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Speed Bump System Based on Vehicle Speed using Adaptive Background Subtraction with Haar Cascade Classifier

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Abstract

Driving at high speed and recklessly is the main cause of traffic accidents. In several places speed bumps are installed as a medium to warn drivers to slow down the speed of the vehicle, but the installation of speed bumps in several places has become a problem in itself with inconvenience for drivers traveling at low speeds, so it is necessary to develop an intelligent system to warn drivers when speeding. vehicles break safety boundaries, making drivers safer and more comfortable. At the vehicle identification stage, a combination of the Adaptive Background Subtraction method with the Haar Cascade Classifier is proposed, and vehicle speed estimation is carried out by calculating the time difference in the detection area or Region of Interest (ROI). Testing was carried out using traffic videos with three conditions, namely day, evening and night, with each condition using the same object data, namely 55 images of car objects. The proposed method produces car detection accuracy with an average of 85% and MSE 0.5 in vehicle speed measurements.

Keywords: background substraction, haar cascade classifier, speed bump, vehicle identification, vehicle speed.

1 Introduction

With the rapid growth of motorized vehicles, road safety has become increasingly important. Traditional speed bump systems are not always effective and can cause inconvenience to road users. Therefore, it is necessary to increase the efficiency and effectiveness of speed bumps through the application of vehicle speed detection and estimation technology using camera assistance. By utilizing this technology, it is hoped that the intelligent speed bump system can automatically adjust the height level according to the speed of approaching vehicles, providing a more adaptive solution and improving overall traffic safety.

In vehicle detection systems, one of the oldest but still competitive object detection methods was introduced by Viola and Jones [1], [2] . This method is the Haar Cascade Classifier , which is a basic method for detecting faces. This method has robust, real time and fast detection making it a good detection algorithm [3], [4] . However, certain test results prove that the algorithm is inefficient when used in low lighting conditions and detects the same object several times [5] . The Adaptive Background Subtraction method is another method that is widely used to detect moving objects in one frame via a static camera and is widely used in computer vision algorithms . This method helps focus on dynamic changes in the image and minimizes the influence of the background on detection [6]–[9] . The current research involves two types of vehicle classification and detection systems using the Histogram Of Or iented (HOG) feature and the Support Vector Machine (SVM) method for vehicle detection with a single camera [10] . Apart from that, a familiar method used in object classification today is Convolutional Neural Network (CNN). CNN is a deep learning method specifically for object detection tasks in computer vision , which is effective in handling complex objects and with higher accuracy than other methods. However, these methods require significant computational resources, especially for training and inference on larger models, and large datasets can be prohibitive [11]–[13] .

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In this research, the focus is on developing a vehicle detection system, namely cars. Development was carried out using a combination of the Haar Cascade Classifier method with Background Subtraction . Combining these two methods becomes a useful strategy to improve vehicle detection against static backgrounds. Haar Cascade is used to detect vehicles (cars), and Background Subtraction to update and improve detection results. The combination of the two can increase the system's resilience to changes in lighting, weather, and other background conditions. The computation of these two methods is more efficient and faster because it uses predetermined features to detect objects. This is an advantage when applied to hardware with limited resources. The results of vehicle detection will be used to calculate vehicle speed estimates and will be the basis for activating speed bumps .

2 Literature Review

In this research, we propose an intelligent system to control vehicle speed. On several roads, there are many speed bump facilities which function to warn drivers to slow down their vehicle speed and pay attention to the surrounding area. However, installing speed bumps in several places is a problem in itself, such as those installed in residential areas and can cause discomfort for drivers traveling at low speeds. So that the mechanism for selectively enforcing speed bumps according to the speed of incoming vehicles is implemented.

Generally, in detecting vehicle speed, the method that is often used is using a radar gun and works on the basis of the dopler effect , which emits a radar wave and is directed at a moving object , and is reflected back to then calculate the speed of the object. Although radar technology provides promising and very accurate results, it has a weakness, namely that if there is a device that produces radio waves in the vicinity, the detection results will be affected [14] .

