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Method of Calibration for Video-photographic Traffic Data Collection: A Case Study using Drone Technology

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Abstract **-** Speed, volume and density are the basic parameters required for any traffic engineering study and most importantly for estimation of roadway capacity. Erroneous capacity estimation leads to faulty and unacceptable design of roadway facilities. For accurate data collection of these basic parameters, video photographic technique is mostly preferred over manual technique in order to achieve flawless roadway capacity estimation. But due to a vast spectrum of constraints, even with the use of video photographic technique, it becomes difficult to collect traffic data accurately which in turn injects huge amount of error in the outcome of the analysis. In the conventional methods of traffic data collection, researchers often adopt the aerial photographic technique to capture error free data from the field. In this present study ground-based video photographic technique was adopted to capture the traffic data and a drone-based technique of traffic data collection was also used to capture the traffic data simultaneously so to propose suitable calibration to be applied.
***Keywords*:** Video Photography, Traffic, camera positioning, parallax error

1. Introduction

Capturing of traffic data from the field is one of the major challenges for the researchers. Several data collection techniques, direct or surrogate procedure are adopted in this domain. Field data related to traffic stream parameters are usually captured using various instrumental techniques. Faulty measurement of traffic stream parameters like vehicular speeds yields erroneous capacity and leads to wrong and unacceptable design of roadway facilities. Traffic conditions on Indian urban streets are very complex and heterogeneous in nature. Presence of numerous categories of motorized and non-motorized vehicles sharing same carriageway, lack of lane discipline and random overtaking behaviour of drivers and lastly direct influence of the pedestrian on vehicular movement makes the traffic system more complicated.

Laser-based technology and video image capturing techniques are widely used in traffic data collection and extraction process where the accuracy rate remains in acceptable limit. Equipment like loop detectors, magnetic detectors, piezoelectric sensors, microwave sensors, infrared detectors etc., are widely used in traffic data collection procedure. Aerial photography was used to measure density on Maryland aerial survey of highway traffic between Baltimore and Washington [1]. The potential use of aerial photographic technique in traffic analysis were also established [2]. Various photographic techniques such as conventional aerial photography, continuous strip stereophotography, time lapse photography [3] was used by the researchers in traffic data collection process. In the conventional methods of traffic data collection, researchers often adopt the aerial photographic technique to capture error free data from the field. In this present study ground-based video photographic technique was adopted to capture the traffic data and a drone-based technique of traffic data collection was also used to capture the traffic data simultaneously for traffic data collection and calibration purpose.

2. Background of Traffic Data Collection Procedures

For accurate collection of traffic data, video photographic techniques are preferred over manual techniques. Due to a vast spectrum of site constraints, even with the use of video photographic technique, it becomes difficult to collect traffic data accurately which in turn injects huge amount of error in the outcome of the analysis. The most inherent error is the parallax error [4] and the error due to variation in light exposure as well as due to the various camera positioning. Parallax error represents distance-related measurement error such as speed and headway [4]. Most video-image systems do not account for the parallax errors involved with a departing view [4]. Video image processing techniques or manual methods are adopted for vehicle detection, travel time and speed decoding. Video image processing systems were also used for the analysis of the captured video images and measurement of traffic data such as traffic speed, volume and density [5]. In the video-photographic technique a video camera is mounted over the tripod placed in the ground or any suitable nearby structures like tall building or foot over bridge over the carriageway. This method of data collection has several shortcomings like narrow field of view, parallax error, superimposition of vehicles by the large vehicles and restricted to a very short study section.

Presently unmanned aerial vehicles (UAVs) like remote controlled drone fitted with high resolution video camera are being popularly used to capture accurate traffic data from the field. Salvo et al. [6] developed a new methodology to evaluate the real traffic flow conditions in urban areas with the videos acquired by an unmanned aerial vehicle (UAV). It was mentioned that these devices would not influence the driver behaviour and their operation did not intervene with the road infrastructures and hence it was possible to investigate the dynamics of traffic flow, the queue length, the manoeuvrability and driver reaction time. In this study a probe vehicle equipped with a differential GPS and a remote-controlled UAV drone fitted with video camera was used to capture vehicles' trajectories. Bruin and Booysen [7] proposed solution for automated traffic flow estimation using computer vision with drone-based equipment for video recording. Drone based techniques of traffic data collection have many advantages. It can capture traffic information on relatively larger section of road depending on flight height. The drivers' behaviour is largely unaffected during data collection and no or limited road infrastructures may be used. On the contrary the limitations are short or limited flight time (usually 15-20 min per battery charge of battery or higher), the wind effect on the drone while in stationary positioning during data collection and moderate coverage of section due to height restrictions (usually 45-65m above the ground). Due to the large angle of view, high resolution of captured video image (4k) the drone-based traffic data collection become popular.

