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Potential of Computer-Vision Cellular-Phone Based System to Extract Traffic Parameters

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Abstract: This research work investigates the potential of computer – vision cellular – phone based systems to extract traffic and pedestrian parameters; using handheld smartphones with different camera characteristics; i.e. resolution, sensor size and image depth. Various locations with different geometry and functions were selected. Different traffic parameters were extracted: vehicle spot speed and three state vehicle speed profiles (steady, acceleration and deceleration), vehicle speed and time headway relation, vehicle classifications, roadway level of service and pedestrian walking and crossing speed in light and congested traffic area.

The difference between actual and measured parameters defined as error and the relationship between error and camera characteristics were investigated. Also, a linear regression models were developed to express actual measured parameters as function of smartphone measures, error as function of camera characteristics.

Analysis of extracted parameters showed there was a high correlation between camera characteristics and the accuracy of measured parameters. In fact, increasing camera resolution and sensor size would give high accuracy results for all studied parameters. The percentage of error was consistently ranged, for vehicle speeds it ranged between (1.4% - 10%), for pedestrian speeds it ranged between (0.5% - 9%) and for vehicles dimensions it ranged between (10% - 25%). The outcomes of this research showed high potential accuracy of smartphone – based vision systems in extracting traffic parameters and opened the door to integrate smartphones in different transportation engineering and civil engineering applications.

Keywords: Computer vision; Cellular phone; Smartphone; Traffic parameters; Vehicle classification; and Pedestrians speed.

1 Introduction

The number of smartphone users has grown enormously in the past few years. Smartphones provide flexibility using software applications known as “apps” [1]. As an instrument and measurement tool, smartphones could make a huge revolution in the data collection. It is equipped with multi functions for sensing and sounding the surrounding environment like Global Positioning System (GPS), internal measurement sensors like accelerometers and audio-visual sensors like camera and microphones. Thus, the smartphones afford a multi-task device spread out on a large scale, provide the mean for time- or location- based measurement system [2].

Moreover, the popularity and portability of the smartphones allowed them to be an excellent data collection tool for civil engineering studies; including surveying management, environmental data, traffic and transportation engineering [3]. Many smartphone applications have been found that can be used as a data collection measure tool in transportation engineering. Using the built – in camera and GPS showing the exact location, maximum and minimum speeds, some applications identify and inspect vehicles movement and type of motion and report its speed, and some file it in a text format [4]. On the other hand, Conventional data collection methods has numerous defects such as; its time consuming, unsafe, inconvenient, not durable and sometimes inaccurate. In addition, conventional methods are complicated and require physical installations with expensive costs [5]. However, smartphones could reduce the cost and time consumption in data collection as it is a hand-held tool. Moreover, it follows-up technological trends and technology. Also, it could take over the already existing road sensors which eliminate repairs costs for the concerned party [6; 7].

Therefore, this research would use a computer–vision-based system utilizing a cellular-phone tool as a hand-held technological trend device to utilize and extract traffic parameters.

Aim of Study

The potential of usage of smartphones to extract traffic and pedestrian parameters is evaluated. Useful extracted

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information using different smartphones with different camera characteristics will be used to develop statistical models to predict some traffic parameters.

2 Literature Review

Vehicular data collection in highways and suburban areas techniques have evolved tremendously in the past few years [8]. Information produced from such techniques are rich in details and devices used in these technologies are developed and enhanced rapidly which became less expensive as competition between the manufactured companies has grown through the years. The techniques of analysing collected images and videos through several vision related areas such as; vehicle detecting, video tracking, and object recognition. In addition, image processing, analysis and enhancement all overlap each other to identify a whole set of datum equivalent to the human vision [9].

The recent studies of using computer vision systems in wide domain of transportation engineering including data collection and analysis, vehicles detecting and tracking, vehicles classifications, pedestrian's speed estimation and in pavement relating studies including flexible pavement distresses data collection and coarse aggregate shape properties, all opened the door into new ideas of integrating computer vision systems in other domains of transportation engineering specifically and civil engineering in general.

This research concerned in the use of smartphones as handheld tool to collect and analyse traffic data, through the integration of smartphones apps and its camera as a computer vision device. In the past decade, cellular phones developed rapidly and still. Smartphones nowadays are very popular and smartphones users' numbers are increased enormously.

