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AN EVALUATION OF THE PERFORMANCE OF A REAL-TIME TRAFFIC FLOW MEASURING CLOSED CIRCUIT TELEVISION SYSTEM

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Abstract: Video imaging in traffic data monitoring to capture real-time and larger set of traffic parameters at once is receiving increasing attention. The study designed, developed and deployed a Closed Circuit Television (CCTV) surveillance system to capture real-time traffic volume on a low volume trafficked road in the University of Ilorin, Nigeria and evaluated its performance in order to determine its applicability and suitability for traffic count. The data capture took place for seven days between the hours of 7 am to 7 pm. The observed vehicles were classified automatically by the installed system based on the respective vehicle lengths for the prevailing vehicle types which include tricycle, car, bus and truck. Also an observatory manual traffic census was simultaneously conducted at the same point on the street at the AM peak period of 9.00 am – 10.00 am for purpose of validation of the system's data. The Chi-square test gave the degree of agreement between the data captured in the CCTV system and the manual method of measurements to be 97.5%, 97.5%, 99.0% and 97.5% for tricycle, car, bus and truck respectively. The data captured by the developed system is therefore reliable and system recommended for vehicles' count and classification.
Keywords: CCTV, real-time, traffic, count, Chi-square

1. INTRODUCTION

— Background

Computer vision systems as applied in traffic data capture and surveillance offers a number of advantages over the earlier traffic survey methodologies. In addition to vehicle counts, a much larger set of traffic parameters, such as vehicle classification, lane occupancy, speed and headway that are important inputs for traffic operations and management, pavement design and transportation planning can be measured in real-time situations and devoid of human error likely with the manual approach. The Closed Circuit Television (CCTV) is typical of such video imaging capturing system with much advantage.

Video imaging detection or intelligent visual surveillance for road vehicles is a type of Road-Side Technology (over-road sensors) which are described by Minge et al (2010) as traffic detection sensors that cause minimal disruption to normal traffic operations during installation, operation and maintenance compared to conventional detection methods. They are sensors that do not require their installation directly onto, into, or below the road surface but are mounted over the center of the roadway or to the side of the roadway (FHWA, 2014) and are based on remote observations. Road-side technologies according to Morgul et al (2014) and Leduc (2008) include video image detectors, active/passive infrared detectors, microwave radar sensors, ultrasonic sensors and passive acoustic sensors. The advantages of the computer vision systems coupled with the significant advances in the field of computer vision has drawn increasing attention in recent times to vision sensors application in traffic data measurement, control and management (Kumar et al, 2012). Other reasons for the bloom in the field according to Deb and Nathr (2012) include:

the startling losses both in human lives and finance caused by vehicle accidents that calls for better surveillance of transportation networks,
the availability of feasible hardware and software technologies accumulated within the last 30 years of computer vision research, and
the exponential growth in processor speeds that have paved the way for running computation-intensive video-processing algorithms even on a low-end PC in real-time.

The video based traffic surveillance system components include the video image acquisition unit (the camera), appropriate cabling, video image processing unit and vision-processing software. Video imaging detection, is a key component as well as a dominant form of detection for developing autonomous intelligent transportation systems (Daigavane and Bajaj, 2010; Qureshi and Abdullah, 2013). The system detects and records vehicle numbers, type and speed by means of different video techniques, with microprocessor used to analyze the video image inputs of a target area on the pavement. In such detectors, the change in the image of the target area as a vehicle passes through the target area is processed. Another approach identifies when a target vehicle enters the video field of view and tracks the target vehicle through this field of view. Still other video sensors use a combination of these two approaches. The features of this system are reduced costs for the data collection, better analysis, accuracy, useful information, and safety (Qureshi and Abdullah, 2013).

In a developing economy, the use of video based traffic surveillance as in Intelligent Transportation System (ITS) is yet to be significantly deployed due principally to the level of technological capability (Jimoh & Adeleke, 2005) and as confirmed by authors' interaction with selected national, provincial/state transportations agencies in the case of Nigeria. However the current dynamism in development and the great leap and improvement in ITS e-driven processes among other reasons makes the video based traffic surveillance (system) crucial if not inevitable. The aim of the study therefore is to design and deploy a real-time video based vehicle detection and counting system thereby promoting its development, deployment and application for transportation system design and management in a developing economy. The objectives of the study include: (i) design, development and deployment of CCTV system for a real-time traffic volume count and vehicle classification (ii) determine the traffic volume using manual approach (iii) performance evaluation of the traffic system in traffic data capture.