3. Study Objective

In the present study the drone system along with ground-based video camera system was used simultaneously to capture the accurate vehicular speed and to propose a suitable calibration to be applied to the speed and density data collected from the ground-based video photographic technique eliminating the associated parallax error.

4. Details of Study Area

The present study was carried out on the major urban arterial streets of Kolkata under Kolkata Metropolitan Development Authority (KMDA), New Town, Rajarhat under New Town Kolkata Development Authority (NKDA), and under Bidhannagar Municipal Corporation, West Bengal, India. Three representative study sections on Kazi Najrul Islam Sarani (KNIS) and one representative study section on Biswa Bangla Sarani (BBS) of New Town, Rajarhat were considered. The KNIS, also known as VIP road, is one of the major traffic carrying corridor of Kolkata, is a defined six lane divided carriageway road connecting Netaji Subhas Chandra Bose International Airport (Kolkata airport) and the northern part of the state of West Bengal. The BBS is also a major arterial road of six lane divided carriageway connecting Kolkata Airport, Salt Lake City, central business area of New Town, Rajarhat, and East Kolkata. Study sections were midblock sections and free from work zone, temporary lane closure or traffic diversion as a part of traffic control management. External cause of traffic hindrance such as on-street parking, road side vending activities etc., were not present. The lane widths vary from 3.5m to 3.6m that carrying one directional heterogeneous traffic. Presence of non-motorized traffic was negligible and no across pedestrian movements were allowed. Vehicular traffic movement under free flow as well as forced flow situation was observed.

5. Methodology of Traffic Data Collection and Data Extraction

Macroscopic traffic stream parameters such as speed, flow and density are the important components for any traffic engineering study and most importantly for evaluation of functional condition of roadway facilities. In the present study traffic data were collected from the field using ground-based video photographic camera system as well as drone-based video photographic camera system simultaneously. Space mean speeds and traffic density for different flow situations were also captured simultaneously using both systems for calibration purpose. Traffic density was extracted from captured video images using frame by frame analysis with defined trap length. Application of these two camera systems of data collection adopted for the present study has been described below.

For application of ground-based video photographic camera system of data collection, the video camera fitted in a tripod stand was placed over a foot over bridge near the marked road section focusing the designated trap length to capture real traffic flow. Trap length of 60m was marked on the carriageway in all study sections. Height of the camera above the road surface was recorded as 9m, where the height of the foot over bridge was measured as 7.7m. The pictorial representation of the data collection system by the ground-based video photographic camera is shown in Fig.1a. Adequate care was taken during the image capturing to ensure that the real traffic situations were recorded with desired resolutions.