The availability and affordability of smartphones made it trendy with very high users' numbers which led to high competition between manufactured companies as it developed the technology of all smartphone components rapidly. Also, drew toward using higher camera resolutions, wider range of images, higher accuracy sensors and lower weight handheld tool. [10] investigated the potential of cellular phones in transportation engineering through several domains. As a measurement tool for traffic parameters, vehicle classifications and road geometry. The outcomes of this study showed a promising and convenient future of using cellular phone cameras in different fields of transportation engineering. It also found a compatibility between cellular phone camera measures and conventional methods, with an average error roaming between 10% to 20%. Depending on image resolution, the average error decreased with the increasing of camera resolutions in all measures.

In a recent study, [11] proposed a new method of obtaining road intersections coordinates and dimensions using cellular phone cameras through Close Range Photogrammetry (CRP). Using three different cell phones with different camera resolution of (5 MP, 8 MP and 20 MP) to capture images of road intersections in Jordan. The researchers found that higher camera resolutions cell phone obtains higher accuracy level. Also, they found a strong potential of obtaining information and data using cell phone cameras[12]. [13] recommended using high resolution and various types of smartphones to inspect the capable accuracy. Also, suggested the usage of smartphones to cover wider domains including pedestrian parameters and other traffic parameters which this study aims to among other purposes including, speed and speed profile measures, vehicle classifications based on AASHTO [14] classifications and building statistical models predicting some traffic parameters.

3 Methodologies

To reach this research's aim, a comparison between the results of conventional data collection technique through video tapping and computer – vision cellular – phone technique was established.

For the computer – vision cellular – phone technique; four smartphones with different camera resolutions were used as mentioned in Table 1. Collecting vehicles speeds and time headways, also pedestrians walking and crossing speeds through a smartphone application that detect objects speed based on the distance between the moving object and the smartphone holder with optical axis perpendicular to the moving object (normal case photography). Figure 1 demonstrate a sample photo of smartphone application (Speed Gun) detecting vehicles and pedestrians' speeds. Different smartphones with variated characteristics used to fulfil the research aims and find the main criterions to the best extraction of data.

Table 1: Utilized smartphones brand and its camera's characteristics.

	Smartphone Brand	Camera Resolution	Sensor Size
1	Samsung S6 Edge	16 MP	1/2.6 inch
2	Samsung S8	12 MP	1/2.55 inch
3	Huawei P8	13 MP	1/3.06 inch
4	iPhone 6	8 MP	1/3 inch

To insure the diversity and generality of data collected for this research; various locations with different geometries and functions were selected. Two main elements were studied; vehicles and pedestrians. The samples were random and representative, and several movement cases were taken into consideration such as steady, acceleration and deceleration. Also, for pedestrians two movement were taken into consideration; side walking and crossing speeds were studied and analysed on the base of gender and traffic situations whether it's light or congested.

As mentioned before, four different smartphones with different resolution were used in this study, to measure vehicles and pedestrians speeds a smartphone application called "Speed Gun" that uses phone camera and camera sensors to track and detect objects speeds. Every vehicle or pedestrian passed were detected by each of the four smartphones at the same time to measure their speeds along with the conventional method. In addition to three cases of steady, acceleration and deceleration of speed profiles, spot speed was taken. Steady state speed profile conducted in an interrupted road section in both locations, Acceleration and deceleration speed profiles established at a signalized intersection at Baghdad Int. Highway in Huwara town. In Ramtha/Jaber St. acceleration profiles conducted in a merging movement at unsignalized intersection and deceleration movement conducted on a 20 meters distance before hump.

Input the shortest distance to target.
You should measure the distance prior.

Fig. 1: A Sample photo of smartphone application detecting vehicles speeds

Likewise, snapshots were taken for vehicles with the four smartphones for each vehicle then entered to "ImageJ" program to measure length of wheel base and height of each vehicle with meter to pixels scale of 1 m to 140 Pixels. Measured lengths and heights were compared to the AASHTO design vehicles dimensions and accuracy levels were computed for each mobile phone. Figure 2 illustrate a sample of vehicle snapshots using different smartphones to measure vehicle dimensions.

