Application of Image Processing Technology to Traffic Volume Survey in Indonesia: Joint Study between National Institutes in Indonesia and Japan

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Abstract: It is vital for road authorities to understand the traffic volume on road networks so that they can develop and implement effective road policies. However, the methods currently used in Indonesia to measure traffic volume lack accuracy and there is a need to develop a robust and reliable method for measuring traffic volume.

National institutes in Indonesia and Japan have been conducting a joint study aimed at devising an optimal method for measuring traffic volume in Indonesia by using image processing technology (IPT) since 2010. Through field surveys in Indonesia, we verified the applicability of IPT to traffic volume surveys in Indonesia by revealing that an IPT device is superior to the current method used in Indonesia in terms of the accuracy of measuring traffic volume. We also identified the optimum camera settings for the most accurate measurement under specific conditions.

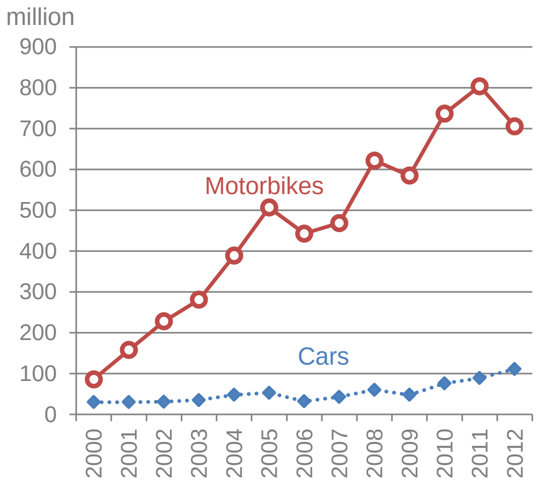
Keywords: Traffic volume survey, Image processing technology, International cooperation

1. INTRODUCTION

Stable economic growth and rising disposable incomes among the middle income group in Indonesia have resulted in a tremendous increase in the number of cars and motorbikes (Figure 1). Road networks have not been sufficiently developed to deal with the rapidly increasing vehicles and thus traffic congestion is getting worse and worse (Figure 2). Traffic volume is a fundamental factor to consider when drawing up road network plans or implementing measures to address congestion issues. However, the methods currently used to measure traffic volume in Indonesia lack accuracy and durability.

In this context, the Institute of Road Engineering (IRE) in Indonesia and the National Institute for Land and Infrastructure Management (NILIM) in Japan launched in 2010 a joint study to devise an optimal method for measuring traffic volume in Indonesia by using image processing technology (IPT). This is one of the activities based on a memorandum concerning cooperative activities that was concluded between the IRE and the NILIM in 2009 (Figure 3). The primary objective of the study is to verify the applicability of IPT to traffic volume surveys in Indonesia by examining how accurately an IPT device can count the number of vehicles, especially motorbikes, which are the dominant mode of road transport in Indonesia. Another objective is to determine the optimum camera settings, specifically the height and angle at which the camera should be installed to obtain the most accurate measurement of the traffic volume.

This article reports some major findings obtained from the joint study to date and introduces a field survey we are currently planning for 2013.



Source: Japan Automobile Manufacturers Association, Inc.

Figure 1. Increasing number of vehicles in Indonesia

Figure 2. Traffic congestion in Indonesia

Figure 3. Director Generals of IRE (left) and NILIM (right), when concluding memorandum in 2009

2. CURRENT TRAFFIC SURVEY METHODS IN INDONESIA

The primary method for measuring traffic volume on arterial roads in Indonesia is the combined use of an inductive loop and a piezoelectric sensor (LPS) as shown in Figure 4.

However, this method lacks accuracy. Obviously, an LPS device cannot detect motorbikes that do not pass over it. Also, when several motorbikes are on the LPS device at the same time, as shown in Figure 5, they are counted as one vehicle or are not counted at all. In terms of durability, the LPS device often fails due to damage caused by overloaded vehicles (Figure 6). The labor and cost for monitoring and maintaining the sensors are considerable. Other disadvantages of these sensors were pointed out by Bennett (2007), based on analyses presented by Martin *et al*. (2003) and Skszek (2001):

- Pavement cutting accompanying the installation of sensors reduces the pavement life
- Roadway work for installing the sensors disrupts traffic