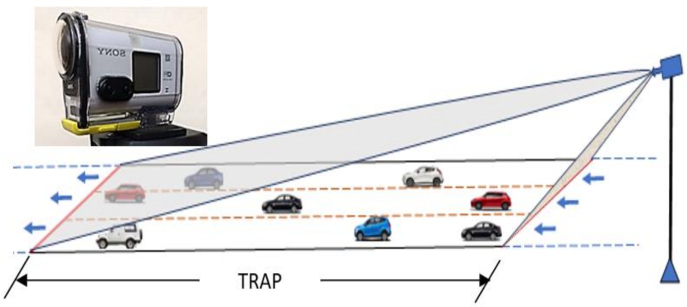

Fig. 1(a): Ground-based video photographic camera system

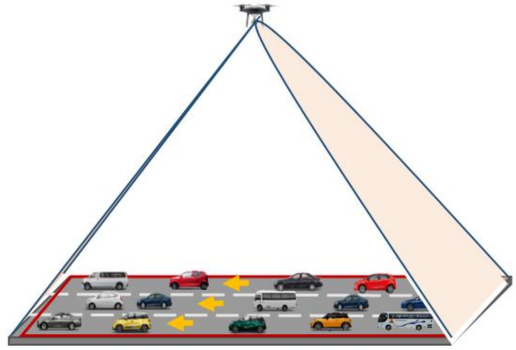

Fig. 1(b): Drone-based video photographic camera system

A remote-controlled drone fitted with high resolution video camera (Phantom 4-Pro model with 4K resolution) was used in this study. Trap length of 60m was marked on the three lane one direction of carriageway. Drone was flown on a height of 50m above the road to capture the entire section of the designated trap length. The drone was kept stationary for 15min flight time to record the video image. The pictorial representation of data collection using drone based video camera system is shown in Fig.1b. During data collection it was ensured that error associated with visual inadequacy could easily be eliminated and the desired quality of video output could be obtained.

The captured video images were displayed in computer for traffic data extraction. Rectangular trap of 60 m length was imported to the video file while extracting the data. Macroscopic traffic data such as space mean speeds (SMS) and density were extracted from the recorded video image. Density values for each lane were extracted and the corresponding speeds of vehicles were also calculated by recording the entry and exit time of individual vehicles crossing the trap lines on each lane. The snap shot of the video image recorded by ground based video photographic camera system and the drone camera system is shown in Fig.2a and Fig.2b respectively. The speeds data extracted from the ground-based video photographic system were calibrated with the help of speeds data observed from the drone-based video photographic image. The vehicle classification used in this study was adopted from the research work of Chandra and Kumar [8] and are presented in Table 1. Composition of vehicles observed in the traffic stream of KNIS and BBS is shown in Fig.3a and Fig.3b respectively.

Fig. 2(a): Snap shot of video image captured by ground based video photographic system

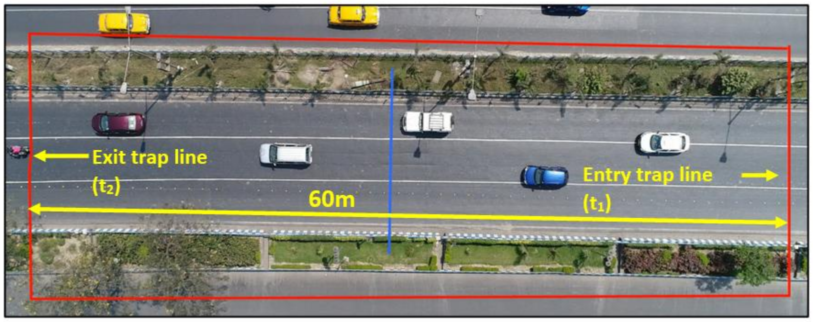

Fig. 2(b): Snap shot of video image captured by drone camera system

Table 1: Vehicle classification

Vehicle Category	Example	Vehicle Category	Example
Standard car (CS)	Sedan and Hatchback cars,	Bus (BUS)	All passenger bus
Big Car (CB)	SUVs, MUVs, Jeep etc.	Two-wheeler (2W)	Motor cycles, Scooter
Truck (TR)	Two, multi axle goods vehicles	Light Commercial Vehicle (LCV)	Large vans, mini trucks
Three-wheeler (3W)	Three wheeled motorized vehicles		