All traffic parameters extracted through conventional methods as actual parameters and smartphones as measured parameters were statistically analysed using Microsoft Excel and SPSS programs.

A) Samsung S6 Edge (16 MP)

B) Samsung S8 (12 MP)

C) iPhone 6 (8 MP)

D) Huawei P8 (13 MP)

Fig. 2: Vehicle snapshots using different smartphones with camera resolutions.

Examining the relation of differences between actual and measured parameters through multiple mathematical relations (exponential, linear, power and logarithmic) and building models using linear regression. The models include actual parameters as function of measured parameters, error as function of camera characteristics and error as function of measured free flow speed, level of service and time headway.

1. Extraction of Traffic Parameters Using Smartphones

Speed distribution and statistical analysis were conducted to measured speed groups. Statistical characteristics were calculated for each measured speed group. Measured speeds were grouped into intervals to draw the normal and cumulative distributions for each speed measure.

Three cases of speed profiles conducted through this study; steady, acceleration and deceleration states. Speed profiles established among 20 meters with five stations. Figure 3 shows a sample of acceleration profiles, it can be noticed that Huawei P8 overestimated speed measurements and iPhone 6 underestimated it. However, Samsung S6 Edge and Samsung S8 profiles were very close to each other. Figure 4 shows a 3D illustration of vehicles speed profiles.

Including more parameters and measurements to this research, level of service of two highways is investigated. Level of service is a measure to the quality of roadway traffic operation. Using the Highway Capacity Manual (HCM) [15; 16; 17] procedure to evaluate level of service, three main factors need to be found; measured free flow speed and average passenger car speed, traffic volumes data and roadway geometric characteristics.

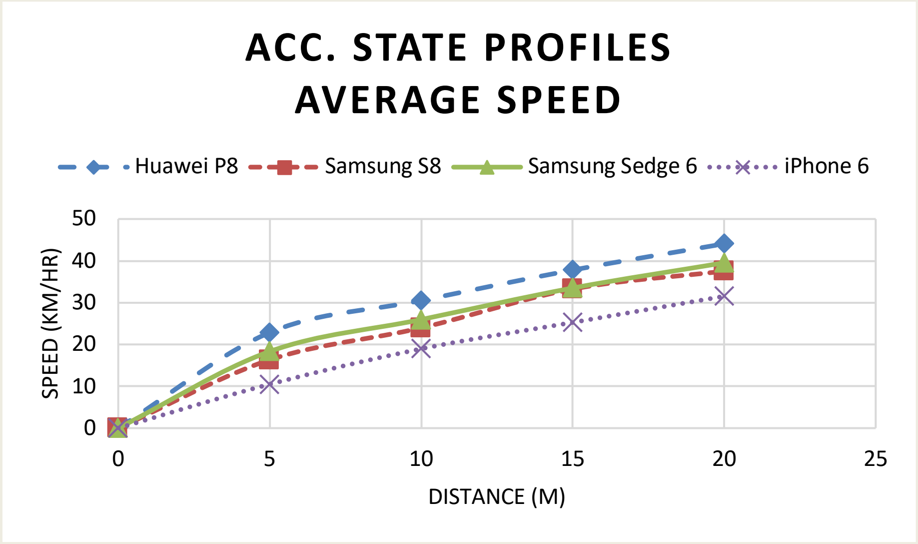

Fig. 3: Acceleration state profiles of average measured speed.

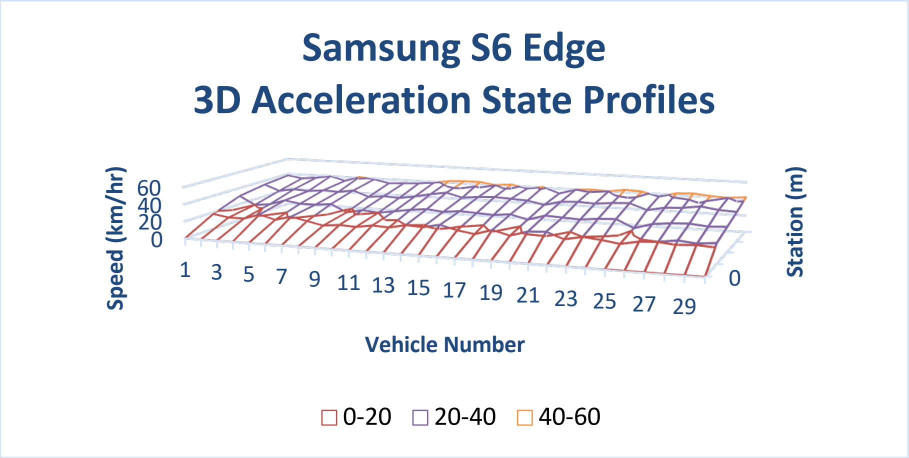

Fig. 4: Samsung S6 Edge 3D acceleration state speed profiles measured.

