

Traffic Queue Length Measurement Using an Image Processing Sensor

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ABSTRACT

As the social economic activities grow variously in recent days, an advanced traffic control system corresponding to the changes of road traffic circumstances becomes an urgent matter. And traffic information service or the profit convenience for travelers and commodity distribution are also needed.

April in 1993 under such situation, the synthetic and epoch-making traffic management system, Universal Traffic Management Society of Japan(UTMS), was established. Among the purposes of UTMS, especially Integrated Traffic Management System(ITCS) aims at the development of a more optimum signal control algorithm which can corresponds to the every moment changing traffic situation. So to realize this, an advanced sensor which can collect more precise and more detail traffic flow information is needed.

September in 1993, UTMS established a new working group, the purpose of which was research and development of an image sensor which provides useful traffic flow information for the traffic signal control which realizes this ITCS. And in this working group we started examining a specification of the image sensor.

This image sensor processes images received from the ITV camera installed above the approach lane at the traffic signal intersection, and can directly measure queue and delay length up to 150m as well as number of passed vehicles, speed, vehicle type and vehicle existence in 30m area.

So we have developed new measurement algorithms and a new hardware, and we succeeded in the development of a new image sensor, SPatial Image processing Traffic flow Sensor(SPITS), which satisfies this specification.

While the function of direct measurement of queue and delay length is the advantage of an image sensor, it is hard to measure them precisely in the distance from the camera position because of poor visibility. SPITS has succeeded in enabling to measure queue and delay length precisely even in the distance with a sophisticated method and in real time processing.

SPITS has been evaluated by field tests. The experimental results show that SPITS has achieved accurate measurement within 10% error of maximum queue length under various conditions(day, night, twilight, rain etc.) and confirm that SPITS is able to provide useful traffic flow information for ITCS.

In this paper we will show these results as well as the queue and delay length measurement method used and hardware configuration.

CHARACTERISTICS OF AN IMAGE PROCESSING SENSOR

As the sensor which collects traffic flow information, mainly Ultrasonic Vehicle Detector has been used. This detector detects vehicle presence by the time difference of the reflection of ultrasonic wave fired from above the road surface to just under it. But especially queue and delay length are measured indirectly by the number of passed vehicles in a unit time. So a sensor which can collect more precise traffic flow information is needed. Also each Ultrasonic Vehicle Detector has to be installed above the road surface per a measurement lane and so there is a fear of spoiling the beauty of the city.

On the other hand, the Image Sensor processes an image received from the ITV camera installed aside and above the approach lane at the traffic signal intersection, so it is able to directly measure a spatial area like shown in Figure 1. And the Image Sensor has the following characteristics.

- (1) It is able to measure speed, vehicle type as well as number of passed vehicles on more than one lane at the same time.
- (2) It is expected to collect more precise and more detail queue and delay length information because of the direct measurement of them.
- (3) It does not spoil the beauty of the city so much because one image sensor installed aside and above the approach lane can measure more than one lane at the same time.

With these characteristics, the image sensor is thought to be one of the main sensors at present.

DEVELOPMENT GOAL

In October 1993, we started to develop an image processing traffic flow sensor taking an advantage of image sensor's characteristics and matching to the purpose of UTMS. So we started to develop an image processing sensor which can measure number of passed vehicles, speed, vehicle type, vehicle existence, queue length, and delay length directly on more than one lane at the same time.

Especially, in case of the queue and delay length measurement in the distance from the camera position, the vehicle on the image is so small that we need an advanced measurement technique to measure them correctly. And we had to measure all these measurement items at the same time and in real time. Also it was necessary to deal with the coming to the practical use.

Therefore we set the following development goal and started to develop SPITS.

- (1) Precise measurement of queue and delay length even in the distance from camera.
- (2) Measuring all measurement items at the same time and in real time.
- (3) Simple adjustment and maintenance in the case of practice use.

Table 1 shows the measurement items of this sensor.