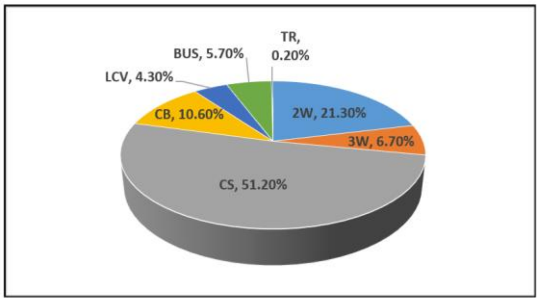

Fig. 3(a): Vehicular composition observed in KNIS

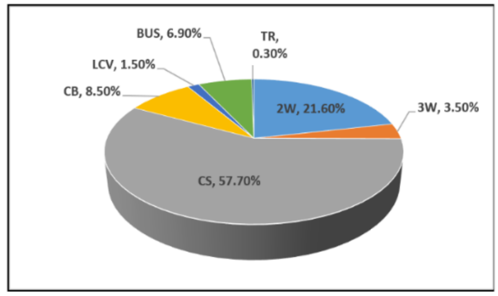

Fig. 3(b): Vehicular composition observed in BBS

Traffic density is a fundamental macroscopic characteristics of traffic flow. It is an important characteristic that can be used in assessing traffic performance from the point of view of users and system operators [9]. The easiest way to visualize traffic density is to consider an aerial photograph of a section of highway and to count the number of vehicles in a single lane having a length of 1 mile [9]. Traffic density data were captured from the field using video image collected by the ground-based video photography as well as from the aerial photographic technique using drone-based video photography. In this study real traffic situation was recorded by installing ground-based video camera focusing on the preselected midblock sections of the study corridors. Drone was kept stationary for 15min flight time to record the video image of the traffic movement. The data collected by the drone-based system was primarily used for calibration purpose to eliminate parallax error [4] associated with the data collected by the ground-based video camera system.

Method of frame analysis technique was adopted in density data extraction from the captured video image of the real traffic situation. For capturing the density from the real traffic situations frames were generated for 5 second interval considering the variable situations of the vehicles occupying the trap length. Density frames were generated using both video images captured by ground-based photography and drone-based video images and number of vehicles occupying in each frame were counted except two wheelers because of its percolation manoeuvring behaviour. The density frame developed in this study from the two image recording systems is presented in Fig.4a and Fig.4b respectively. The video images of stopped traffic situations were not considered for the frame analysis and density data extraction.

6. Calibration of Extracted Data

Capturing error free traffic data from the field is considered to be one of the important attributes towards the desired outcome of any research work. In this study traffic data were collected from the field using ground-based video photography as well as by drone-based video photography. During capturing of the traffic movement in the field, it was noticed that an error occurring while noting the entry and exit time of the vehicles as well as the number of vehicles occupying the designated trap from the ground-based video image captured. Fig.1a exhibits the occurrence of such errors observed during the data decoding process. The observed travel time taken by the vehicles to cross the designated trap length was less than the actual travel time resulting higher speeds of vehicles in the traffic stream, whereas the number of vehicles observed in the designated trap was less than the actual occupancy resulting lower density values. These kinds of errors were yielded due to faulty visual observation of exit trap line from the captured ground-based video image during data extraction process. This error was eliminated by introducing the drone-based video photographic technique. Drone- based video image is 'the overhead view describes the situation in which the camera's field of view is perpendicular to the travel direction and the traffic moves horizontally from left to right (or right to left) on the display [10]. From the Fig.1a and Fig.1b it is very much clear that parallax error and other associated visual inadequacy can be easily eliminated when the height of the camera is adequate. To eliminate these associated errors, both drone-based and ground-based video camera was used simultaneously during the data collection stage for same real time observation. Recording of the vehicles movement in the designated trap was carried out by both the systems using real time synchronization. Identical traffic situations were carefully recorded by both camera systems with proper resolution. Further number of vehicles occupying within the designated trap in the same identical traffic situation with real time synchronization were extracted from both the systems separately. Fig.4a and Fig.4b shows the snap shot of the identical frame developed during data extraction process.

In order to calibrate speeds data 415 data set of similar vehicles observed from both images were used and linear relationship was developed. On the other hand, 216 observed density values from each video images were used to develop linear correlation between density captured from drone based-video images and the density estimated from ground-based video images for the same traffic conditions. The calibration equations developed for speeds and density data were further applied to the respective data extracted from the ground-based video images to obtain corrected speed and density information.

