight is conducted based on the parameters decided during the flight planning stage. The flight depending upon the user's preference and flying expertise, is controlled either manually via the radio controller or automatically via the auto-pilot function. This step in conjunction with the flight planning step requires a number of safety and legal issues to be carefully addressed as mentioned in the previous step.

During the UAV flight implementation, it also has to be made certain that the captured video is not shaky or wobbly. While minor stability issues can be handled during the pre-processing stages, the camera platform has to be stable enough to achieve a high quality video. For this purpose, most UAVs hold a gimbal (3-axis) which allows the rotation of the camera about a single axis only (Barmounakis *et al.*,2016). The gimbal has its own motion sensors (similar to those that hold the UAV stable) and small motors. It keeps the motion of the camera independent (within certain limits) from the motions of the UAV (motions from tilting to move forward or sideways, or when hit by a gust of wind). The camera operator is able to aim the camera at will (overriding the 'lock' of the camera position relative to the environment). We discuss some individual flight implementation standards adopted by the researchers in their traffic-related UAV studies as following:

Barmounakis *et al.* (2016) conduct a UAV flight over a low-volume intersection in the university area. The UAV was hovered at a particular point from where all the legs of the intersection were clearly visible as shown in the figure 4. The flight attained a maximum height of 70m and the authors were able to record a 14-minute video excluding the take-off, landing and the time to reach the recording point. The authors particularly selected a site where no alternate sufficiently high position was available in the surroundings to have a complete overview of the intersection. The flight was planned to be executed on a sunny day with moderate wind speed. Also, it was particularly made sure that the flight is conducted during the noon hours so that the effect of shadows is minimal, thereby ensuring an efficient detection of vehicles during the analysis stage.



Figure 4. View of the Intersection from a UAV (Source: Barmounakis *et al.*, 2016)

Similarly, Salvo *et al.* (2014¹) implement their UAV flight for the collection of traffic data over a road segment in the suburbs of Palermo City, Italy. The authors after a thorough planning process conducted the UAV flight and were able to collect a 15 minute video with 10 frames per second in HD quality (1280x720). A series of flights were conducted to acquire the desired video length due to the technical limitations of the hardware. Also, the flights were conducted during the noon hours in order to minimize the effects of the shadows of the objects. Salvo *et al.* (2014²) in their another, study conduct the UAV flight over the intersection in the vicinity of the university. The authors conducted 5 flights over the area under observation at an altitude of 60m and acquired a total of 20 minute HD quality video. The UAV was hovered (zero speed, constant altitude) at 5 different points during the series of flights.

Zheng *et al.* (2015) employed a different approach to validate their driver-behaviour monitoring study. To counter the safety restrictions imposed by Federal Aviation Authority (FAA) and local law enforcement agencies, the authors

used 2 types of methods for controlled testing of their methodology. A test track with RC cars instead of real cars was set up to evaluate a UAV-based traffic study. Apart from this, the experiment was also conducted in the university grounds in controlled conditions.

3.4. Data Acquisition

The acquisition of data from the UAV is also a critical step of the proposed framework and is largely dependent on the scope of the study. The data that has to be acquired from the UAV includes the high quality UAV recorded video footage of the region of interest along any other data from sensors (infrared, thermal, ultrasonic etc.) mounted on the UAV. In some cases, the flight telemetry data (altitude, horizontal speed, vertical speed along with the position and the orientation data) is also acquired from the UAV in order to calibrate the recorded video. As indicated by Cramer (2001), the integration of position and orientation data generated by the navigation unit of the UAV leads to a reduction of the number of physical control points that are required for the orientation and calibration of the UAV videos. Overall, the scope specific data is acquired from the UAV and is then further treated and processed during the later stages of the framework.

The data acquisition can be real-time or offline depending upon the requirements of the project. Most of the studies mentioned up till now in this paper such as (Salvo *et al.*,2014¹; Salvo *et al.*,2014²; Barmounakis *et al.*,2016 etc.) employ an offline processing approach in which the video data is acquired and processed after the completion of the UAV flight. However, some studies such as (Zheng *et al.*, 2015; Sekmen *et al.*,2009 etc.) employ a real-time data acquisition and processing techniques. Zheng *et al.* (2015) propose a methodology for a real time vehicle tracking system in order to monitor and study the drivers' behaviour to prevent accidents and promote highway safety. The proposed system is based on the live transmission of the UAV video to the ground station computer on which a near real-time image processing is conducted followed by a statistical analysis for vehicle risk modelling. (Luo *et al.*,2011; Sekmen *et al.*, 2009) are other such studies which employ a real time data acquisition and processing approach. The authors present an airborne traffic surveillance system to detect and track multiple moving objects in real-time.

3.5. Data Processing & Analysis

Video Analytics have attracted significant attention mainly because they enable researchers to easily collect detailed trajectory data and at the same time have a visual observation of the phenomenon (Barmounakis *et al.*, 2016). A lot of research has been carried out for fixed camera video analysis systems such as (Micchalopoulos,1991; Cao *et al.*,2007; Wang *et al.*,2008). However, the analysis of a traffic stream from a video recorded via an unstable aerial platform i.e. a UAV is a relatively new topic. This process is more complex as compared to the analysis of a moving traffic stream from a stationary or fixed camera system.