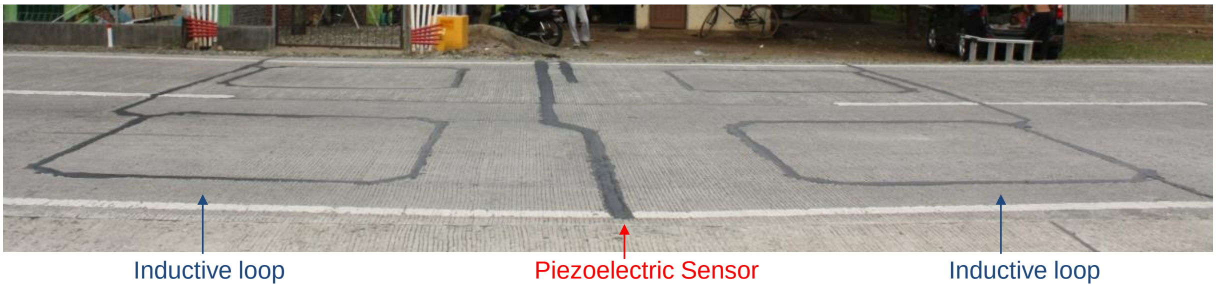


Figure 4. Configuration of LPS device

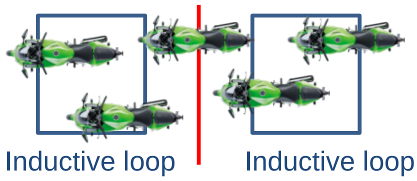


Figure 5. Several motorbikes on LPS device at same time can lead to incorrect counts

Figure 6. Damaged sensors

3. IMAGE PROCESSING TECHNOLOGY (IPT) DEVICE USED IN STUDY

We used an IPT device that involves the spatio-temporal Markov random field model (S-T MRF model), which was proposed by Kamijo *et al*. (2000). As shown in Figure 7, when the device detects a moving object within the analysis area in the image, the device starts following it. If the object passes the first check line and the second check line in this order, it is counted as a vehicle. The device also measures the size of the moving object when it reaches the first check line, and can thus classify vehicle types. The size is expressed by pixels of the rectangle that encloses the object. We set a single threshold to distinguish cars from motorbikes. As shown in Figure 8, when the size of the moving object is over the threshold, it is counted as a car; if not, it is counted as a motorbike. The specifications of the camera used in the study are shown in Table 1.

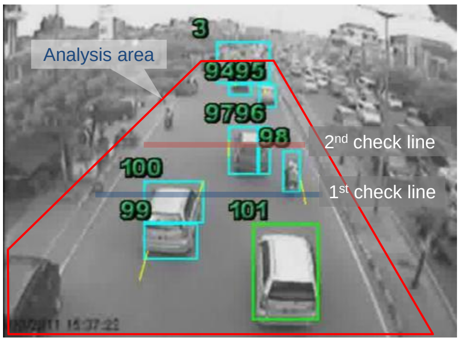


Figure 7. Measurement of traffic volume with IPT device

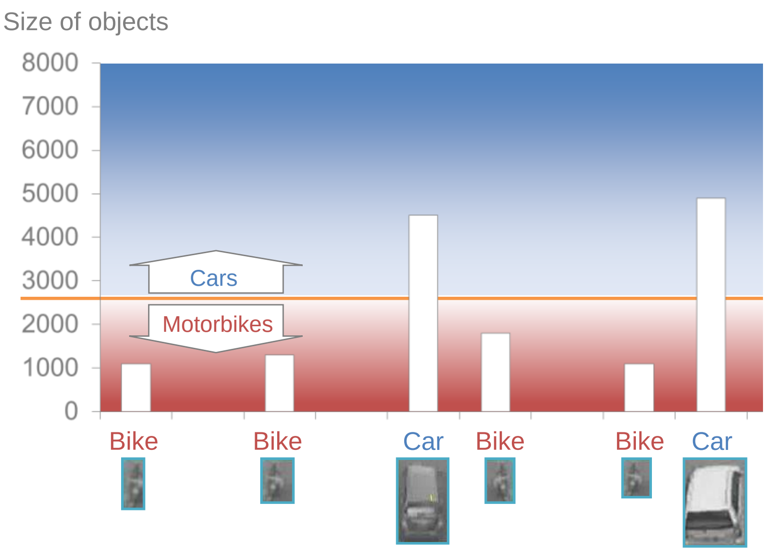


Figure 8. Classifying vehicle types according to size of objects

Table 1. Specifications of camera

CCD Type	1/3”
Horizontal Resolution	420 TVL
Minimum Illumination	0.4 Lux
Electronic Shutter (s)	1/50 – 1/100000
Gamma Correction	0.45
Dimensions (mm)	L: 100, W: 55, H: 52

4. ANALYSES AND RESULTS

4.1 Applicability of IPT

4.1.1 Field survey

To confirm the applicability of the IPT device, we conducted a field survey on a national arterial road in Bandung City, Indonesia (Figure 9 and Figure 10) in October 2011. This road lies in an urban area and functions as a feeder road for a national toll road system (indicated by orange lines in Figure 10). The traffic volume in one direction is estimated to be 15,000 to 20,000 vehicles per day. We installed a camera on a pedestrian bridge at a height of 7 m from the ground and at an angle of 45 degrees from the vertical (Figure 10) and videotaped traffic on the left side of the roadway (vehicles travel away from the camera) under several conditions, which are categorized by time of day (in the daytime and after dark) and traffic conditions (not congested and congested).

