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Traffic Flow Measuring System by Image Processing

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ABSTRACT

In this paper, we show a new image sensor for measuring traffic flow. The image sensor is set at an intersection. The image sensor measures traffic flow by vehicle tracking. The tracking is done by gray level pattern matching. Gray level pattern matching is suitable for outdoor use since it is robust against change of scene brightness. Then we provide the hardware for high speed gray level pattern matching. After showing our new method for measuring traffic flow by the image sensor, we measure traffic flow at an actual intersection and describe the results. The sensor measures traffic flow accurately under various conditions.

INTRODUCTION

To resolve traffic congestion and to make good use of roads, several traffic signal control systems[1] and traffic information service systems[2] have been developed. In traffic control systems, traffic signals at several intersections are controlled cooperatively so as not to localize traffic in certain areas. Traffic information service systems inform drivers of traffic situations to prevent traffic congestion from spreading. For these systems dynamic traffic information is necessary. An image sensor is one of the most important techniques to get the information at many road points.

Image sensors can measure dynamic traffic indices such as the number of passing vehicles and the speeds of vehicles, twenty-four hours a day.

Image sensors have been studied by many researchers in recent years[3]. Conventional image sensors usually use a background image subtraction method. First, a background image is made and stored in an image memory. The background image is a road image without any vehicles. Usually it is not easy to get the background image, especially near an intersection, because it is rare that there is no vehicle near an intersection. Therefore the background image is synthesized from several images, i.e. parts of road images without any vehicles are collected to synthesize the background image. Then the background image is subtracted from every new frame taken by a TV camera. The difference between the background image and the new image represents vehicles in the new image. Therefore, an accurate background image is indispensable to detect vehicles accurately. Additionally, the background must be updated quickly according to changes in road conditions caused by brightness and weather changes. However, it is difficult to update the background image for a road near an intersection just as it was difficult to obtain the original background image.

In this paper, we propose a new method of measuring traffic flow. In our method, the sensor does not use background images, rather it uses gray level pattern matching.

GRAY LEVEL PATTERN MATCHING

Gray level pattern matching is one of digital image processing operations. We can detect a certain gray level pattern in a whole image by the operation. First, we store a gray level image which is similar to the searching object into an image memory. The kept image is called a template. Then we scan a new image, calculating the similarity between the template and a portion of the new image. There are several formulas for calculating similarity. we use the correlation coefficient,

$$R(i,j) = A(i,j)\left\{B(i,j)\times C\right\}^{-\frac{1}{2}}, \qquad (1)$$

where R(i,j) is the correlation coefficient at i and j in x-y coordinate system, A(i,j) is covariance of a portion of the new image f(x+i,y+j) and the template image g(x,y), B(x,y) is variance of a portion of the new image and C is variance of the template image. C is a constant value when the template image g(x,y) is fixed. They are represented as follows,

$$A(i,j) = \sum_x \sum_y f(x+i,y+j)g(x,y) - \frac{1}{N}\sum_x \sum_y f(x+i,y+j)\sum_x \sum_y g(x,y), \qquad (2)$$

$$B(i,j) = \sum_x \sum_y f(x+i,y+j)^2 - \frac{1}{N}\left\{\sum_x \sum_y f(x+i,y+j)\right\}^2, \qquad (3)$$

and

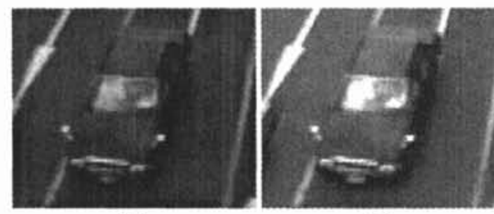
$$C = \sum_x \sum_y g(x,y)^2 - \frac{1}{N}\left\{\sum_x \sum_y g(x,y)\right\}^2. \qquad (4)$$

The correlation coefficient is robust against differences of brightness and contrast. Figure 1-(a) is an original template image, Figure 1-(b) is a brighter image. The correlation coefficient represents complete coincidence between these images. However the correlation coefficient is not robust against change of scale. Figure 2 is the same vehicle image, but smaller. In this case, the correlation coefficient represents disagreement between the two images. Generally to resolve this problem, several templates are used for one vehicle. Several templates have different scale images for one vehicle.