Multiple approaches have been employed in the existing literature for the processing and analysis of the UAV-based traffic data. These approaches can be broadly classified into two categories:

(i) *Semi-Automated Video Analysis*: The semi-automated video processing and analysis approach has been employed in a number of traffic related UAV studies. Such an approach is easy to set up and ensures a high level of accuracy and reliability. Also, no complex image processing algorithms are required which implies that far less computational power is needed. On the other hand, this approach is more laborious and generally requires more manpower as it generally involves the establishment of some physical ground control points (GCPs) or have certain lengths accurately measured on the site in order to calibrate the UAV images. 'Tracker' is an open source video analysis and modelling tool (Brown, 2008, 2009, 2010) which is commonly used for feature tracking in semi-automatic analysis studies. This software makes use of the stabilized and calibrated video to speed up the tracking process and produce more consistent data by eliminating the need for marking each frame (Barmounakis *et al.*, 2016). A few studies that utilize a semi-automatic video analysis approach are (Salvo *et al.*, 2014¹; Salvo *et al.*,2014²; Barmounakis *et al.*, 2016).

(ii) *Automated Video Analysis*: An automated analysis of the UAV acquired traffic data involves a series of advanced image processing filters and techniques in order to detect and track the relevant road users. The automated video analysis is gaining popularity especially for the real-time traffic monitoring and tracking applications. Although such

an approach is quick and requires minimal manpower, it still has some limitations. Generally, the accuracy of such systems fluctuates dramatically with changes in conditions such as light, climate etc. Additionally, the automated system requires a high computational power and is difficult to initially set up as it involves complex algorithms for each sub-task of the analysis. Some studies that propose an automated video analysis include (Zheng *et al*,2015; Apeltauer *et al*,2015; Oh *et al*, 2014; Azevedo *et al*, 2014, Luo *et al*,2011; Sekmen *et al*,2009). The authors attempt to make use of fast and robust object detection and tracking techniques for the processing of UAV videos.

However, for both the approaches, the basic workflow remains the same as illustrated in the figure 5. The analysis of the UAV-based traffic footage involves some pre-processing and stabilization procedures. These are necessary in order to make the video ready for the actual analyses steps. After the Geo-Referencing or calibration of the images to the real world coordinate system, the detection and tracking of different road users is carried out either automatically or semi-automatically as discussed earlier.

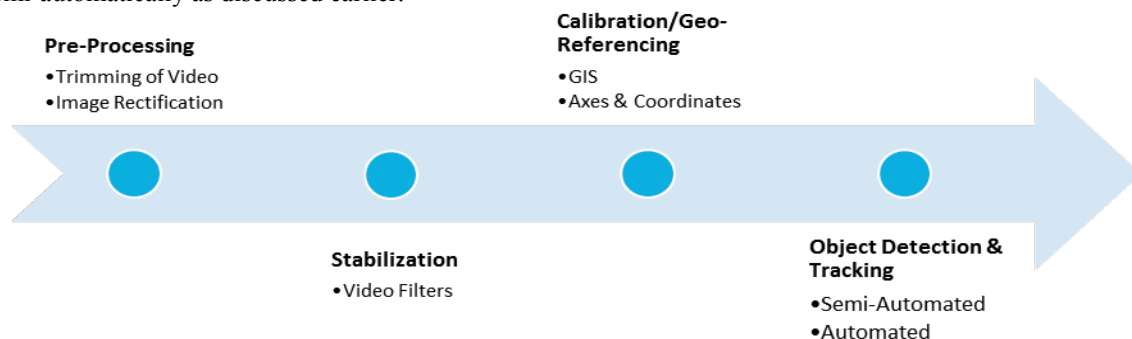


Figure 5. The Data Processing Steps

3.6. Data Interpretation

The interpretation of the processed video data is the next step in the framework. The interpretation is done with the help of different types of graphs and charts that are generated as an output of the data analysis procedures. This step too, along with the preceding steps of the proposed framework, is directly dependent on the scope of the study. The trajectories of the vehicles or other road users extracted during the analysis part are displayed in x-y planar graphs to understand the behaviour and trend of the road users. Similarly, such trajectories are also represented graphically to illustrate the traffic movement across the intersection as depicted by Barmpounakis *et al.* (2016) in figure 6 .