Figure 9. Bandung City

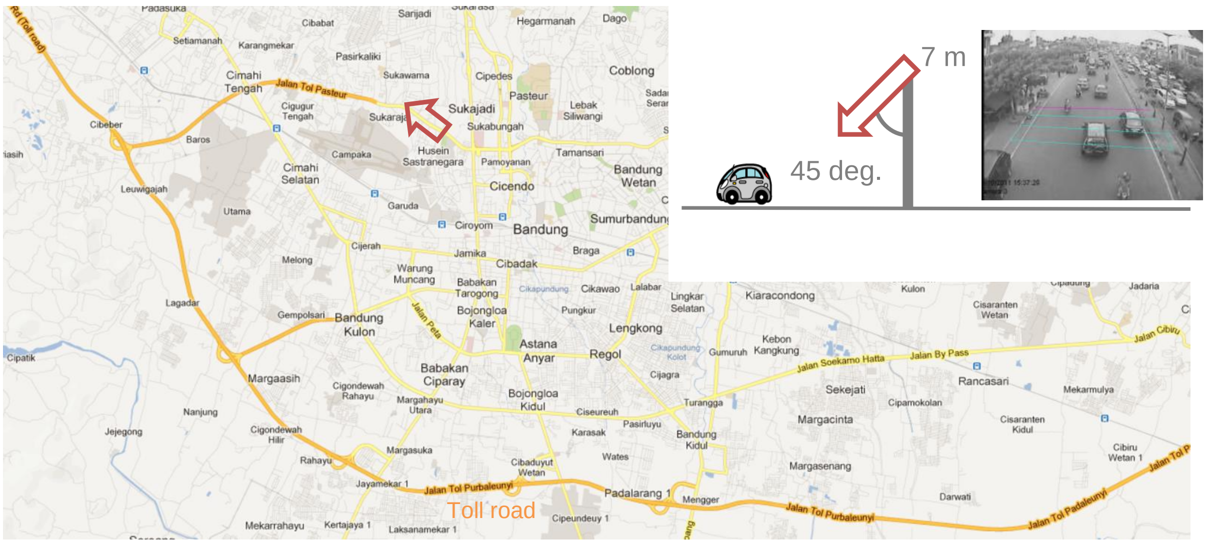


Figure 10. Camera settings

4.1.2 Results

From the traffic images obtained in the field survey, we measured traffic volume with the IPT device and calculated the error ratio, which is defined in Equation (1). The error ratio in total was 9.9% (n = 811). By vehicle type, the error ratio for motorbikes was 13.1% (n = 472) and for cars it was 5.3% (n = 339).

$$\text{Error ratio} = \frac{|V_M - V_{IPT}|}{V_M} \tag{1}$$

where, V_M : *traffic volume manually counted from video images*
V_{IPT} : *traffic volume measured with IPT device*

(1) Comparison of the error ratio between in the daytime and after dark

We had assumed that the error ratio would increase after dark due to the lack of illumination, which could prevent the device from recognizing moving objects. To examine whether or not, and to what degree the darkness influences the error ratio, we compared the error ratio for “in the daytime” and “after dark,” when traffic was not congested. As shown in Figure 11, although the error ratio for “after dark” was slightly larger than that for “in the daytime,” the error ratio was below 10% for both cars and motorbikes. We learned that the accuracy of measuring vehicles was not largely different between “in the daytime” and “after dark.”

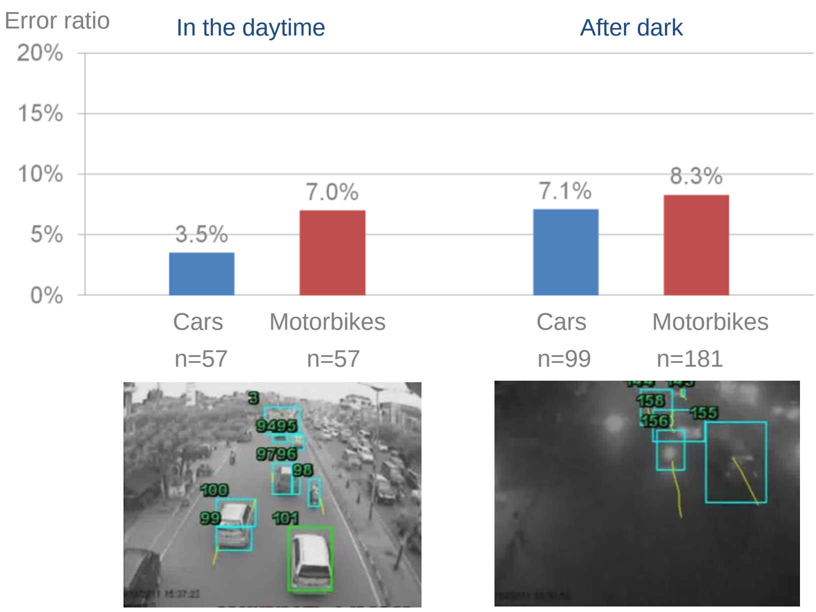


Figure 11. Comparison of error ratio (daytime vs. after dark)