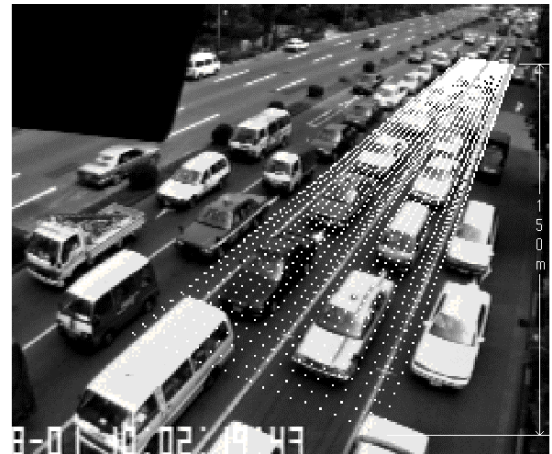


Figure 1 Measurement area and Sampled Points

Table 1 Measurement Items

Items	Measurement Lanes	Measurement Line or Area
Vehicle count	max. 4 lanes	on the line 15m from stop line
Speed	max. 4 lanes	on the line 15m from stop line
Vehicle type	max. 4 lanes	on the line 15m from stop line
Vehicle existence	max. 4 lanes	area of 15-45m from stop line
Queue length	2 lanes represented	area of 15-165m from stop line
Delay length	2 lanes represented	area of 15-165m from stop line

Table 2 Hardware Specification

	Camera Unit	Control Unit
Dimensions	W108 x H150 x D280mm	W300 x H500 x D200mm
Applicable temperature range	-20 to +50 degrees centi-grade	-20 to +60 degrees centi-grade
Output	NTSC, 1.0Vp-p/75Ω, composite	I/F : RS232C
Pick-up device	Monochrome 1/2" CCD	

SYSTEM CONFIGURATION

We will show the outline and the configuration of SPITS in the following.

System configuration

SPITS consists of Camera Unit and Control Unit. Camera Unit is installed above the approach lane on an arm attached to a high pole settled roadside. And Control Unit is installed at the lower part of the pole.

We use a monochrome CCD camera and an EE-lens is attached to correspond to brightness changes in outdoors. And Camera Unit and Control Unit are tightly closed to endure the outdoor uses, so we are thinking of circumstances endurance. Table 2 shows the hardware specification.

The image signal from Camera Unit is inputted to Control Unit. And by processing the inside of measurement area set in advance, traffic flow information is measured. Then measurement results will be transferred to the Traffic Control Center or Console

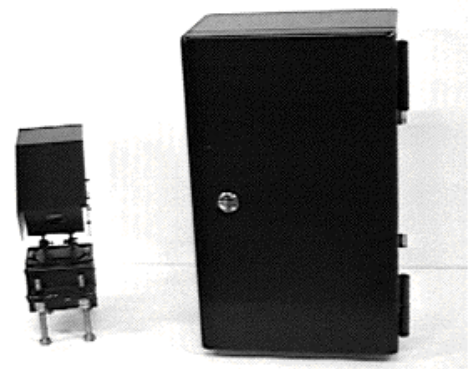


Figure 2 Camera Unit and Control Unit

Unit where the measurement results are stored.

Figure 2 shows the appearance of Camera Unit and Control Unit.

Hardware Configuration

We developed an exclusive hardware in Control Unit which has a simple configuration and can run high-speed processing. Figure 3 shows the hardware configuration.

The NTSC image signal inputted from Camera Unit is amplified and analog-digital converted. Preprocessing Unit makes a *Sampled-Points Image* from the input image, and to this *Sampled-Points Image* executes the image processings such as Time Difference, Background Difference, or Spatial Difference in high-speed.

By using the executed results of Preprocessing Unit, CPU calculates traffic flow information such as queue length. CPU also executes controlling Preprocessing Unit, transfer processing of the measurement results to the Traffic Control Center and moreover the man-machine processing.

In the case of initial adjustment or maintenance, a display board can be easily attached, and by using a monitor TV or a mouse we can perform an initial setting of measurement area and so on.

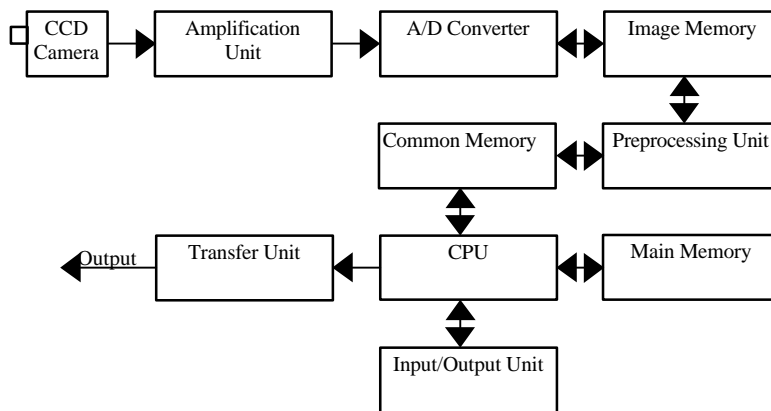


Figure 3 Hardware Configuration

QUEUE AND DELAY LENGTH MEASUREMENT ALGORITHM

We designed the basic idea of queue and delay length measurement algorithm as following.