In measuring traffic flow, an image sensor has to track various types of vehicles such as dark, bright, small, large and so on. In general, to track various vehicles, a lot of templates are prepared. Therefore an image sensor has to perform large calculations.

VEHICLE TRACKING METHOD

We propose a new vehicle tracking method. In our method, an image sensor tracks various types of vehicles with one template for each vehicle. Figure 3 shows an outline of our method. The image sensor has an initial detection area in the center of the image. This area is the starting area of vehicle tracking. First, the image sensor detects the front shape or headlights of a vehicle and keeps their images as templates. Then the image sensor tracks front shapes of vehicles from the previous frame to the current frame by gray level pattern matching.



(a) (b)

Figure 1-(a) Original template image.
-(b) Brighter image.

Figure 2 Smaller image.

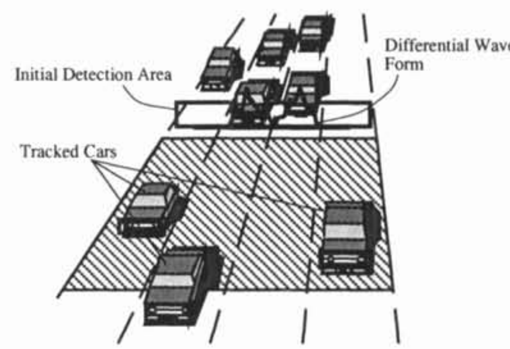


Figure 3 Outline of the tracking method.

Figure 4 shows the flow of our method. First, our image sensor takes an initial template at a detection area. The image sensor performs spatial differential filtering to detect the front part of a vehicle because there is a bright and dark pattern and big value for the differential calculus at the front part. Then the sensor tracks the vehicle by gray level pattern matching. In this method our image sensor uses only one template to track one vehicle. So it is unnecessary to prepare kinds of templates. When the tracking is completed, the image sensor counts the number of vehicles for each lane and measures their speeds by their tracking time and their tracking distance.

In our method, it is important to make a good initial template in the initial detection area. A wrong template causes a wrong trace of shadows and road marks, and faulty counting. In the daytime the image sensor uses a differential operation in the vertical direction to get the right template in the initial detection area. Additionally the sensor removes tracking objects such as shadows that have a small differential value. Moreover, the sensor checks each distance among several tracking templates to avoid a duplicate count. At night, the image sensor selects a pair of headlights as a template. The image sensor makes a brightness profile at the initial detection area, and detects narrow profiles as headlights, and removes broad profiles as reflections of lights. Consequently the sensor does not need any background images.

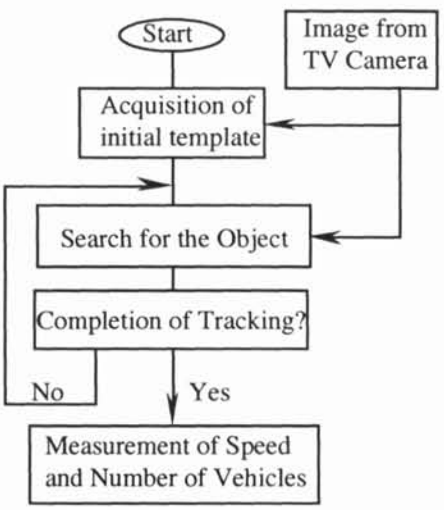


Figure 4 Flow chart of the method.

HARDWARE

Vehicle tracking by gray level pattern matching requires high speed processing. Therefore we developed an image processor that has a CPU board, an image processor board and communication equipment. Figure 5 shows a photo of the image sensor. The image processor board consists of an image memory and the image processor that performs image preprocessing such as spatial filtering, histogram processing, gray level pattern matching and so on. The image processor performs spatial filtering of a 512 by 440 pixel image in 9 ms. Additionally, the processor can track about ten vehicles simultaneously for gray level pattern matching in 90 ms.