This research has been carried out before, which presented a speed bump system based on speed detection and number plate recognition techniques. This research has the advantage of deactivating the speed bump system according to the number plates registered in the database. However, it is necessary to develop aspects of the method for detecting vehicle speed which still uses two pressure sensors to determine the difference in trigger time between the two sensors [15] . This sensor has the same working principle as a piezoelectric sensor , which consists of two fields attached to each other, and will produce an electric voltage when the piezo field experiences pressure. The sensor's ability to determine and monitor the weight of the vehicle, so it is good if used in detecting vehicles , however, has its own weaknesses, it is sensitive to road temperature which can limit the use of the sensor and in the installation process on poor road surfaces it can require re-installation of the sensor [16] .

Research related to methods for detecting objects (vehicles) on highways has been carried out by several researchers, using the Adaptive Background Subtraction method . This method is used to separate the background image (background) from the object to be detected or vehicle (foreground). There is a self-adapting renewal process in the background which occurs if there is a change in light intensity or there is a stationary object that has been there for a long time and moves out of the background , this will leave a hole behind it which will be detected as a fake object. The method works well and is resistant to changes in weather and lighting [6]–[9] .

The existence of detection and vehicle speed which are still not completely perfect from various aspects is what encourages researchers to look for better alternatives in terms of performance and cost. This research offers a vehicle detection system using cameras that can provide more reliable results and at a lower cost. This development can help law enforcement identify dangerous activities by drivers. The vehicle detection process applies the Adaptive Background Subtraction method to identify differences between the background and vehicles moving in the ROI area. Haar Cascade Classifier used to detect objects within the ROI area that has been identified by Adaptive Background Subtraction, where this method is an effective learning method in object detection. This method combines several concepts, namely Haar Features , Integral Image , AdaBoost Learning , and Cascade Classifier . Next, the speed of the detection results obtained will be calculated and become a speed bump enforcement parameter .

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3 Research methods

In this research, the main process is carried out by detecting vehicles on the highway (see Figure 1).

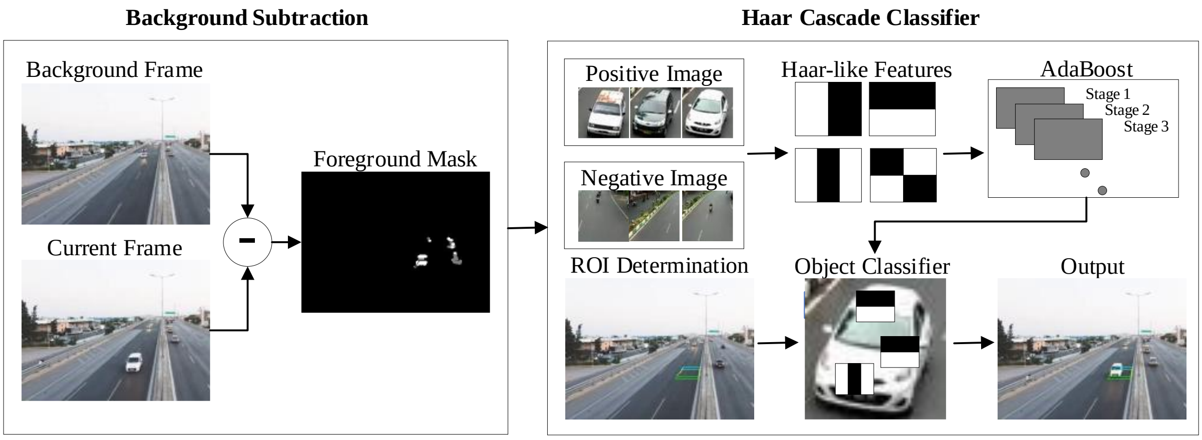

Figure 1. Main process of vehicle detection

Figure 1 shows The process starts from input image in the form of video . After that, the background subtraction method is applied to separate the foreground (vehicle object) and background (background) by taking several initial frames to initialize the background model. The method is applied to calculate the difference between each pixel in the current frame and the background, by determining a threshold value to identify the pixel as part of the foreground . Additional morphological operations (erode, dilate) are applied to remove noise and improve segmentation results.