"moving vehicles" from "existing vehicles" leaves "delay vehicles".

By the way, in the distance from the camera position, it is hard to measure queue and delay length precisely because of poor visibility. But we just noticed that we don't have to recognize each vehicle in the case of measuring queue and delay length and that it is effective to detect the vehicle groupings consisting of more than one vehicles in that case. Then we can consider the basic idea as following.

"vehicle groupings of moving vehicles" from "vehicle groupings of existing vehicles" leaves "vehicle groupings of delay vehicles".

We realize this algorithm mainly by two processes, image preprocess and queue length measurement process. We will give an outline of each process as following. Figure 4 shows the flowchart of this algorithm.

Image Preprocess

In the Image Preprocess, we extract data in the sample point positions which were beforehand set like Figure 1 from the input image and make a *Sampled-Points Image*. If we set these sample points elaborately, we could reduce whole computation quantity while securing the data which is necessary to measure in precise. Next we detect the status such as existing or moving of every sample point by the combination and by utilizing each characteristics of basic image processing methods such as time difference, background difference and spatial difference.

The outline of each image processing method is shown below. Also Table 3 gathers the characteristics of each method.

Time Difference

It is the method to calculate a difference among two images in time t and time $t+\alpha$ and detect change quantity in time α .

And by binarizing the calculated change quantity of each sample point with appropriate threshold, the "move detected sampled-point" is detected.

Table 3 Characteristics of Image Processing Methods

	Time Difference	Background Difference	Spatial Difference
Appliance	Detection of moving vehicles	Extraction of vehicles	Detection of vehicles' edges
Characteristics	Robust against environmental change. Not able to detect stopping vehicles.	Able to extract only vehicles' Image. Necessary to update the Background Image	Able to detect both moving and stopping vehicles. Influenced by noisy background.

Background Difference

It is the method to calculate a difference between the input image and the background image which is a road surface image including no vehicles. By processing this method, a *background difference image* which is only of vehicles is made.

Spatial Difference

It is the method to calculate the change quantity of the brightness data with the neighbor pixel. By processing this method for the *background difference image*, and by binarizing the calculated change quantity of each sample point with appropriate threshold, edges of vehicles can be detected. So the "*existence detected sampled-point*" is detected.

Queue Length Measurement Process

In this process, we detect moving vehicle grouping and delay vehicle grouping from the results of Image Preprocess, and calculate the delay range. Also, we make a stable output which is strong in the noise by smoothing the calculated delay range by referring to the output at the time of back and forth.

This process is composed of main five processes. We will show those outlines below.

Moving vehicle grouping detection process

In case of the time difference process, for a sampled point with small change quantity, a *move detected sampled-point* can not be detected and the crack sometimes occurs in the vehicle body. The detection of the noise is also seen. Therefore, we need to make the body range of the moving vehicle clear and the noise must be removed.

But we have an idea that to recognize each vehicle as the vehicle grouping in case of queue and delay length measurement is effective. So we introduced a concept of the vehicle grouping BLOCK. That is, BLOCK has the size which was beforehand set according to the distance from the camera and so on. And when the number of *moving detected sampled-points* in this BLOCK is above the appropriate threshold value, we register the BLOCK as the *Moving BLOCK*.

By making BLOCK, we can make the body range of the moving vehicle clear and remove the noise. It is also possible to detect the moving vehicle grouping which stride two lanes by setting BLOCK to the optional position.

Delay sampled-point detection process

Out of the *existence detected sampled-points* which were detected by the processing of the spatial difference, this process removes those in the range of the Moving BLOCK and detects *delay detected sampled-points*.

Delay BLOCK detection process

Using the technique like the detection of the Moving BLOCK, this process detects the Delay BLOCK out of the *delay detected sampled-points*.

Delay range calculation process

This process calculates the delay range of each lane. We regard the detection range of Delay BLOCK every lane as the congestion range at the lane.