(2) Comparison of the error ratio between not congested and congested

We also examined how the error ratio differs when traffic was congested in the daytime. We regarded the traffic as being congested when the traffic volume in one direction exceeds 7,000 vehicles per hour. As shown in Figure 12, when traffic was congested, the error ratio for motorbikes jumped to 18.2% from 7.0%. This is because the gap between vehicles is smaller and they are more likely to overlap each other in the image when traffic is congested than when not congested.

Such a large difference in the error ratio between "not congested" and "congested" was not observed for cars (not congested: 3.5%, congested: 5.5%). A possible reason for this is discussed in Chapter 5.

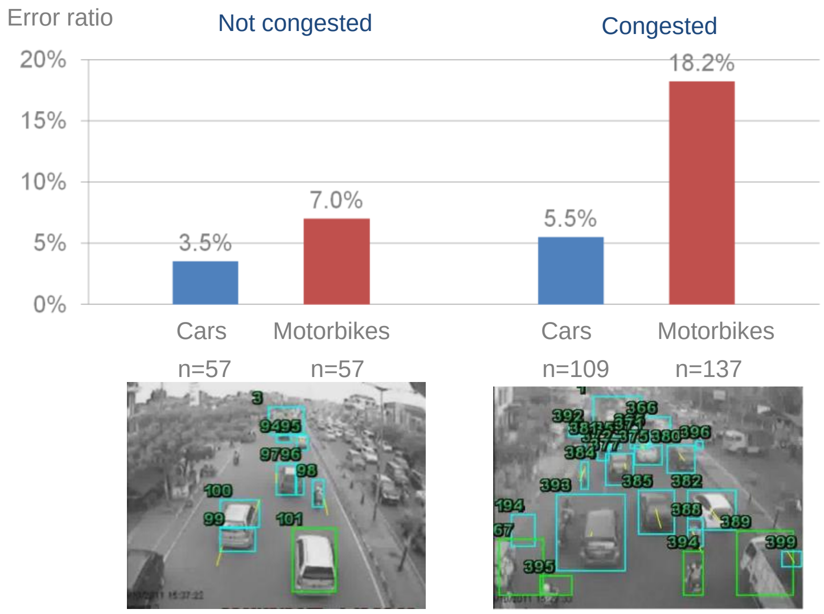


Figure 12. Comparison of error ratio (not congested vs. congested)

(3) Relationship between error ratio and "time of day" & "traffic conditions"

We then conducted an analysis using the quantification theory type I (QTTI), where the dependent variable is "the error ratio" and explanatory variables are "traffic conditions" and "time of day." Table 2 shows the results for cars. As we had expected, the coefficient of determination (R^2 = 0.1796) was rather small, indicating that "traffic conditions" and "time of day" are irrelevant to the error ratio of cars.

On the other hand, the results for motorbikes show that the coefficient of determination (R^2 = 0.9993) was remarkably high (Table 3). The partial correlation coefficients for both variables (traffic conditions: 0.9996, time of day: 0.9422) were also high. Their category scores agreed with the conditions discussed above, which is that the category scores for "congested" and "after dark" are higher than those for "not congested" and "daytime," respectively. The range for "traffic conditions" (0.1075) is much higher than that for "time of day" (0.00789). This indicates that "traffic conditions" has a more significant influence on the error ratio than "time of day." It also indicates that the error ratio is likely to be 10.75% points higher when the traffic is congested than when not congested, which is statistically significant at a 1% confidence level (t-value: 38.32, one-sided P-value: 0.0083).

We found that the error ratio for traffic volume measured with the IPT device is expected to be less than 19% even in congested traffic. The error ratio for the LPS device can sometimes reach as high as 70%. Therefore, we have confirmed that the IPT device is superior to the LPS device in terms of the accuracy of measuring traffic volume and that the IPT device is applicable to traffic volume surveys in Indonesia.