— Area of the Study

The study concentrated on providing a real-time traffic detection and vehicle counting CCTV system along Toye-Afolabi route in the main-campus of University of Ilorin, Ilorin, Nigeria. The road majorly carries traffic to a number of academic faculties and other units in the University which include Faculty of Engineering, Computer Services and Information Technology (COMSIT), Network Operating Centre (NOC), Faculty of Agriculture, Faculty of Information and Computer Sciences, Works, Pharmacy among others.

2. METHODOLOGY

— System Architecture Design

A traffic data collection system which is based on CCTV is proposed which architecture is shown in Figure 1 and consists of:

1. Imaging sensor
2. Video processor
3. Transmission medium between camera and Traffic Monitoring and Control Unit (TMC) and
4. Mounting structure

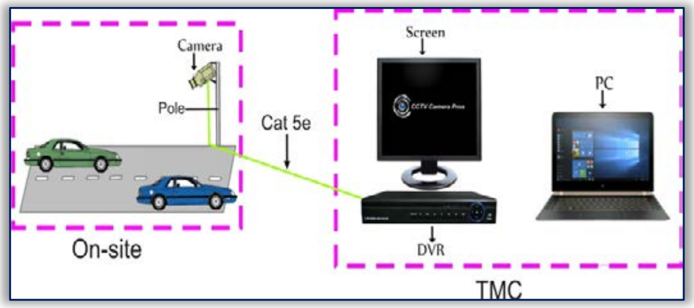


Figure 1: System architecture

The design metrics of each of the system components are further discussed subsequently.

— Equipment Selection

The equipment selection focuses on the evaluation and implementation of the key components which are the camera and communication media technologies. Their selection directly affects the traffic capturing performance and also decides the selections of other components like the digital video recorder (DVR).

≡ Camera

The two basic requirements of a CCTV system for traffic surveillance are reliability and picture quality with the former being more important because the installation will be exposed to the outdoor environment. Therefore those characteristics of the camera that describe its reliability and durability under a wide range of light, temperature, and moisture conditions are of primary importance. The camera is also positioned to provide the desired coverage of the traffic and to reduce the opportunity for vandalism. Thus, compliance with the requirements for the traffic parameter(s) measurement as stated in Qatar Public Works Authority (2013) informed the selection of the Ausno camera that works in the day and night. Plate I shows the Ausno camera with the following specifications.


Plate I: Ausno Camera, model: SE-CI351B (6mm)

≡ Communication medium

A very important feature of the Traffic Surveillance system is the communication medium which specifically determines the capacity of the system, because it's a measure of the amount of data that can be transmitted through it. The communication cable used is Cat 5e shown in Plate II. The choice of this Cat 5e as communication medium among others reflects the following five attributes:

- # allows much longer cable runs than coaxial cable
- # saves money on installation costs, especially with long distance runs
- # allows for virtually interference-free video transmission
- # can be used to transmit power to the camera control functions and
- # is easier to pull, making it easier to install.

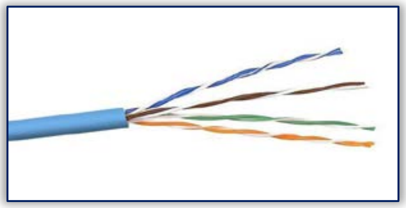


Plate II: Cat5e cable

— Determination of Camera Angle of View

The camera is positioned as high and as vertical as possible to the road (Ribeiro, 2014) and made to assume a good angle of view in order to obtain the best results as the probability of occurrence of vehicle occlusions is reduced. The angle of view of the camera is determined from Equation 1 while the schematic diagram of the camera installation is shown in Figure 2.

$$\tan\beta = \frac{d2}{d1} \quad (1)$$

where β is camera angle of view, d1 is the camera height, d2 is region of interest

— Processing and Storage

Increasingly, surveillance systems integrate one or more layers of analytics that mediate the flow of information between the operator(s) and the camera(s). This intermediate video processing is most commonly referred to as Video Analytics and it helps to prioritize information in real-time and brings significant events to the foreground for human agents that require intervention or further monitoring. The video analytics is done using MATLAB. The processing algorithm for the video data in order to convert them to volume and vehicle classification is summarized in the flow chart shown in Figure 3 and the source-code is as presented in www.mathworks.com.