Delay range correction process

Traffic congestion has the characteristics that it doesn't suddenly emerge or break off, and it never cancels from the queue end. Therefore, this process makes the output of the measurement result stable by smoothing the uneasy change of the delay range or by replacing the impossible change by referring to the output at the time of back and forth.

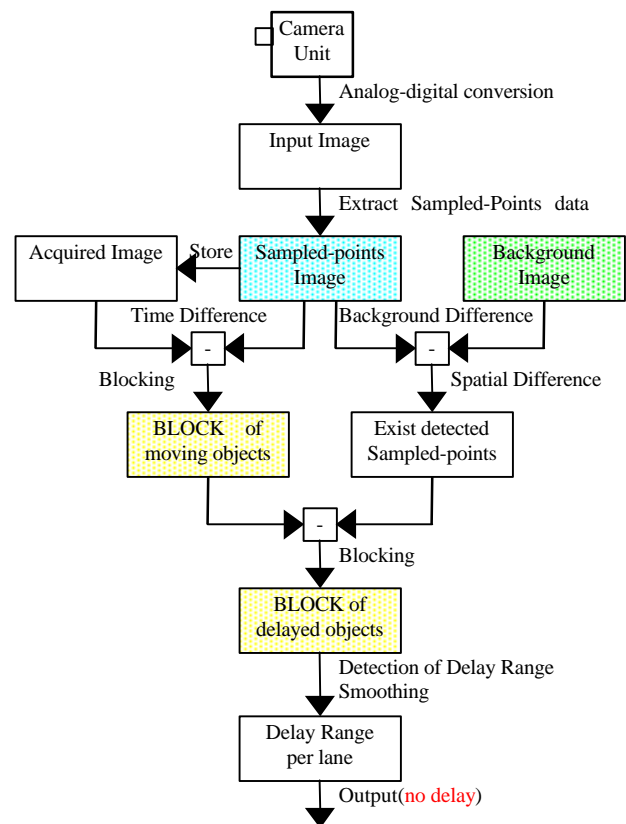


Figure 4 Flowchart of Queue Length Measurement

Characteristics of the Measurement Method

Now, we gather and show the characteristics of the Measurement Method in the following.

- (1)By the processes of making BLOCK or smoothing, we can reduce the influence by the noise, and so we can output the precise and stable queue length measurement result.
- (2)By automatically calculating the parameter which depended on the spot according to the distance from the camera position and so on, it secures measurement precision in the distant place and the operation management such as adjustment or maintenance can be simplified.
- (3)Because this method doesn't depend on the lane position, it is possible to detect the vehicle grouping which stretched for two lanes.
- (4)With elaborate sampled-points position setting, we could reduce whole computation quantity while securing the data which is necessary to measure in precise. Therefore, it is possible to make a hardware scale small and the cost of the whole system can be reduced.
- (5)The output delay time is so small that SPITS can provide traffic information to the traffic signal control in real time.

FIELD TEST

We made an measurement experiment in the field with SPITS on August, 1995, in Tokyo.

In this experiment, we measured the measurement items of UTMS specification, number of passed vehicles, speed, vehicle type, existence, queue length and delay length at the same time. But here we especially report the measurement result of queue length.

Measurement condition

In this experiment, Camera Unit was installed in the position about 2m aside from the roadside and 10m above from the road surface near the stop line on the approach lane at the intersection. And we set the measurement area as the range of 15-165m from the stop line and 2 lanes.

Thinking of continuation operation, we experimented under various conditions such as daytime, twilight, night, rain and so on. Measurement results were collected to the personal computer.

Way of evaluating

We consider a low-speed running vehicle is in congestion. When the way of the congestion was moving and the congestion continued after that, we consider the most far position being in congestion as the queue length.

The measured queue length is outputted every second and we evaluate the measurement precision with the maximum queue length each signal cycle. In other words, measurement precision is calculated by the following computation formula.

$$\text{measurement precision(\%)} = (\text{The measurement value of the maximum queue length}) / (\text{The true value of the maximum queue length}) \times 100$$

Here, the true value of the maximum queue length was measured by the direct watching in the spot.

Also, thinking of continuation operation, we evaluated an influence over the measurement precision by the combination with the measurement time(daytime, twilight, night), the weather (fine, rainy) and Traffic quantity(light, heavy).

Evaluation result

Table 4 shows the average of the measurement precision in each measurement time and we can confirm the stable measurement precision within 10% error.