Table 2. Quantification theory type I (QTTI) analysis for cars

Variable		Category score	Range	Partial correl. coef.	t-Value	P-value (one sided)
Traffic conditions	Not congested	−0.00528	0.01056	0.3882	0.4212	0.3731
	Congested	0.00528				
Time of day	Daytime	0.00255	0.00510	0.1996	−0.2037	0.4360
	After dark	−0.00255				

$R^2 = 0.1796$

Table 3. Quantification theory type I (QTTI) analysis for motorbikes

Variable		Category score	Range	Partial correl. coef.	t-Value	P-value (one sided)
Traffic conditions	Not congested	−0.05375	0.10750	0.9996	38.32	0.0083
	Congested	0.05375				
Time of day	Daytime	−0.00395	0.00789	0.9422	2.813	0.1087
	After dark	0.00395				

$R^2 = 0.9993$

4.2 Optimum Camera Settings

4.2.1 Field survey

In an attempt to determine the optimum settings for the camera, we conducted a second field survey in 2012. We installed a CCTV camera on a lighting pole at different heights (5 m, 6 m, and 8 m from the ground) at a fixed angle of 70 degrees from the vertical (Figure 13). Similarly, we installed the camera at different angles (30, 45, 60, 75, and 90 degrees from the vertical) at a fixed height of 8 m above the ground (Figure 14). We videotaped the traffic when it was not congested in the daytime. The focus of the camera was adjusted so as to capture the widest possible images for each camera setting.

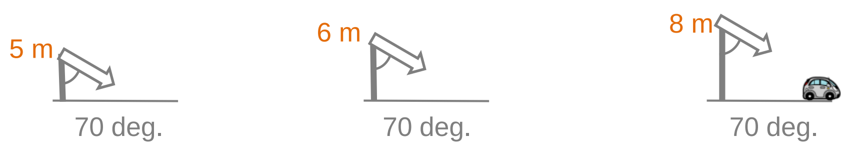


Figure 13. Camera settings at different heights

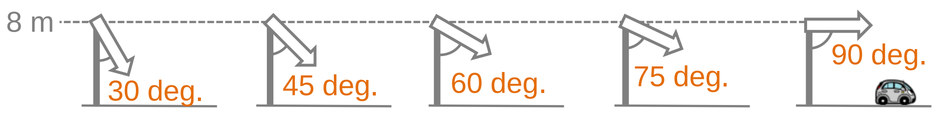


Figure 14. Camera settings at different angles

4.2.2 Results

(1) Height

We analyzed the traffic on the left side of the roadway and looked at how the error ratio varies when a camera is installed at various heights, with its angle fixed at 70 degrees from the vertical. As shown in Figure 15, the higher the camera was installed, the lower the error ratio was for both cars and motorbikes. This is because a camera that is installed higher up can capture a greater longitudinal length of roadway (indicated by the red arrows in Figure 15), which gives the IPT device more chances and a longer time to recognize moving objects correctly, thereby reducing the error ratio.

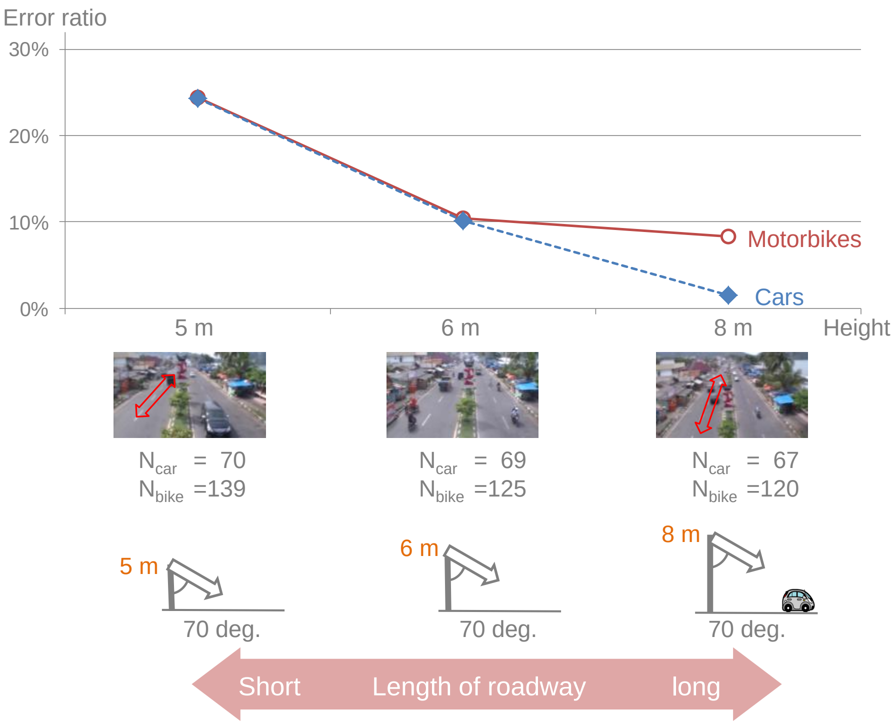


Figure 15. Error ratios with different camera heights

(2) Angle

We examined the error ratio according to various angles of the camera, with the camera height fixed at 8 m. Figure 16 shows that the error ratio was the lowest at an angle of 60 degrees (cars: 0%, motorbikes: 3.1%). As the angle approached the vertical from 90 to 60 degrees, the error ratio decreased. This is largely because the overlapping of vehicles is reduced when the vehicles are observed from a position closer to the vertical.