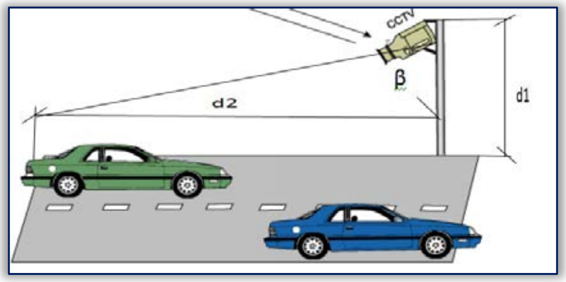


Figure 2: Geometry for camera angle of view

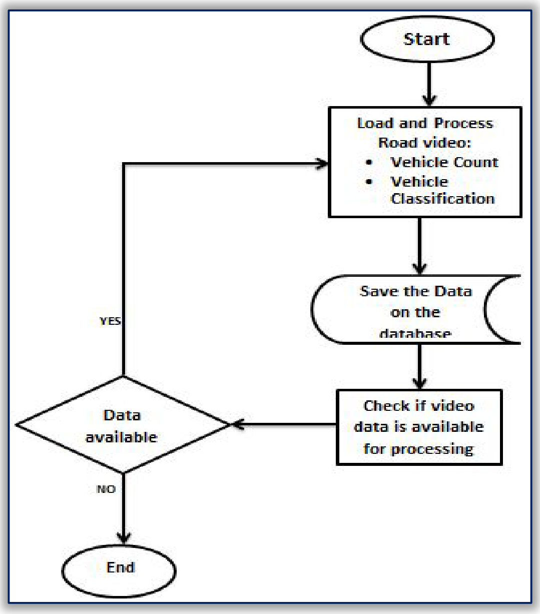


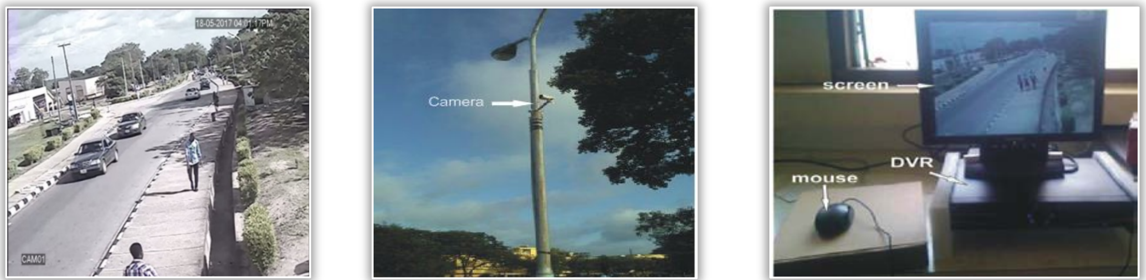
Figure 3: Flow chart for video processing

— System Development, Deployment and Operation

The following were involved in the system development, deployment and operation:

» Run the cable
» Mount the camera
» Connect the connectors (video balun and power connector)
» Power the camera
» Power the Digital Video Recorder (DVR)
» Connect monitor to the DVR
» Configure the DVR

The developed system comprises basically a camera unit, the communication cable and the traffic monitoring and control unit (TMC). Camera position was carefully selected with respect to both traffic lanes being monitored in order to avoid masking effects and it is also oriented with traffic moving away from the unit in order to avoid blinding effects at night on the camera due to vehicle headlights. The camera unit was installed at a height of 5 m (to allow for clear view and prevent vandalism) and at a camera angle of view of 31-degree (calculated from Equation 1) on a street light pole along Toye-Afolabi route, University of Ilorin as shown in Figure 4a. Toye-Afolabi road shown in Figure 4b is a 6 m wide, 2-lane single carriageway with sidewalks on both sides and speed bumps for speed calming.



a) b) c)

Figure 4: (a) Field view of the road on which the camera is deployed, (b) Installed camera on the street-light pole, (c) Data logger (DVR)

The TMC shown in Figure 4c, used to monitor and operate the system is set up in a laboratory. The TMC comprises the Visual Display Unit (VDU), the DVR, a PC and accessories.

— Vehicle Classification Techniques

The basis for vehicle classification techniques is the measurement of vehicle parameters such as the length, the number of axles and their spacing and the gross vehicle weight, which form the characteristic vectors. This classification uses the artificial vision that processes images based on some pattern recognition (image tracking type). The decision whether a vehicle falls into a given category is taken by comparing the characteristic vector with the vector in the model of this category.

