Abstract—This paper presents a thermal features’ relative angle method to separate vehicles for nighttime traffic. The objective of research is to identify and separate vehicles that have ambiguous thermal features. The features comprising of windscreen, engine heat and elsewhere, are depicted as different intensities in each thermal image. Moreover, the relation between the three features observed from the set-up camera can be illustrated as an angle of windscreen to heat, which differentiates one group of vehicles from another. There are three operating modules proposed in this research, comprising vehicle-thermal features detection, relative angle calculation and separation, respectively. Initially, the detecting process finds a vehicle engine heat-feature by subtracting the road’s intensity, selecting a suspected area to cover the vehicle’s windscreen feature. Secondly, the relative angle calculating model is implemented to find a relative angle. Eventually, the decision of vehicular group is made on the angle by the separating module. Experimentally, using three types of vehicle consisting of a car, van, and truck, the accuracy of separation is extremely high.

Keywords—vehicular separation; thermal imaging; nighttime traffic

I. INTRODUCTION

Nowadays, countries all over the world are attempting to reduce energy consumption because fuel prices are rising dramatically and there are no signs of a turning point. Such a crisis also unavoidably affects the transportation systems. However, at present there is a system called ITS (Intelligent Transportation Systems), which is designed to evaluate traffic situations. A vital function of ITS, related to the evaluation, is to automatically and effectively control traffic flow-characteristics, consisting of flow, density and space and mean speed of vehicles. One criterion for controlling the characteristics is vehicle-category. Presently, vehicle-category processing by image method is popularly used because of visible analysis, portability, non-destructive and its real-time technique. Currently, this technique uses visible light-images from video cameras as a source for analysis in both day and nighttime. Unfortunately, in the case of a low intensity light situations such as nighttime, because the system is based on visible light, the category is affected when the lights from vehicles and the environment occlude the camera’s visibility. For this reason, this research proposes a thermal-imaging method for analyzing vehicle’s thermal distribution as a solution. Different types of vehicles generate diverse thermal patterns, making identification possible on this basis. In addition, the advantage of this method is the ability to identify a type of vehicle when occluded by non-thermal insulator objects, as opposed to the visible lights method. Advantages of this research are multiple applications such as traffic-monitoring, vehicle speeds detection, on-road securities, autonomous vehicle, automatic toll-fare collections whenever visible light constrains the related analysis.

II. REVIEW OF LITERATURE

Nowadays, daytime vehicle identifying methods are suitable with high intensity light in an observing scene. However, as illustrated in Fig. 1(a), it does not work with low light situations in nighttime traffic. In the case of nighttime, [4] proposed two-step tracking algorithm to CCD (Charge-Coupled Device) images, headlights from other vehicles created difficulties in vehicle detection as shown in Fig. 1(b). In addition, [5] declared that when using CCD images for nighttime traffic, the fine camera adjustment is also required. In [6] detected vehicle headlights and taillights in order to inspect whether there are other vehicles in close proximity or not. However, it is unreliable when the vehicles turn off their lights. Previous research on vehicle detection by ITS, utilizing different image processing techniques depended on the specific situations and based on visible lights. In this research, we apply thermograph technique for identifying vehicles, especially when it is absolutely dark. The technique has also been utilized for vehicle tracking and classification by [7], [8] with acceptable results. According to the researchers, their models aimed to classify types of any vehicle based only on the size of reflected heat underneath the vehicle. Consequently, the accuracy of classification was still relatively low because there was not enough information for categorizing moving vehicles on the road into various types. To improve the classification accuracy, [9] utilized more thermal features from the front of a vehicle. These features included the windscreen, reflected heat underneath the vehicle and other sources. However, the classification result
was inefficient with some vehicles. As this reason, to aid the analysis, a concept and design, regarding vehicular thermal-features’ relative angle was undertaken. The research concept and processes are explained below.

III. THE RESEARCH CONCEPT

The concept of thermal features of vehicle utilized in the research is detailed in the following subsection.