The results of the background subtraction method will be continued by classifying the foreground obtained using the Haar cascade classifier method . In this method, two processes are carried out, namely training and testing. The training process is carried out by preparing a positive image (vehicle) and a negative image (background), the result of which is a model in the form of an .xml file . In addition, the input image will have a Region of Interest (ROI) determined to limit the detection area. In this case, the test was carried out on a single-lane and single-lane highway. The results of this stage followed by the vehicle detection process by carrying out an object classifier from the results of the background subtraction method which is compared with the training results using the Haar Cascade Classifier method .

The final process of the system is calculating the speed of the detected vehicle. The calculation results will become parameters in activating the speed bump . In accordance with Republic of Indonesia Government Regulation no. 79 of 2013 concerning Road Traffic and Transportation, the speed limit given on roads for residential areas is a maximum of 30 km/hour, so that this speed is the maximum limit for activating a speed bump [17] .

There are clearer stages of the research explained as follows:

3.1 Data collection

Data collection was carried out by taking (image acquisition) videos of the road using a camera with the camera positioned from the side of the road and facing downwards, and limited to one lane and lane, because activating the speed bump only applies to one vehicle (see Figure 2).

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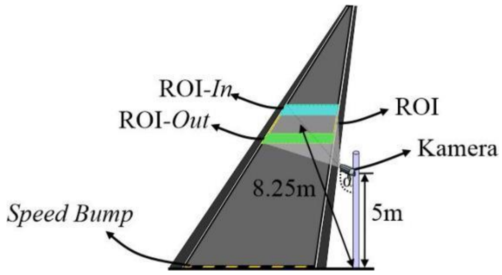

Figure 2. The main process of vehicle detection

The camera layout is determined by a straight slope in the detection area or *Region of Interest* (ROI) . The camera tilt angle is determined using the function for calculating *the inverse tangent* (*arctan*), which is shown in equation 1.

$$\alpha = tan^{-1}(L/H) \tag{1}$$

where, L is the distance between the camera pole and the center point of the ROI and H is the height of the camera placement pole.

So we get,

$$\alpha = tan^{-1}\left(\frac{8{,}25m}{5m}\right) = 50{,}53°$$

3.2 Image Pre Processing

The video image used will then be converted from the original color Red Green Blue (RGB) to grayscale, with the aim of increasing efficiency , reducing complexity and data size in image calculations , because each pixel only requires one intensity value , namely the grayscale value . After that, the video will be read frame by frame .

In this research, determining ROI is shown to limit the detection area, thereby reducing the risk of detection errors and the detection process becomes more focused and accurate. Determining the ROI is done by determining the coordinate points (x, y), as in Figure 3. The ROI is also used as an indicator to determine whether a vehicle has been detected, and this research provides two additional ROIs which are used to differentiate the input (ROI In) and output (ROI). Out) from car detection which is used in the car speed calculation process.

3.3 Vehicle Detection

In the detection process, There are several stages carried out, namely : Implementation of Background Subtraction and Haar Casacade Classifier .

3.3.1 Implementation of Background Subtraction

At this stage, the video image will go through the background subtraction stage , where the image will be separated between moving objects from the background. The initial background or background will be taken at the beginning of the video frame . Each video frame is then subtracted from the background model. The result is an image of difference or " difference image ". Each pixel in this image will show the difference between the pixel value in the actual frame and the pixel value in the background model. By using a threshold value , the difference between a moving object and the background can be identified. Pixels with differences above the threshold value are considered part of the moving object, while those below the threshold value are considered part of the background.

The results of the thresholding process require several post-processing steps to clean noise or better define object boundaries. At this stage, the Opening morphology operation (a combination of erosion and dilation operations) will be carried out to remove *noise* small and connects the parts of the object (see Figure 3).

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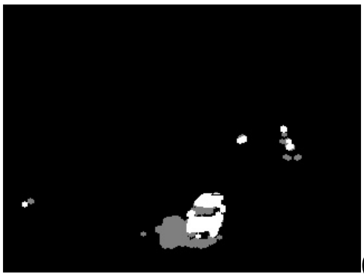
(a)

(b)

Figure 3. Results of the Background Subtraction process (a) Original image and (b) resulting image

3.3.2 Implementation of Haar Cascade Classifier

At this stage, the car image that has been detected in the subtraction background will be filtered again through several stages, including (1) Haar-Like Features , (2) Adaboost (Adaptive Boosting), and (3) Cascade Classifier

1. **Haar-like Feature**
   Haar-like features are features used to detect patterns in images. This feature is similar to a convolution filter. The type of feature used can be a rectangular feature, a horizontal line, or a vertical line (see Figure 1). To increase the speed of feature calculation, integral image is used , which allows the calculation of pixels in an image area with constant time.