As the angle further approached the vertical past 60 degrees (60 to 45 and 30 degrees), the error ratio increased. This can be attributed to a reduction in the longitudinal length of roadway in the image (indicated by the red arrows in Figure 16). At the same time, turning the camera angle to the vertical must have a positive effect on lowering the error ratio: the overlapping of vehicles is further reduced. However, for camera angles of less than 60 degrees from the vertical, the negative effect of the reduced longitudinal length of roadway outweighs the positive effect of the reduced overlapping of vehicles in the image.

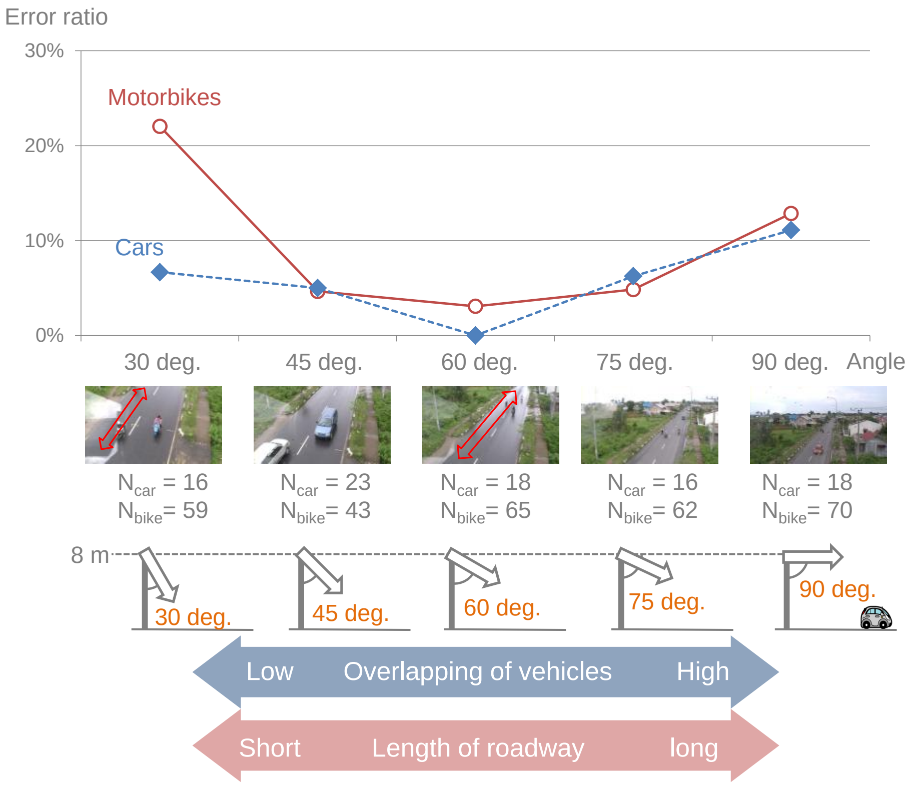


Figure 16. Error ratios with different camera angles

5. DISCUSSION

(1) Optimum camera settings according to various traffic conditions

As shown in **4.2.2(2)**, we revealed that the optimum angle is 60 degrees for the most accurate measurement. However, this does not mean that the same applies for any given set of traffic conditions. The optimum angle of 60 degrees was derived from the analysis of traffic images that were obtained when the traffic was not congested in the daytime. We assume that when congested, where the gap between vehicles is smaller, the optimum angle should be closer to the vertical than 60 degrees (say, 45 or 30 degrees).

Further study is necessary to identify the optimum camera settings according to various traffic conditions.

(2) Methods for examining the relationship between camera settings and the error ratio

When obtaining traffic images in the second field survey, shown in **4.2**, we used a single camera and installed it at various settings (heights and angles) to examine the relationship between the camera settings and the resulting error ratio. Although these images were all obtained when traffic was not congested in the daytime, other traffic conditions in these images were not necessarily identical. For example, the number of cars and motorbikes and the chances of overlapping were different among the images. Therefore, we cannot reject the possibility that the revealed relationship between the camera settings and the error ratio (Figure 15 and Figure 16) might have been influenced by the difference in traffic conditions.

From the next field survey on, we must simultaneously use multiple cameras to obtain traffic images of the same time period. This will enable us to make a genuine comparison of the error ratio resulting from the difference in camera settings, and exclude the influence of the difference in traffic conditions.