A. Concept of Thermal Features of Vehicle

Considering various vehicular types, each type is created for different purpose. The front and side of a vehicle are designed for aerodynamics, driver’s visibility, load, balance, and thermal transfer, respectively. As in Fig 2., concerning the vehicle’s front, the height of the windscreen, compared to other types, is different. Moreover, the distance between windscreen’s base and space underneath the coachwork of a vehicle is also different from others. From the side-perspective, the diameter of a vehicle’s wheel differs among types of vehicle. Furthermore, the space underneath the coachwork of a vehicle also differentiates it from others. From the side-perspective, the diameter of a vehicle’s wheel differs among types of vehicle. Similarly, when the vehicle’s engine is operating, the temperatures of relative parts also rise. For this reason, ventilation is needed to prevent the engine overheating. For each vehicular model, the engine space is designed for the heat to dissipate underneath the coachwork for ventilating when the vehicle is moving. According to thermal-imaging, the higher temperature has higher intensity. Therefore, various intensity levels always occur in an observed scene. Invariably, three thermal features occur in a vehicular observation in a thermal image, consisting of windscreen, vehicle body and heat underneath the coachwork. The ratio of windscreen image height and heat is different in different types of vehicles. Moreover, the thermal identity of a vehicle’s front, compared to other types, is also different. Figures 2(a), (b) and (c) show the thermal features of different vehicles consisting of a car, van and truck, respectively. Meanwhile, Fig. 2(d) illustrates the thermal configuration of all those vehicles.

Figure 2. Thermal Features of Vehicles and Thermal Vehicular Model
IV. PROPOSED VEHICULAR SEPARATING MODEL OF THE RESEARCH

Because of the different approach for vehicle identification compared to traditional research methodology, this research instead uses the intensity of thermal features to identify vehicle types. As shown in Fig 3, the operation of the proposed model of research begins by inputting thermal image frames into the seperating process. All steps of the model are as follows:

A. Vehicle detection Module

To detect suspected objects and analyze whether they are vehicles or not, the range of intensity of free road is used as a key factor. Unlike other research that has used the background subtraction to detect a vehicle from an image frame, this research uses the free road intensity subtraction method. Basically, all vehicles are driven on the road surface so that the heat from their engines automatically occurs beneath them. For this reason, the road intensity, which implies the comparison to vehicle is utilized to extract the objects in a thermal image. To specify the range of free road intensity, in this research the frequency of the free road intensities is modeled as a Normal distribution, which is shown in Fig. 4. The range of free road intensities is defined as any values that lie between the mean of the road's intensities, \( \mu_r \), minus a times the standard deviation of the road's intensities \( \sigma_r \), and \( \mu_r \) plus a times of \( \sigma_r \). The value of a is utilized for specifying the probability of the data's range; a=1 yields approximately 68 \%, a = 2 yields approximately 95\% and a = 3 yields approximately 99 \%, respectively. Meanwhile, any values above or below the range of road intensities are considered a heat-feature and windscreen, including other features of an object, respectively. To find the range of road intensities, a sample area of free road is selected and defined as an array, \( R \). The size of \( R \) is \( m \times n \) pixels and each pixel has the intensity of \( r_{mn} \). The value of \( \mu_r \) and \( \sigma_r \) of the distribution can be computed by Eq(1) and Eq(2), respectively. The threshold intensity for use in the road intensity subtraction method is given as \( R_i \) in Eq(3). In this research, a = 3 is utilized for computing the \( R_i \) in order to get about 99\% probability of free road intensity. If a thermal image, \( I \), is the array with the size of \( rxc \), then the intensity \( i_{rc} \) of each pixel after the road intensity subtraction process will be given as Eq(4).

\[
\mu_r = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} R_{mn}}{m \times n} \tag{1}
\]

\[
\sigma_r = \sqrt{\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (R_{mn} - \mu_r)^2}{m \times n}} \tag{2}
\]

\[
R_i = \mu_r + a \sigma_r \tag{3}
\]

\[
i_{rc} = \begin{cases} 
0 & i_{rc} \leq R_i \\
1 & i_{rc} > R_i 
\end{cases} \tag{4}
\]

As illustrated in Fig.5, in the initial \( I \), many heat objects appear on the road surface, and will be used as the positioning indices in the image. When considering each object, the heat feature is given as an array (dimension of \( H_h \times b \), \( H_h \)), where \( H_h \) and \( b \) suggests the height and width of the heat, respectively. Following the location of the heat feature, the next operation is to find an area suspected of including a vehicle, that can be utilized for evaluating whether it is a vehicular boundary or not. In this research, to find the suspected area, the heat feature is cropped vertically at both edges from the base to two times of \( H_h \). The cropping method is to separate the engine's heat, windscreen-feature and elsewhere-feature from other regardless features. When the locus of the suspected area is found, it will be used to project I (the original frame) for locating the suspected features in the image. We define the projected area as an array with the size of \( dxb \) (given \( d \) equals \( 2H_h \)), \( P \), which has \( P_{db} \) intensity in each pixel.
B. Relative Angle Computing Module