2. **Adaptive Boosting (Adaboost)**
   Adaboost is an algorithm that functions to select haar features in large quantities by only selecting certain haar features. Adaboost is used to select specific features to be used in setting the threshold . Adaboost combines many weak classifiers to form a strong classifier . Weak classifier is an answer with an inaccurate level of truth. Adaboost selects a number of weak classifiers to combine and adds weight to each classifier so that a strong classifier is formed . One quick method for adapting to a weak classifier is to limit the weak classifier to a set of classification functions that each depend on a single feature.

3. **Cascade classifier**
   Cascade Classifier stage is divided into several stages or levels (cascade) with each level having several weak classifiers . The Strong Classifier is only executed if all weak classifiers in the previous level pass. This allows for a faster detection process as many features can be rejected earlier. The cascade is adjusted during training to ensure accurate detection and good computing speed. Cascade parameters such as false acceptance rate and detection rate can be tuned to meet application specific needs.

3.4 Vehicle Speed Detection

The speed of the detected vehicle will be calculated by dividing the length of the ROI area by the vehicle time. In this case, the length of the ROI is measured in the actual situation.

To calculate vehicle speed, the equation used is:

$$V_m = \frac{s}{t} \tag{2}$$

with, Vm is the vehicle speed (meters/second) , s is the length of the area covered (meters) , and t is the vehicle travel time (seconds) . Meanwhile, to calculate the speed in the video, the vehicle travel time can be developed into:

$$t = \frac{ft}{fps} \tag{3}$$

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with, ft is the number of frames counted from the time the vehicle enters until it exits the ROI , and fps is the number of frame rates of the video. Next, by substituting equation 2 into equation 3 , you will get equation 4 to calculate the vehicle speed in the video , namely:

$$\text{vehicle speed} = \frac{s\,.\,fps}{ft} \tag{4}$$

The number of vehicle frames (ft), can be calculated using equation 5, where in this case, the ROI length (s) is 5 meters and frame rate videos is 30 fps. To find the value of ft , it can be assumed that if it is known that the system detects vehicles entering and exiting the ROI with a time (t) = 1.5s, then:

$$\text{ft} = \text{t x fps} \tag{5}$$
$$\text{ft} = \text{1.5s x 30fps= 70 frames}$$

So the number of vehicle frames (ft) is 70 frames.

3.5 System Testing

To evaluate the performance of the method used, it is done by testing the effectiveness of the system which is measured using two aspects, namely by reference to the Confusion Matrix from vehicle detection, and the average error rate or Mean Square Error (MSE) from vehicle speed calculations.

In the Confusion Matrix , there are 4 possible cases that occur, including; True Positive (TP) is the number of car objects detected correctly, True Negative (TN) is the number of non-car objects, False Positive (FP) is the number of other objects detected as cars, and False Negative (FN) is the number of car objects that are not detected as cars. Based on the Confusion Matrix , it is determined by calculating Accuracy using equation 6.

$$\text{Accuracy} = \frac{\text{number of car objects detected}}{\text{total number of objects}} \tag{6}$$

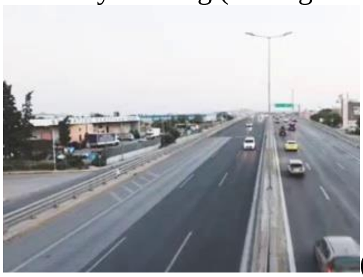
Apart from that, MSE is used to determine the difference between the estimator and the estimation results and as a benchmark for an estimator. The results obtained are always positive numbers. The closer to zero (0), the better the estimator's performance. To calculate the MSE value, equation 7 is used.

$$MSE = \frac{1}{N}\sum_{i=h}^{N}(y_t - y\hat{}_t)^2 \tag{7}$$

where, N is the number of samples, $y_t$is the actual value of the index and $y\hat{}_t$is the predicted value of the index.