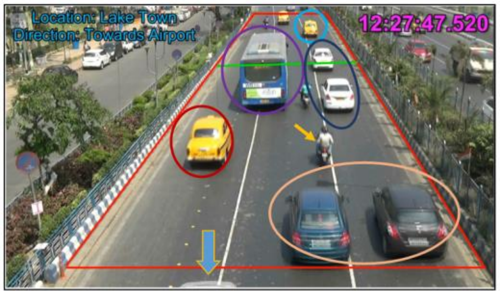

Fig. 4(a): Density frame generated from ground based video image

Fig. 4(b): Density frame generated from drone video image

Calibration for Speed Data

The similar vehicular movements in the traffic streams were captured simultaneously by the drone-based video camera as well as by the ground-based video camera with real time synchronization. The speeds of the identified vehicles were extracted separately from both captured images. The descriptive statistical analysis was performed for two data sets and is presented in Table 2. Z-test for two samples for mean for the speeds data was also carried out in the calibration process and is presented in Table 2. The correlation equation developed for speeds data calibration is presented in Eq. 1 and is graphically represented in Fig.5.

From the Z-test for two samples for mean for the speeds data showed that Z(calculated)was larger than Z(critical), and this could be implied the rejection of null hypothesis showing that speeds data captured by both images were not same. The normalcy for the two data sets were examined with the help of Kolmogorov-Smirnov test and Shapiro-Wilk test and the result is presented in Table 3. Histogram of extracted two sets of speeds data and normal distribution curve drawn on the sample population is shown in Fig. 6. It is clearly understood that the data sets were not normally distributed rather positively skewed. This could further be proved in the K-S test where estimated significance value was less than the critical value of 0.5 in both data sets.

$$Corrected\ Space\ Mean\ Speed = 0.810(Estimated\ speed\ from\ ground\ based\ video\ image) \quad (1)$$

Table 2: Statistical parameters and Z- test (two samples for mean) of Speeds data

Statistical Parameters	Observed from ground-based video image	Observed from drone-based video image
Observations	415	415
Mean Speed (km/h)	32.979	27.333
Standard Deviation	13.1335	9.8277
Standard Error	0.908466	0.679797
Median Speed (km/h)	30.1676	24.32432
Mode	19.63636	28.57143
Kurtosis	-0.26082	-0.02936
Skewness	0.78953	0.975448
Minimum Speed (km/h)	15	13
Maximum Speed (km/h)	69	54
Z calculated	4.985	
Z critical	1.959964	

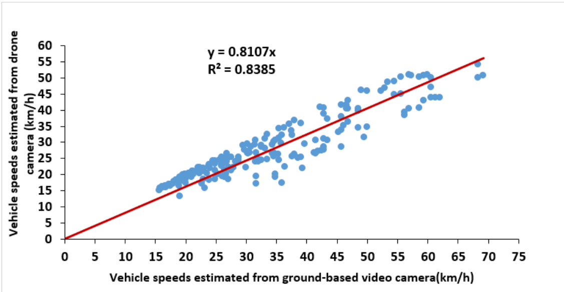

Fig. 5: Graphical representation of speeds data calibration

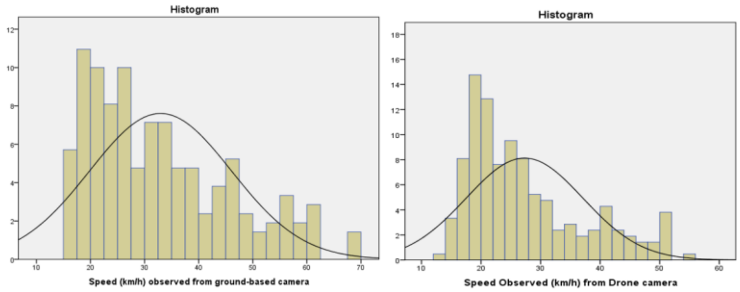

Fig. 6: Histogram and normal distribution plot on two sets of speeds data

Table 3: Normalcy Test for Speeds data

Speeds Data Observed	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	DF	Significance	Statistic	DF	Significance
From ground-based video image	0.117	414	0.000	0.921	414	0.000
From drone-based video image	0.141	414	0.000	0.891	414	0.000