The developed system uses vehicle length as the variable for classification by employing the Federal Highway Authority classification schemes as reflected in the FHWA Length-based Classification Boundaries and 4-Bin Classification and

Related Vehicle Types to Each Bin (Federal Highway Administration, 2016; Weinblatt et al., 2013). In the system, the detected vehicle regions were classified as tricycle, car, truck or bus.

— Measuring System Accuracy for Vehicle Classification

The acquisition of reliable traffic data by the developed system is critical therefore the performance of the system is validated for both the unclassified and classified data captured. The manual counting is the most traditional and trusted method for regular traffic data collection. It is recommended by Federal Highway Administration as ground truth data to evaluate the performance of traffic counting equipment (Turner et al, 2010). Hence for the performance evaluation and validation, manual traffic data was collected for 7 days, one hour each day from 9 am – 10 am which is the AM peak hour and used as ground truth data. The data obtained from the two methods i.e video detection and manual methods were statistically analyzed using the Chi-square goodness of fit test for total traffic and individual classes. Equation for the computation of χ^2 is given in Equation 2.

$$\chi^2 = \sum_{t=1}^{n} \frac{(AC_t - MC_t)^2}{MC_t} \qquad (2)$$

where, χ^2 = chi-square, AC_t = the automatic video detection counts, MC_t = the manual counts during the same time interval and n = no of data set i.e. days of the week

3. RESULTS AND DISCUSSION

— Traffic Data

Traffic video images captured by the camera unit are input to the data logger which is the DVR. The DVR processes the image data for vehicle detection, classification and counting. The data logger component builds up usable traffic data and provides an archive. The data which showed four vehicle types of tricycle, car, bus and truck was collected for seven days, 12-hours per day and the result is shown in Table 1. Table 2 gives the corresponding 7-day manual traffic count data for the 9 am – 10 am AM peak period.

Table 1: Traffic Data Captured with CCTV

	Vehicle Type	7-8am	8-9am	9-10am	10-11am	11-12am	12-1pm	1-2pm	2-3pm	3-4pm	4-5pm	5-6pm	6-7pm	Total
Monday	Tricycle	294	331	340	324	318	304	312	319	329	337	307	280	3795
	Car	202	262	290	200	184	211	198	200	218	231	210	178	2584
	Bus	0	1	2	5	3	4	2	2	1	0	1	0	21
	Truck	0	1	3	1	3	3	2	4	1	0	1	0	19
Tuesday	Tricycle	210	279	289	331	312	304	284	296	310	317	308	292	2932
	Car	151	170	188	209	174	175	162	171	169	182	163	138	1751
	Bus	1	2	4	3	3	4	3	1	0	1	0	1	22
	Truck	2	5	4	6	12	8	3	5	4	3	0	2	52
Wednesday	Tricycle	330	339	357	332	322	319	293	249	295	305	277	255	3141
	Car	178	184	191	169	163	162	178	161	172	170	150	139	1728
	Bus	1	3	3	3	4	4	0	1	3	2	1	0	24
	Truck	1	4	5	2	7	8	2	0	5	3	1	0	37
Thursday	Tricycle	274	280	292	288	284	289	277	279	282	285	268	230	3328
	Car	181	193	204	192	169	172	160	168	173	171	159	127	2069
	Bus	0	1	2	1	2	1	1	0	1	2	0	1	12
	Truck	2	0	4	2	2	3	1	0	3	1	0	1	19
Friday	Tricycle	274	264	262	270	298	269	272	275	282	267	262	258	3253
	Car	158	161	150	165	177	180	168	172	178	166	169	140	1984
	Bus	0	1	2	0	2	1	2	0	2	1	0	0	11
	Truck	0	3	2	2	4	0	2	3	3	0	0	1	20
Saturday	Tricycle	9	19	17	13	11	8	6	16	10	14	11	10	123
	Car	3	11	6	3	7	5	4	4	7	5	8	3	55
	Bus	0	0	0	0	0	0	0	0	0	1	0	0	1
	Truck	0	3	2	0	1	0	2	0	0	2	0	0	10
Sunday	Tricycle	25	40	38	22	18	30	23	25	21	27	32	26	269
	Car	5	11	14	6	7	9	9	12	8	11	13	9	92
	Bus	0	1	0	0	0	2	0	0	2	0	0	0	5
	Truck	0	2	4	3	4	0	2	0	1	0	0	0	16

Table 2: Manual data set at AM peak (9 am – 10 am)