4 Results and Discussion

In testing this research, the video acquisition results that have been taken will be included in the program. Testing was carried out using a notebook with an i3-4030U 1.90GHz processor, 6 GB RAM , and the Windows 10 operating system . The video images used were taken during the day, evening and early evening (see Figure 4).


(a

B

C)

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Figure 4. Video images in (a) midday, (b) afternoon and (c) evening

The video will be processed in several predetermined stages. If in the process the system detects a car object that is detected in ROI In and ROI Out , it will be marked with a red box (see Figure 5).


(a)

(b)

Figure 5. Car object detection results on (a) ROI In (object entering), and (b) ROI Out (object exiting)

The results of this detection will determine the results of the speed calculation. Thus, only cars detected in both ROIs (In and Out) will be processed to calculate the estimated car speed. Using equation 4, The first parameter required is the distance from ROI In , whose length is measured in real conditions. The second parameter is the number of frames calculated from the time the car is detected in ROI In until the time the car is detected in ROI Out . The speed of the car will be known and become a parameter in the next process to activate the speed bump .

Figure 6 (a) displays the results of speed calculations in conditions where the car speed is <30 Km/hour, so that the speed bump remains in the inactive or off position . Meanwhile, Figure 6 (b) shows the results of speed calculations in conditions where the car speed is ≥ 30 Km/hour, so that the speed bump position becomes active or on .

(a)


(b)

Figure 6. Car object detection results on (a) ROI In (object entering), and (b) ROI Out (object exiting)

The test was carried out using 3 videos at different times, namely day, evening and night and with a total of 55 cars used for each condition, and the detection results obtained were shown in Table 1.

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Table 1. Detection Results

No	Video Testing Time	Number of Cars	Actual Number of Cars (TP)	Accuracy (%)
1	Midday	55	51	93
2	Afternoon	55	47	85
3	Evening	55	42	76
		Average		**85**

The results obtained are shown in Table 1, where the accuracy values obtained for each video testing time are different, even though the number of car objects used is the same. It can also be seen that the test time affects the accuracy results, where the lower the light intensity, from day to evening and night, the accuracy value of car object detection decreases. This is caused by several factors, including;

1. Light Variability; background subtraction and haar cascade can be greatly affected by significant changes in light. If the light in the environment changes drastically, this method may have difficulty distinguishing between the object and the background.
2. If there are objects in the background that have similar characteristics or shapes to the car object, these algorithms can have difficulty differentiating between the two.
3. If a haar cascade model is not trained with a dataset that includes a sufficient variety of environmental conditions, object appearances, and different scenarios, then its ability to perform accurate detection can be limited.

After the car object is detected, further testing is needed to prove the accuracy of the speed calculations produced in the system by calculating the speed from the video. However, before this is done, it is necessary to verify the results of the speed in real time with the speed on the video. This is done by looking at the speed displayed on the speedometer when the car crosses the ROI. The resulting speed becomes the main source of speed in the video and a speed comparison is carried out on the system. The test was carried out using six car samples whose detection accuracy was calculated in the previous discussion and the speed calculation results are shown in Table 2.

Table 2. Speed Calculation Results

3rd car	Real Time Speed	System Speed	Error	Total	MSE
1	20	20	0	3	0.5
2	30	30	0		
3	40	40	0		
4	60	59	1		
5	80	81	1		
6	100	99	1		

Based on the speed calculation test results, using equation 7, an MSE value of 0.5 was obtained. In calculating the MSE value, a result that is close to perfect is a very small error value, namely close to zero. So the MSE value obtained in this research is still not perfect, due to several problems, namely the existence of a heavy computing process, resulting in a difference in speed in the system compared to the speed in the video, on the other hand, if the computing process runs normally it can produce speed in the system running normally, so can produce speed calculations that match the video in real time .

5 Conclusion

Research shows that the combination of background subtraction and Haar cascade has not reached the expected level of performance when seen from the accuracy results obtained, namely an average of 85% in day, evening and night conditions, this is due to certain factors that hinder object detection. effectively. Results This combination also occurs due to problems in terms of detection

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speed and object localization precision. For further research, it is necessary to evaluate and consider the use of alternative object detection methods that may be more suitable to the context or type of object encountered, such as deep learning or more complex methods.

Thank-you note

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