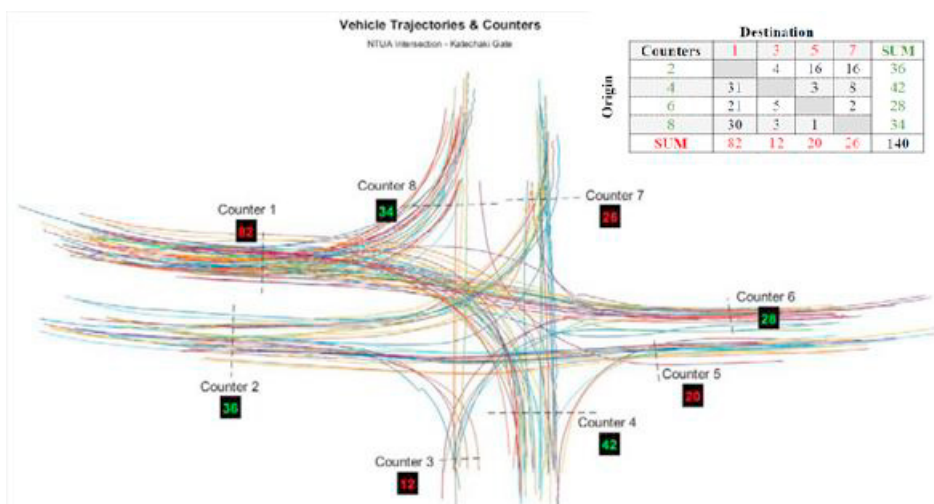


Figure 6. Graphical Representation of Vehicle Trajectories for a Given Intersection (Source: Barmpounakis *et al.*, 2016)

The authors (Barmpounakis *et al*,2016) especially focus on the unusual trajectories that may compromise the traffic safety situation. This is also followed by the construction of OD matrices in order to quantify the traffic volume for

each leg of the intersection. Similarly, other authors such as Salvo *et al.* (2014¹) determine the traffic kinematic parameters i.e. flow and density during the analysis phase of the study. These parameters are then compared with the flow and density values determined via theoretical macro-simulation models i.e. Greenshields, Greenberg, Underwood models etc.

3.7. Optimized Traffic Application

The optimized conclusion of the traffic study in accordance with its scope is the final step in our proposed UAV-based traffic analysis framework. The study-specific traffic parameters determined during the analysis and interpretation steps are employed to improve the existing traffic models which ultimately help in solving the real-world traffic situations. This application dependent optimization may include a number of traffic related objectives such as traffic signal optimization, observation of drivers' behaviours, lane change manoeuvres etc. Moreover, a real-time information system can optimize the traffic operation by sending alerts to the concerned departments in case of incidents and emergencies (Barmounakis *et al.*, 2016).

Salvo *et al.* (2014¹) conclude their study by comparing the traffic parameters obtained via the analysis of the UAV-acquired video with the traffic parameters obtained via macro-simulation models. Similarly Salvo *et al.* (2014²) attempt to determine the gap acceptance of all vehicles that try to enter the principle traffic stream at an intersection by using a UAV-acquired video dataset. Additionally, Barmounakis *et al.* (2016) try to optimize the traffic safety and flow conditions by understanding the road user behavior in intersections by observing unusual trajectories and behavior.

4. Discussion & Conclusions

In this paper, we present an extensive yet systematic review of the existing traffic-related UAV studies by moulding them in a step-by-step framework. Up till now, there have been general survey studies (Puri, 2005; Kanistras *et al.*, 2013) regarding the research applications of UAVs in the field of transportation, but there has been no such detailed framework based on the existing literature.

With the passage of time, the UAV technology is rapidly being accepted as a very useful and dynamic technology, particularly for the collection of detailed and accurate traffic data. This relatively low cost technology provides high resolution video data while covering a larger area. The mobility and flexibility of the system further increases the worth of this technology. However, despite of a number of advantages, 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 the safety and privacy concerns are the biggest hindrances in making this technology more effective. Although, high-end technology could be used to increase the battery life, this however exponentially increases the cost of ownership. Therefore, the current low cost technology can be utilized most effectively by combining it with the other traffic data collection apparatus.

The UAVs can be used to collect data beyond the range of fixed sensors in order to get a detailed and accurate data over space and time. This can particularly be useful 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. Moreover, the management of traffic incidents can also be improved drastically with the help of such technology. Therefore, it can be concluded that advancement in technology, effective regulations and systematic frameworks will result in a safer and more efficient usage of the UAVs, particularly for the traffic applications.

With the significant increase in the number of UAVs, state laws are now being formulated and implemented all over the world to avoid major mishaps. In this situation, there is a dire need for a systematic and detailed step-by-step framework for the conduction of UAV flights. Apart from it, the proposed framework may prove to be helpful for various traffic related UAV studies such as traffic surveillance, network traffic analysis and behavioural studies. The development of such a framework may optimize the usage of limited UAV flight time, thereby resulting in an efficient conduction of the traffic study. Additionally, it may also serve as a foundation for more advanced studies involving the swarms of UAVs. Overall, the proposed framework serves as a comprehensive guide for the conduction of a UAV-

based traffic study. The steps involved in the process outline all the hardware as well as software ingredients that are essential to ensure a safe and efficient operation, management and control of a UAV-based traffic study.

Our future research will mainly focus on the implementation of the proposed framework in a real-world situation to observe and analyse traffic streams in Belgium. A particular focus will also be on the scenario evaluations, in terms of feasibility measures and cost-benefit analysis, in comparison to other existing technologies.

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