(3) Methods for counting by vehicle type

As shown in **4.1.2**, the error ratio for motorbikes tends to be greater than that for cars. This is evidenced by the results obtained from the first field survey: the difference in the average error ratio for motorbikes (13.1%, n = 472) and that for cars (5.3%, n = 339) was statistically significant at the level of 0.1% (t = 3.686).

Of course this tendency can result from essential factors, such as the difference in typical movements between cars and motorbikes and the difference in their body sizes, which we assume have some influence on the ability of the IPT device to recognize moving objects.

However, the tendency can also stem from the method for classifying vehicle types. As shown in Figure 17, when a car and a motorbike overlap in the image, the device sometimes mistakenly recognizes them as a single moving object. All too often in this case, the device regards the object as a car not a motorbike because the size of the object (consisting of a car and a motorbike) exceeds the threshold of a motorbike's size (Figure 18). This means that the count for motorbikes is incorrect, while the count for cars is correct.

We therefore realized the need to improve the method for classifying and counting moving objects by vehicle type. One idea to do this is to have the device examine whether the width of the moving object is appropriate or not. For example, when the width of a moving object in the image exceeds a length equivalent to 2.5 meters (actual object size), which is the width of an ordinary vehicle, the object is counted as a special vehicle that is tagged with a flag showing that it may be a mistaken count.

Figure 17. Mistaken count

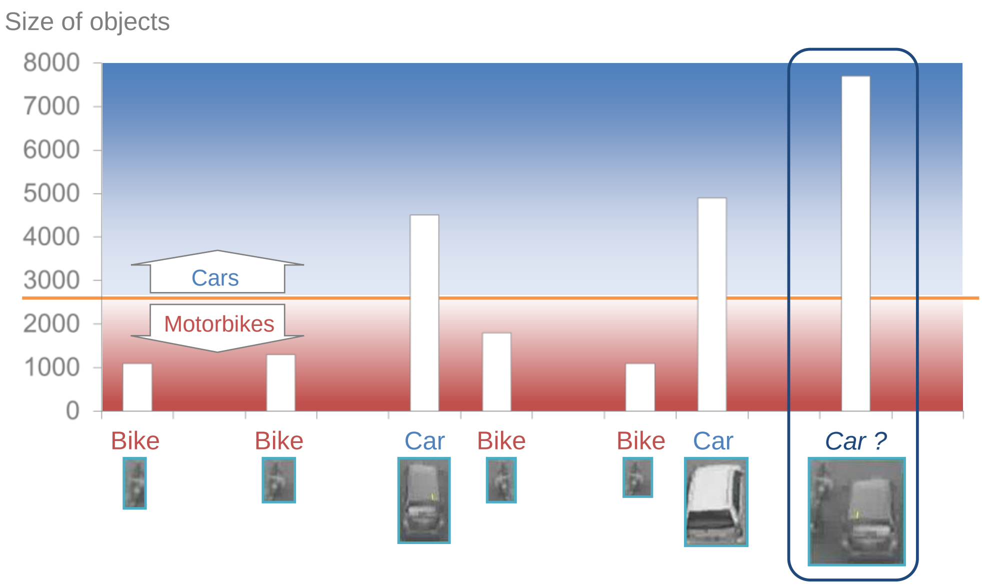


Figure 18. Classifying vehicle types according to size of objects

(4) Negative impact of headlights on the accuracy of measuring traffic volume

In 4.1.2(1), we demonstrated that no distinct difference in the error ratio between “in the daytime” and “after dark” was observed. This was derived from traffic images in which the vehicles travel away from the camera, and thus the back of the vehicles was videotaped. However, some practical use of the IPT device in Japan has informed us that the error ratio can often be significantly great for traffic images in which the vehicles travel toward the camera after dark. This is because the headlights cause halation in the image, thereby rendering the IPT device unable to recognize any moving objects.

We assume that this negative impact of headlights can be alleviated by installing a camera higher up with its angle being closer to 90 degrees from the vertical (see Figure 16). Therefore a further study is necessary to gain knowledge about the impact of headlights on the accuracy of traffic counts by revealing the relationship between the camera settings (height and angle) and the error ratio for traffic images where the front of vehicles is observed with their headlights on after dark.

6. STUDY PLANNED IN 2013 (THIRD FIELD SURVEY)

(1) Optimum camera settings according to various traffic conditions

As shown in Table 4, in the first field survey in 2011 we analyzed traffic images obtained in different conditions (in the daytime or after dark, not congested or congested) with a fixed camera setting (7 m above the ground and 45 degrees from the vertical). In the second field survey in 2012 we studied traffic images obtained under certain traffic conditions (in the daytime and not congested) with various camera settings (various heights and angles).

As stated in Chapter 5, we need to study the optimum camera settings according to various traffic conditions. In 2013 we will conduct a third field survey, which will use five cameras to observe traffic at the same time with various cameras settings. We will install the cameras on a pole at different angles of 0, 15, 30, 45, and 60 degrees from vertical and videotape traffic for 24 hours. We will then categorize the obtained images into six types of conditions (Table 5) according to traffic volume, which is one of the indicators to show how congested traffic is.