Also, Figure 5 shows the measurement result of the queue length every second and the true value of the maximum queue length every signal cycle in 15:45-16:15 on August 3rd, and so we confirm that SPITS has measured the queue length precisely.

As the main error factor, the detection failure of a ashy black car whose brightness difference from the road surface is small and the lightless car in night was seen, and also the detection failure when a small car is hidden in the rear of the large-sized vehicle was seen, too. And the factor that the precision decline in case of the rainy weather on August 2nd is thought to be the decline of visibility because of the headlight reflection at the wet road surface.

Table 4 Results of Field Test

Day and Time	Weather	Traffic	Accuracy
August 2, 15:00-17:00(Day)	rainy	heavy	98.5%
18:30-19:00(twilight)	cloudy	heavy	95.0%
19:00-20:30(Night)	cloudy	heavy	96.8%
August 3, 14:45-16:45(Day)	fine	heavy	98.6%
18:30-19:00(twilight)	fine	heavy	95.2%
19:00-20:30(Night)	fine	heavy	95.6%
August 5, 15:00-17:00(Day)	fine	light	98.2%
18:30-19:00(twilight)	fine	light	92.8%
19:00-20:30(Night)	fine	light	96.8%

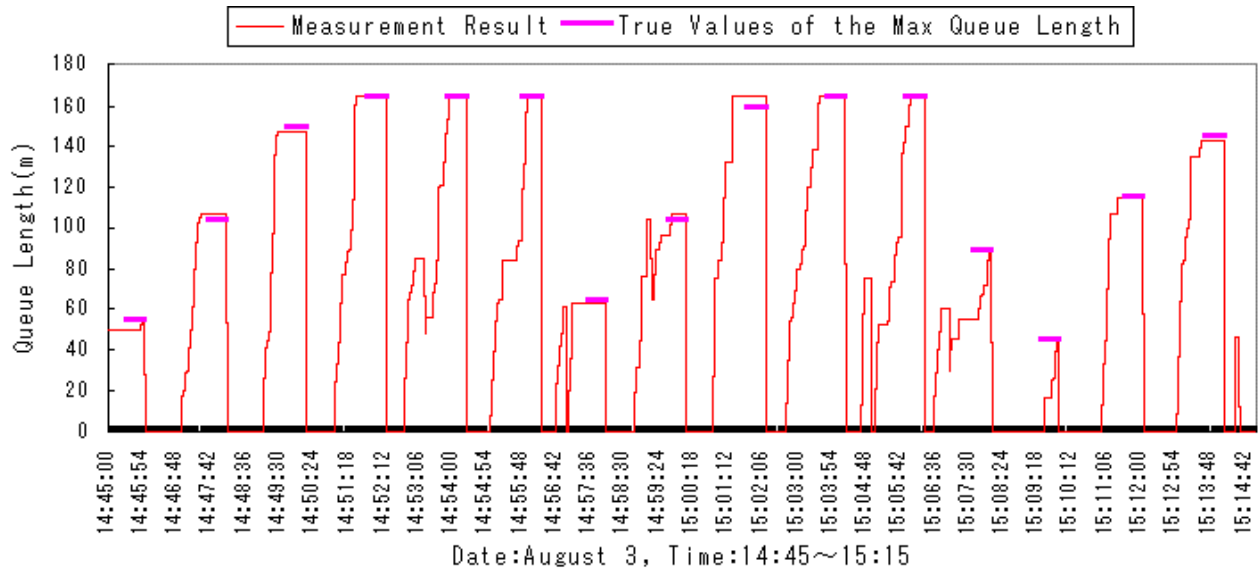


Figure 5 Measurement Result

CONCLUSION

We have developed a new image sensor, SPatial Image processing Traffic flow Sensor(SPITS), which satisfies UTMS specification which is the measurement of number of passed vehicles, speed, vehicle type, vehicle existence and queue and delay length directly at the same time. Also, SPITS is able to measure queue and delay length precisely even in the distance where visibility is poor with a sophisticated method and processes in real time with a high-speed hardware.

The experimental results of field tests show that SPITS has achieved accurate measurement within 10% error of maximum queue length under various conditions(day, night, twilight, rain etc.). Also, in the other measurement items, too, the high measurement precision can be achieved. And simplification in case of practice use is realized, so SPITS is considered to reach a practical use step.

Therefore we confirm that SPITS is able to provide useful traffic flow information for ITCS.

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