Table 2: Baghdad Int. Highway (Huwara) level of service evaluation.

Mobile brand	Free flow speed	Average passenger car speed	Level of service, LOS
Samsung S Edge 6	86	84	B
Samsung S8	83	80	B
Huawei P8	91	89	B
iPhone 6	77	75	C
Actual	85	83	B

Table 2 shows the measured free flow speed and average passenger car speed for each smartphone

measurement for both studied roads. It shows that the Samsung S6 Edge and Samsung S8 were the closest measurements to the actual speed, iPhone 6 underestimated the measurement which led to underestimation for the level of service. Also, Huawei P8 overestimated the measurement but still level of service estimation remained as the actual estimation.

Speed and time headway relationship investigated and a comparison between measured and actual speeds and headways were conducted. Headways less than 4 seconds were included in this study because above that following drivers cannot be assumed to be in the car following regime with sufficient certainty [**18; 19; 20**].

Speeds were sorted into intervals and the average time headway corresponding to speed were found. Figure 5 shows each measurement speed – time headway relation and how time headway changes through speed change, as shown, firstly; as speed increase the time headway decrease until reach a point of speed approximately 25 – 30 km/hr and 1.5– 2 seconds of headway where time headway starts to increase as the speed increase.Its noticed that Samsung S6 Edge and Samsung S8 were almost as same as Actual measurements in comparison to Huawei P8 and iPhone 6.

Snapshotted of vehicles were taken and vehicles classified into passenger car, single unit truck and intermediate semitrailer. Then wheel base and height of each vehicle were measured using “ImageJ” program. Vehicles classes percentages are calculated and presented in the following figure. The study included 73% of passenger cars, 19% of single unit trucks and 8% of intermediate semitrailers.

The comparison between measured dimensions and the AASHTO design vehicles dimensions conducted. The average passenger car measured length ranges between 2.63 m to 3.8 m compared to AASHTO length of 3.35 m. Also, average single unit truck length ranges between 3.96 m to 5.54 m compared to AASHTO length of 6.1 m. The average passenger car measured height ranges between 1.43 m to 1.68 m compared to AASHTO length of 1.3 m. Also, average single unit truck height ranges between 2.49 m to 4.00 m compared to AASHTO height of 3.75 m.

Similar to vehicle speeds, pedestrian speeds were detected using smartphones and a comparison between actual and measured speed was established. In addition to classifying pedestrians based on gender and finding the difference between males and females walking and crossing speeds among congested and light traffic areas.

Walking speed in congested areas expected to be lower than walking speed in light traffic area. The average measured walking speed in light traffic area ranges between 1.27 m/s and 1.37 m/s while in congested area it ranges between 0.95 m/s and 1.05 m/s. Likewise, crossing speed in light traffic area ranges between 1.44 m/s and 1.54 m/s while crossing speed in congested area ranges between 1.36 m/s and 1.46 m/s.

In addition, crossing speed in light and congested areas is higher than walking speed in both light and congested areas. And female walking and crossing speeds are lower than male walking and crossing speed

1. Data Analysis and Discussion

The difference between actual parameters and measured parameters defined as the error of each mobile phone measurement. Also, the relationship between error and camera characteristics including camera resolution and sensor size is investigated through multiple relations used in this investigation includes exponential, power, logarithmic and linear relations using Microsoft Excel.

In addition, a linear regression established finding three major relations;

•Actual measurements as a function of smartphone measures

• Error as a function of camera resolution and sensor size

Multiple relation is investigated between error and camera characteristics. The most fitted relations are shown in Table 3. Figure 5 illustrate the relation between camera characteristics and error.