EXPERIMENTS

We checked the applicability of our image sensor to actual traffic conditions by some experiments on an actual road. An intersection in a big city was chosen for the work. We set the image sensor near the intersection. Experiments were done in various conditions such as heavy traffic, light traffic, in the daytime, at twilight, at night, on a cloudy day and on a rainy day.

The intersection had five lanes in each direction. The TV camera was set at a height of 10 m. The image sensor measured traffic flow from the first to the fourth lane traffic in the five lanes. We applied the image sensor to the traffic flow of about 3,000 vehicles for two hours under each condition described above. Figure 6 shows an input image to be processed.

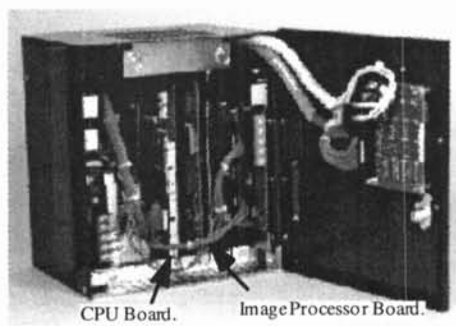


Figure 5 Photo of the image sensor.

Figure 6 Input image.

RESULTS

(1) The accuracy of vehicle counting

We counted numbers of passing vehicles for about two hours for each condition. The image sensor counted vehicles in four lanes. Table 1 shows vehicle counting mean accuracy in all lanes for every five minutes for each condition. The table shows that the image sensor could count vehicles with less than 3.0 % error for every five minutes under these conditions. The image sensor kept its accuracy at night, even vehicles that were using only parking lights. Although we checked the accuracy in each lane for every five minutes, we do not show the accuracy in the table for lack of space. In heavy traffic, in a daytime and on a rainy day, the image sensor counted with the worst accuracy, that is 10 % error. When the image sensor worked with the worst accuracy, there was a parked vehicle in the first lane. Then many vehicles did not move straight to avoid the parked vehicle. Therefore the image sensor failed to classify these passing lanes.

Table 1 The accuracy of counting vehicles.

Time	Weather	Traffic	Measured vehicles	Error(%) Mean
day	sunny	light	2,477	1.8
		heavy	3,988	2.1
	rainy	light	-	-
		heavy	3,803	3.0
twilight to night	sunny	light	2,059	2.0
		heavy	3,103	2.7
	rainy	light	-	-
		heavy	3,002	2.2

(2) The accuracy of vehicle speed measuring

We measured speeds of passing vehicles for thirty minutes for each condition. We set measuring speed area as 10 m along these lanes. The image sensor measured mean speed of each vehicle for the area. Table 2 shows that the errors of measuring speed at lane 2 and lane 3 were less than 10 % in standard deviation. To track vehicles front bumper accurately is very important to measure speed accurately. The accuracy of measuring speed became worse when the image sensor tracked reflected head lights on the surface of the road on a rainy day.

CONCLUSIONS

We showed a new image sensor for measuring traffic flow, including the numbers and speeds of passing vehicles. The sensor tracks vehicles without any background image by gray level pattern matching. Therefore the image sensor is robust against a lot of changes of conditions. Additionally, because the image sensor does not use a binary process with any threshold, it is easy to adjust.

Traffic signal control systems require the image sensor have an error less than 10 % in measuring traffic flow. Though the resolution of the processed image was not so high for its wide view, the image sensor satisfied this requirement.

Table 2 The accuracy of measuring speed.

Time	Weather	Traffic	STD. DEV. (Measured vehicles)	
			Lane 2	Lane 3
day	sunny	light	9.0 (151)	9.3 (178)
		heavy	9.4 (230)	7.7 (264)
	rainy	light	-	-
		heavy	8.2 (304)	9.5 (344)
twilight to night	sunny	light	7.3 (218)	8.1 (241)
		heavy	8.9 (287)	9.0 (304)
	rainy	light	-	-
		heavy	8.6 (565)	7.7 (646)

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