Table 4. Field surveys

<table>
<tr><th rowspan="2">Time of day</th><th rowspan="2">Traffic conditions</th><th colspan="2">Camera settings</th></tr>
<tr><th>Fixed (45 deg., 7 m)</th><th>Various</th></tr>
<tr><td rowspan="2">In the daytime</td><td>Not congested</td><td rowspan="4">First field survey in 2011</td><td>Second field survey in 2012</td></tr>
<tr><td>Congested</td><td rowspan="3">Third field survey in 2013</td></tr>
<tr><td rowspan="2">After dark</td><td>Not congested</td></tr>
<tr><td>Congested</td></tr>
</table>

Table 5. Camera settings for third field survey

Error ratio

Six types of conditions		Camera angle from the vertical				
		0 deg.	15 deg.	30 deg.	45 deg.	60 deg.
In the daytime	Not congested	? %	? %	? %	? %	? %
	Moderately congested	? %	? %	? %	? %	? %
	Heavily congested	? %	? %	? %	? %	? %
After dark	Not congested	? %	? %	? %	? %	? %
	Moderately congested	? %	? %	? %	? %	? %
	Heavily congested	? %	? %	? %	? %	? %

(2) Combined use of the LPS and IPT device

The road authority in Indonesia wishes to understand not only how many vehicles are using roads, but what types of vehicles, especially heavy vehicles, are using them. The IPT device we are using in this study allows us to set several thresholds to classify vehicles into more than two categories. However, it has been learned that the accuracy drops when attempting to measure the traffic volume with several categories.

In the meantime, the LPS device has a function to count the number of axles of passing vehicles and thus classifies vehicles accordingly. We are interested in learning the possibility of adding a record of the number of axles, which is obtained from the LPS device, to the corresponding record of vehicles, which is obtained from the IPT device. In the third field survey, we will measure traffic volume by using both the LPS and IPT device at the same time to examine how accurately those records can be matched and whether or not heavy vehicles can be classified according to the matched records (Figure 19).

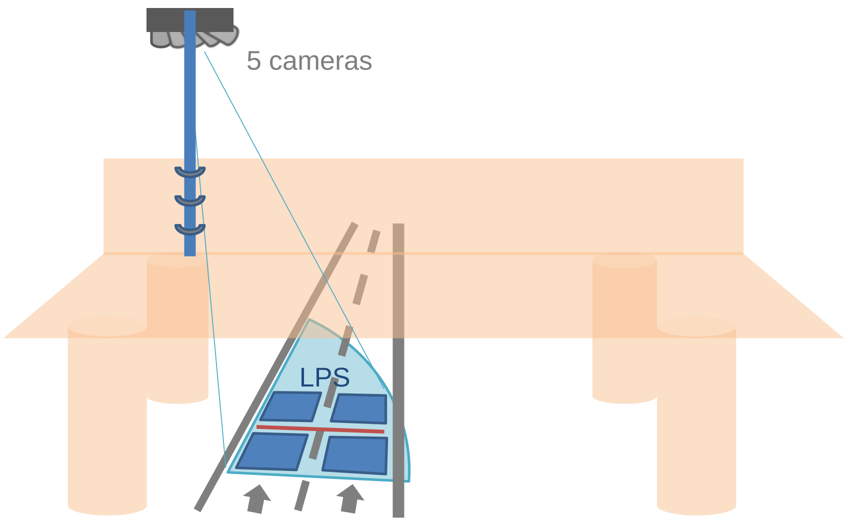


Figure 19. Settings for third field survey

7. CONCLUSION

By analyzing traffic images, we verified the applicability of the IPT device to traffic volume surveys in Indonesia and gained knowledge about the optimum camera settings for the most accurate measurement. The following results were obtained:

- The error ratio of traffic volume measured by the IPT device was on average 5.3% for cars and 13.1% for motorbikes.
- The error ratio for motorbikes tends to increase by 10.8% in congested traffic.
- No significant difference in the error ratio between “daytime” and “after dark” was observed.
- Installing the camera at a greater height (up to 8 m) makes it possible to capture a longer movement of vehicles in an image, which helps reduce the error ratio.
- An angle of 60 degrees from the vertical is optimum to measure traffic volume accurately under conditions where the camera is 8 m from the ground and the traffic is not congested in the daytime.

By examining the results obtained from the third field survey in 2013, we are going to identify challenges to overcome in introducing the IPT device to traffic surveys in Indonesia. In 2014 We will study how to place the IPT and the existing LPS devices at 16 traffic observations points on arterial roads so as to understand traffic volume at each point as well as traffic flows on the road networks in Indonesia the most efficiently.

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