In case of vehicles dimensions’ measurement, height is more correlated than length because of the horizontal movement of moving cars which can affect the measurement of length to be less accurate. Figure 6 illustrate the differences between actual and measured vehicles heights.

Noticing the illustrated differences between actual and measured vehicles length, it’s clear that mobile phones with better camera characteristics obtain more accurate vehicles

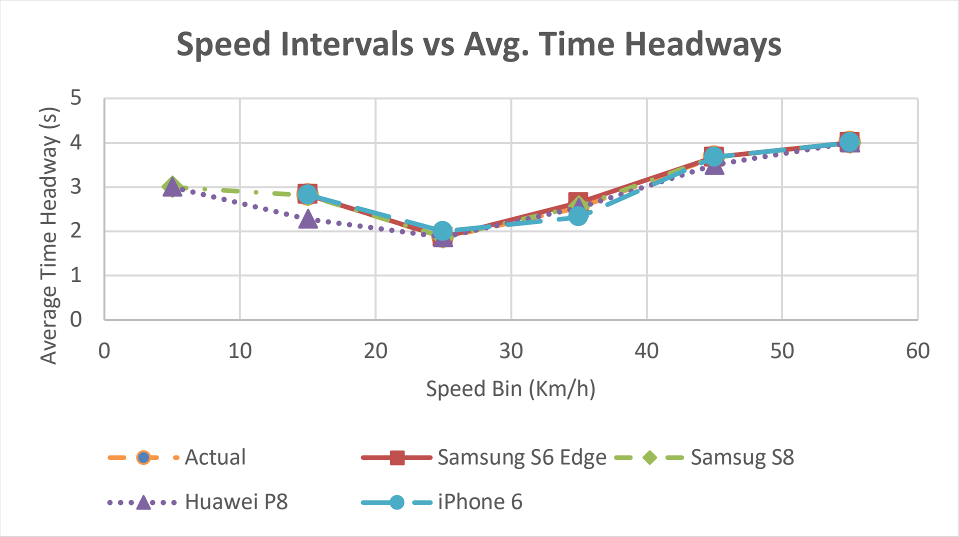

Fig. 5: Speed bin verses average time headway.

Table 3: Errors and camera characteristics best fitted relation.

Category		Variable	Fitted Relation	Model	R^2	Adj. R^2
Vehicles Speed		R	Exponential	$18.47e^{(-0.0116x)}$	0.8577	0.7866
		SS	Exponential	$0.4044e^{(-0.028x)}$	0.9025	0.8538
Vehicles Class.	Length	R	Exponential	$21.08e^{(-0.827x)}$	0.7885	0.6828
	Height	R	Power	$1.1896x^{(-2.377)}$	0.8324	0.7486
Pedestrian Speed		R	Logarithmic	$-2.8\ln(x)+3.3228$	0.8223	0.7335
		SS	Exponential	$0.4025e^{(-2.442x)}$	0.8373	0.756

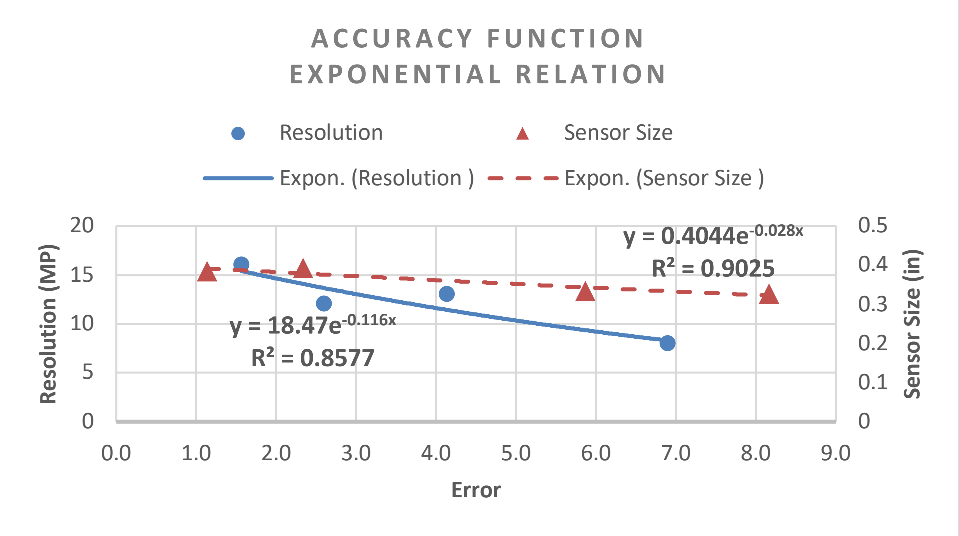

Fig. 6: Illustration of camera characteristics and error relation (Exponential Relation).