As mentioned in Fig. 2(d), in this research, the vehicular model observed by the camera’s set-up can be illustrated as Fig. 6. The intensity of the windscreen and other features are defined as any values below \( \mu - a\sigma \), where \( \mu \) is the mean and \( \sigma \) is the standard deviation of the sample set. To separate the windscreen, \( I_w \), from other features, the method of Automatic Thresholding is implemented. In this research, resulted by Automatic Thresholding, \( T_w \) is defined as the threshold separating the windscreen-feature from elsewhere-feature in \( P \). To find the location of the windscreen feature pixels in \( P \), Eq(5) is utilized. Hereafter, the threshold is implemented, the cluster of 1s in \( P \) represent the windscreen-feature.

\[
p_{db} = \begin{cases} 
1 & \text{if } p_{db} \leq T_w \\
0 & \text{if } p_{db} > T_w 
\end{cases}
\]  

(5)

- The Computation of the Relative Angle: When the vehicle recognition model as in Fig. 6. is complete, the next operating step is to compute the relative angle, \( \theta_{fw} \) of the vehicle model. As illustrated in Fig. 6, the area of the vehicle model is defined by four spots comprised of (0,Yt), (0,0), (b,Yt) and (b,0), respectively. Inside the area, there are three sub areas, consisting of windscreen, non-heat projecting and the heated areas, respectively. The \( \theta_{fw} \) is the angle measured clockwise from the locus (0,Yb) to (Xw,Yt). The left upper most spot of the windscreen feature is illustrated by the purple dashed line at 5.23 degrees. The red dots and connection line are for the average value of \( \theta_{fw} \) of those cars. The red dots and connection line are for the \( \theta_{fw} \) of 45 vans, and the green dots and connection line are for \( \theta_{fw} \) of 45 trucks. When the van and trucks in Fig. 7(b) and (c) are for a van and truck, respectively.

C. Vehicle Separating Module

For separating cars from vans and trucks, \( V_g \) as in Eq(9) will be utilized for evaluation. If \( V_g \) equals to 1, van or truck is the result of separating. Meanwhile, if \( V_g \) equals to 0, car is the result of the decision.

\[
H_w = |Y_t - Y_b|
\]  

(6)

\[
L_f = |X_w - 0|
\]  

(7)

\[
\theta_{fw} = \frac{180}{\pi} \tan \left( \frac{L_f}{H_w} \right)
\]  

(8)

\[
V_g = \begin{cases} 
1 & \text{if } \theta_{fw} \leq T_\theta \\
0 & \text{if } \theta_{fw} > T_\theta 
\end{cases}
\]  

(9)

V. Experimental Results

For testing the proposed vehicle category method in nighttime traffic, a Fluke Ti25 thermal camera is utilized to manually capture 135 thermal images of various vehicles on Suksawad Road, Trungkru, Bangkok, Thailand. Samples of free roads used for the object's detection process are shown in Fig.10(a). Furthermore, Figure 10(b), (c) and (d) illustrates samples of cars, vans and trucks, respectively, on the road. With reference to the above vehicular thermal images, the results of each operating stage of identification modules are explained as follows:

A. Results of vehicle detection

- Vehicle Heat Detection Using The Method of Road Intensity Subtraction

A sample of vehicle heat detection using the road intensity subtraction method is illustrated in Fig.5.

B. Results of the Relative Angle Computations and Vehicular Decisions

Figure 9 shows samples of \( \theta_{fw} \) of various vehicles comprising cars, vans and trucks, respectively. The blue dots and connection lines are for the \( \theta_{fw} \) of 45 cars, meanwhile, the blue dashed line at 53.37 degrees, illustrates the average value of \( \theta_{fw} \) of those cars. The red dots and connection line are for the \( \theta_{fw} \) of 45 vans, and the green dots and connection line are for \( \theta_{fw} \) of 45 trucks. When the van and trucks are gathered altogether, their average \( \theta_{fw} \) is illustrated by the purple dashed line at 5.23 degrees. The red dashed line, which is at a 29.31 degree angle, is the average level between the blue and purple dashed lines. In addition, the red dashed line will be utilized as a given threshold \( T_\theta \) for separating the cars from vans and trucks.

VI. Conclusion and Comment

The research presents a vehicular separation by thermal features’ relative angle for nighttime traffic. The results of correct separation are satisfactorily high. However, with 135 samples in the experiment, it is feasible to have less correction if tested on larger amount of samples. Therefore
it is left for further researchers to prove in order to get the additional information about the separating correction.

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![Figure 8. Sample of captured thermal images](image1)

![Figure 9. Sample Results of Relative Angle of Vehicles](image2)

REFERENCES