Day	Vehicle type			
	Tricycle (veh)	Car (veh)	Bus (veh)	Truck (veh)
Monday	363	296	3	3
Tuesday	290	193	2	3
Wednesday	357	193	4	11
Thursday	301	210	3	4
Friday	273	162	1	2
Saturday	16	7	2	3
Sunday	40	14	0	5

— System Evaluation and Validation

≡ Unclassified vehicle count

Table 3 shows the unclassified vehicle counts in both the CCTV and manual systems. The chi-square test was used to determine if there is any significant difference in the data collected in the two methods. The null and alternative hypotheses for each Chi square test are stated as shown in Equation 3. The calculated χ^2, degree of freedom (df) and level of confidence obtained are as shown in Table 3. The result shows that there is no significant difference in the two techniques for the unclassified vehicle count with a level of confidence obtained of 99.5%, which shows that the null hypothesis is valid. This validates the data collected by the CCTV system.

$$H_0 : ACt = MC_t$$
$$H_1 : ACt \neq MC_t \quad (3)$$

where, AC_t = the automatic video detection counts, MC_t = the manual counts during the same time interval

Table 3: Comparison of the unclassified vehicle count obtained by video graphic and manual methods at AM Peak Period (9.00 – 10.00 am)

Day	Video count (veh)	Manual count (veh)
Monday	635	665
Tuesday	485	506
Wednesday	556	565
Thursday	502	518
Friday	416	438
Saturday	25	27
Sunday	56	59
Chi square	0.640	
df	6	
Level of confidence	99.5%	

≡ Classified vehicle count

The accuracy of classified count was checked for the categories of vehicles on the roadway. Comparison of the classified vehicle count obtained by manual and video graphic is shown in Table 4. Chi-square test was also performed on the classified count. The null and alternative hypotheses for each chi square test are as given in Equation 3. The χ^2, df, and level of confidence obtained for each of the vehicle types are as shown in Table 4. The result shows that there is no significant difference in the two techniques for the four types of vehicles at a level of confidence of 97.5%, 97.5%, 99.0% and 97.5% for the four types of vehicles namely; tricycle, cars, bus and trucks respectively.

Table 4: Comparison of classified vehicle count obtained by video graphic and manual methods at AM peak

Day	Tricycle		Car		Bus		Truck	
	Video (veh)	Manual (veh)	Video (veh)	Manual (veh)	Video (veh)	Manual (veh)	Video (veh)	Manual (veh)
Monday	340	363	290	296	2	3	3	3
Tuesday	289	290	188	193	4	2	4	3
Wednesday	351	357	192	193	5	4	9	11
Thursday	292	301	204	210	2	3	4	4
Friday	262	273	150	162	2	1	2	2
Saturday	15	16	7	7	1	2	2	3
Sunday	38	40	14	14	0	0	4	5
Chi square	0.8755		0.9707		0.4911		0.9754	
df	6		6		5		6	
Level of confidence	97.5%		97.5%		99.0%		97.5%	

4. SCALABILITY

The developed data capturing system in the study is designed for continuous traffic data capture and surveillance. It is scalable and can process data from more than one camera source thereby increasing the data collection area. This is because the DVR used in the system can take up to four cameras, with the additional cameras the system can be scaled up to provide a video imaging and signal processing system that provides area-wide detection of vehicles with the promise of lower maintenance costs.

5. CONCLUSION AND RECOMMENDATION

The developed CCTV system uses video image processing techniques in a MATLAB programming environment to identify moving vehicles and collects traffic parameters which include flow and vehicle classification on the road system and also presents visual image of the surroundings (e.g. the sidewalk). The captured data shows a traffic composition of tricycle, cars, buses and trucks. The peak period of flow is between 9.00 am and 10.00 am while the evening peak is at 4 – 5 pm. The AM peak period average traffic flow when the highest traffic is recorded is 591 veh/hr. The cost of the scheme is N144,000. The developed system performance was assessed using Chi square test and adjudged to provide accurate traffic data. The system allows easy access to data and data processing is automated thereby making data availability timely. It is extendable for pedestrian traffic and wider view of observations.

The developed real-time traffic flow measuring CCTV surveillance system can be scaled up for road network coverage and will in future be studied for analysis of large volume traversed movement corridor. Its application should also be encouraged in developing economies to enhance traffic surveillance, management and planning, but provision should be made of a sustainable source of electricity to waive the major challenge of electricity shut down experienced during the study as CCTV system is solely dependent on electricity.

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