dimensions, the average difference in length rangers between 0.439 m to 1.117 m and the average difference in height ranges between 0.340 m to 0.439 m.

Linear regression established to extract the actual parameters through measured parameters, regression analysis with 0.05 level of significance used to develop models. In regression modelling, best models have high R2, high adjusted R2, high F – value and high significance with P – value less than 0.05.

Models of each mobile phone was established in all measurement's cases including speed and vehicles dimensions, Table 4 summarize models of each mobile phone in both speed and vehicles dimensions' cases. All models are significant with high R2 values and F – values, this indicates a high correlation between data extracted from smartphones and actual data.

Models of error as function of camera characteristics which indicated how likely the smartphone to get more accurate measurements, there is high correlation between resolution and sensor size with error, inversely.

Table 5 shows the average error for every measured category in this study. It can be noticed that errors in pedestrians speed are less than error in vehicles speed concluding that at lower speeds the accuracy can be higher.

In addition, in vehicles dimensions' measurements the length errors are higher than height errors due to the horizontal movement of vehicles which can affect the pixels intensity of the taken snapshot which leads to affecting the accuracy of measurements.

The percentage of error was consistently ranged, for vehicle speeds it ranged between (1.4% - 10%), for pedestrian speeds it ranged between (0.5% - 9%) and for vehicles dimensions it ranged between (10% - 25%).

Table 6 shows that the most significance models were pedestrians speed and vehicle speed error models as function of camera resolution and sensor size with respectively adjusted R2 of 0.994 and 0.999, higher F – values of 1481.51 and 2068.5 and significance of P – values of 0.002 and 0.016 less than 0.05.

On other hand, vehicle classification model is less significant because of the horizontal movement of the vehicles that gave higher errors which affected the model significance.

Also, all models show an inverse relation between camera resolution and sensor size with measurements errors, smartphones with higher resolutions and bigger sensor sizes gave lower errors and higher accuracy in measuring the studied parameters.

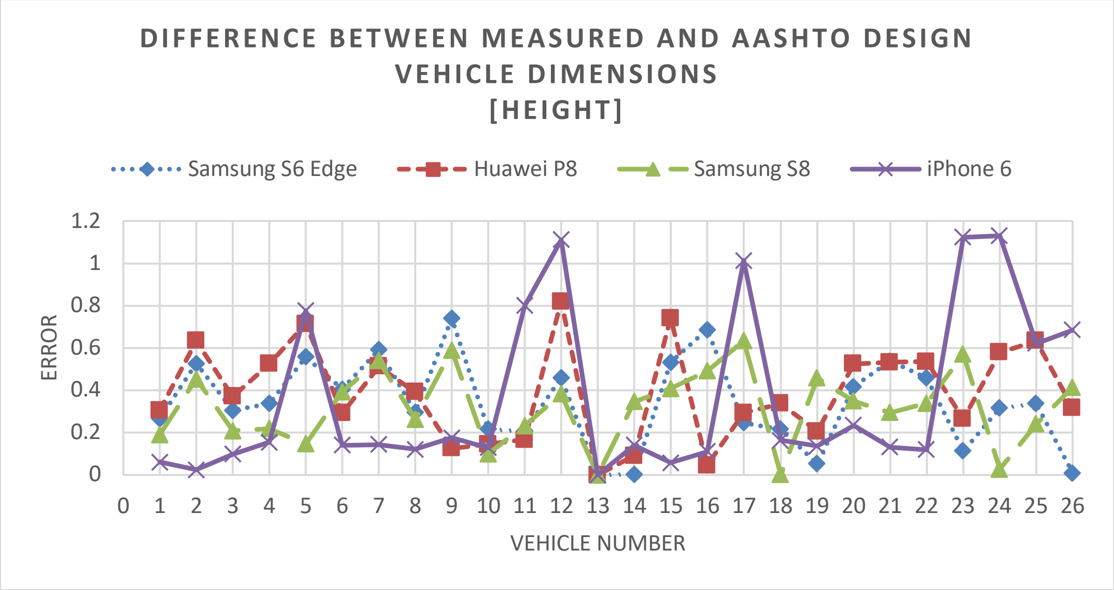

Fig. 7: Difference between actual and measured vehicles height.