Calibration for Density Data

Density frames of the similar traffic streams were captured simultaneously by the drone-based video camera and the ground-based video camera with real time synchronization. Density values of identified traffic streams were extracted separately from both captured images using frame to frame analysis. Descriptive statistical analysis was performed for two density data sets and is presented in Table 4. Z-test for two samples for mean for the density data was also carried out in this calibration process and is presented in Table 4. The correlation equation developed for density data calibration is presented in Eq.2 and is graphically represented in Fig.7. From the Z-test for two samples for mean for the density data showed that Z(calculated)became larger than Z(critical), and this could be implied the rejection of null hypothesis showing that density data captured by both images were not same. The normalcy for the two data sets were also examined with the help of Kolmogorov-Smirnov test and Shapiro-Wilk test and the result is presented in Table 5. Histogram of extracted two sets of density data and normal distribution curve drawn on the sample population is shown in Fig.8. It is clearly understood that the data sets were not normally distributed rather positively skewed. This could further be proved in the K-S test where estimated significance values were less than the critical value of 0.5 in both data sets.

$$Corrected\ Density = 1.138\ (Estimated\ Density\ from\ ground\ based\ video\ image) \qquad (2)$$

Table 4: Statistical parameters and Z- test (two samples for mean) of density data

Statistical Parameters	Observed from ground-based video image	Observed from drone-based video image
Observations	216	216
Mean Density (vehicles/km/direction)	189	220
Standard Deviation	83.60571	89.2409
Standard Error	7.796272	8.321757
Median Density (vehicles/km/direction)	183.3	216.7
Mode	116.7	183.4
Kurtosis	-0.06779	0.105087
Skewness	0.522022	0.500289
Minimum Density (vehicles/km/direction)	50	50
Maximum Density (vehicles/km/lane)	416	483
Z calculated	2.67	
Z critical two tail	1.959964	

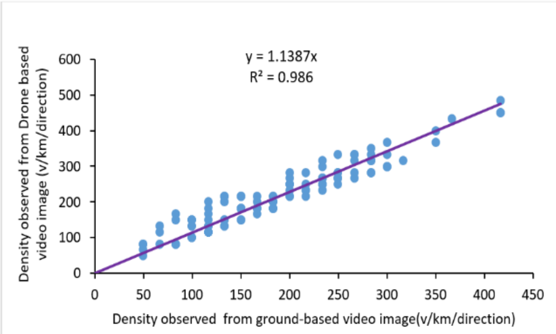

Fig. 7: Graphical representation of density data calibration

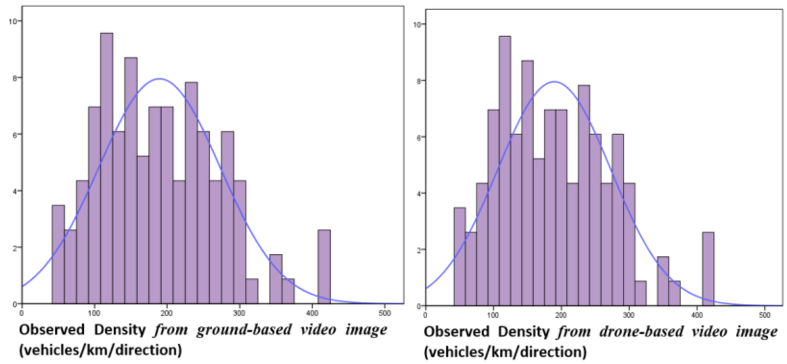

Fig. 8: Histogram and normal distribution plot on two sets

Table 5: Normalcy Test for density data

Density Data Observed	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	DF	Significance	Statistic	DF	Significance
From ground-based video image	0.099	215	0.008	0.966	215	0.005
From drone-based video image	0.080	215	0.067	0.974	215	0.025

7. Conclusions

Aerial video photographic technique of data collection was used in this study along with conventual ground based video photographic technique. The purpose behind the use of aerial video photographic technique using drone system was to capture the real traffic situation and to estimate the parallax error associated with the data collected from conventual ground based video photographic technique. In order to eliminate the parallax errors a calibration equation was developed for the speed and density observations. It was established that the space mean speed extracted from the video image captured by ground-based video photographic technique yield more vehicular speed compared to the real vehicular speed. On the contrary, density data extracted from the captured video image of the ground-based video photographic system generated lesser density value compared with real density. Therefore, it can be concluded that such elimination of parallax errors with other associated visual inadequacy through developing calibration relationship is very essential to capture the real traffic data from the field.

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