Table 4: Actual measures as function of smartphone measures regression models.

Actual Speed = f (Measured Speed)					
Mobil Brand	**Model**	**R^2**	**Adj. R^2**	**F – value**	**Sig.**
Samsung S6 Edge	$1.007x + 0.973$	0.999	0.999	52883	0
Samsung S8	$1.026x + 0.538$	0.999	0.999	72258	0
Huawei P8	$1.084x + 0.683$	0.999	0.999	72799	0
iPhone 6	$1.048x + 0.47$	0.999	0.999	10794	0
Actual Vehicle Length = f (Measured Vehicle Length)					
Samsung S6 Edge	$0.807x + 0.403$	0.951	0.949	470	0
Samsung S8	$0.913x + 0.532$	0.920	0.917	275.6	0
Huawei P8	$0.857x + 0.31$	0.909	0.905	239.23	0
iPhone 6	$0.714x + 0.424$	0.907	0.902	236.5	0

Table 5: Errors and camera.

characteristics models data

Mobile Brand	Resolution	Sensor Size	Average Error			
			Vehicle Speed, km/hr	**Pedestrians Speed, m/s**	**Vehicles Dimensions, m**	
					Length	Height
Samsung S Edge 6	16	0.385	1.1	0.011	0.439	0.340
Samsung S8	12	0.392	2.3	0.029	0.479	0.358
Huawei P8	13	0.333	5.9	0.06	0.737	0.389
iPhone 6	8	0.327	8.2	0.0913	1.117	0.439

Table 6: Error regression models.

Error = f (Resolution (R), Sensor Size (SS))					
Category	**Model**	**R^2**	**Adj. R^2**	**F – value**	**Sig.**
Vehicle Classification	-0.008 R – 5.35 SS + 3.20	0.989	0.967	44.9	0.105
Vehicle Speed	-0.396 R – 67.6 SS + 33.5	1	0.999	2068.51	0.016
Pedestrians Speed	-0.006 R – 0.619 SS + 0.338	1	0.994	1481.83	0.002

Declaration

The author declares ownership of tables, figures and images in this manuscript.

Conclusions

The following conclusions can be derived from this research:

- There is high correlation between camera characteristics and the accuracy of measured vehicles and pedestrians speed explained exponential relation as best fitted relation.
- The relation between camera resolution and sensor size to measurements accuracy found to be inverse relation, higher camera resolutions and bigger sensor sizes obtain more accurate measurements with lower errors.
- Vehicles speed accuracy functions are more correlated than pedestrians speed accuracy functions due to pedestrian's behaviour which can be unpredictable and affect the measurement accuracy.
- Vehicle height measurements are more accurate than length measurements due to the horizontal movements of vehicles which affects the pixels intensity in vehicles photos.
- Models representing the actual measurements as function of smartphone measurements are significance with high R^2 values and F – values.
- Models representing the vehicle speed errors as function of camera characteristics are the most significance. In addition to the models representing %Error as function of measured free flow speed and roadway level of service.

In spite of the findings and the promising conclusions of this research, a further recommendation would complement the performance of usage smartphones for traffic and pedestrians' studies:

- Enhancing the usage of smartphones in transportation engineering; including traffic data collection, monitoring and interaction between road users and the competent authorities.
- Investigating the potential of using wider range of smartphone camera characteristics including camera resolution and sensor size.
- Integration between smartphone applications development experts and transportation engineering experts to obtain high quality smartphone applications related to traffic and pedestrians' parameters.
- Widening the usage of smartphone applications in civil engineering and transportation engineering other domains.
- Opening the door for researches to integrate smartphones in civil engineering and transportation engineering future studies.

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Conflict of interest: The authors declare that there is no conflict regarding the publication of this paper.

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