Vehicle Detection Using Double Slit Camera

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Abstract. We propose one-directional traffic flow measurement method using double slit camera. Two slit cameras are installed in overhead location with longitudinal alignment. They shoot real traffic scene in downward direction. Slit camera outputs pseudo two-dimensional image that consists of space domain and time domain. We detect vehicles from statistical pixel value of each line of a slit. Standard deviation is effective to detect bright color vehicles. We use the changes of a standard deviation and a change of an average as well as the standard deviation to detect dark color vehicles. We detect traffic flow parameters such as occupancy, time headway and time between two cars using slit camera. In double slit configuration, we detect spot speed of vehicles by the time difference of its appearance at each slit. We estimate vehicle length by normalizing the vehicle region. We also divide vehicles into type of vehicle by length.

1 Introduction

Traffic flow is counted using various vehicle detectors. Vehicle detectors are generally divided into three groups by the principle of detection. First group detectors sense the pressure when vehicle steps on a sensor, second group detectors detect a magnetic disturbance on a loop coil when vehicle passing through and third group detectors detect the reflection of a beam from vehicle. Vehicle speed is detected using Doppler radar or multiple detectors located between two points [1], [2]. Computer vision is also applied to traffic flow measurement [3], [4]. Analyzing a image sequence, a lot of traffic information such as number of vehicles, speed of vehicles, space headway are extracted in addition to multiple lanes. Area sensor is generally used as an imaging device to apply traffic flow measurement. The area sensor is suitable to detect two dimensional traffic flow such as intersection and junction.

Traffic flow except intersection is regarded as one-dimensional motion, therefore, line sensor is suitable to detect one directional traffic flow [5]. Line sensor camera outputs pseudo two-dimensional image that consists of space domain and time domain. We introduce three measures to detect vehicles in a real traffic scene. The first one is a standard deviation of pixel values for detecting bright color vehicles. The second and third are the change of a standard deviation and the change of an average respectively, for detecting dark color vehicles. We also detect some traffic flow parameters from time axis information of a slit image. In double slit configuration, we detect spot speed of vehicles, and estimate vehicle length. We classify vehicle into type of vehicle by length.

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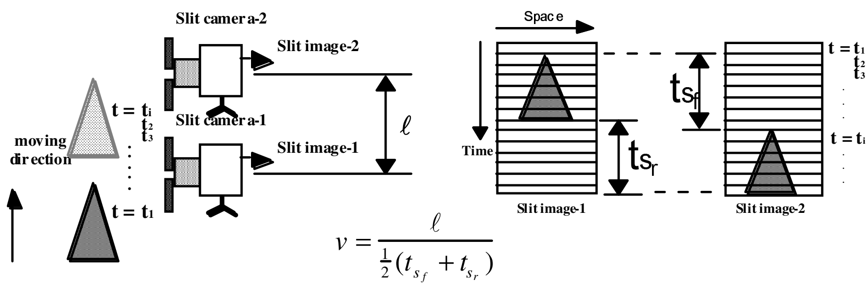
2 Slit Camera

Slit camera is originally developed for sport event to record and decide goal order. One directional motion which is perpendicular to a slit will be recorded as a two dimensional image, where a slit direction corresponds to a space axis and the direction perpendicular to the slit corresponds to time axis. When the object moves faster than a film running speed at the slit, the object on the slit image comes out shrinking along time domain. When the object moves same as a film running speed, the object on the slit image comes out undistorted image. When the object moves slower than a film running speed, the object on the slit image comes out extending along time domain. The direction of motion does not affect in a slit image, therefore, the result is just the same as if both objects move opposite direction each other.

To be briefly, line sensor camera is a slit camera that the screen material is replaced a conventional photo film with CCD array. In industrial applications, it is used to record and analyze shapes of parts on a belt conveyer. It is also useful to record a very long object such as a train. In ITS world, this is a good tool for one directional traffic measurement. In those applications, the slit camera position is fixed. If we move a slit camera, we can obtain 360-degree panorama (rotation), wall or road side street scene (translation). If an on-board slit camera is looking down to the road surface and the slit is aligned to latitude direction, longitudinal vehicle motion will give road surface unfolding image.



$$v = \frac{\ell}{\frac{1}{2}(t_{s_f} + t_{s_r})}$$

Fig. 1. Principle of vehicle detection using double slit

3 Vehicles in Slit Image

We aim to detect vehicles from each of the scan lines. We study relationship between vehicle's slit image and it's statistical pixel value of scan line, under the different finish of vehicle's body and different daylight. In Fig. 2 ~ Fig. 6, left images show various type of vehicle's image at different daylight, center figures show standard deviation of each scan line, and right figures show average of each scan line.

1) Standard deviation of road surface keeps almost constant, even if daylight slightly changes (Fig. 2 ~ 6).
2) Average of pixel value varies if daylight changes (Fig. 2 ~ 6).
3) Standard deviation becomes an effective measure for detecting bright color vehicle (Fig. 2).
4) Non-glossy object such as fabric top cover has low standard deviation (Fig. 3).
5) Standard deviations become lower, when dark color vehicle is took shot in under-exposure or relatively less daylight (Fig. 6).

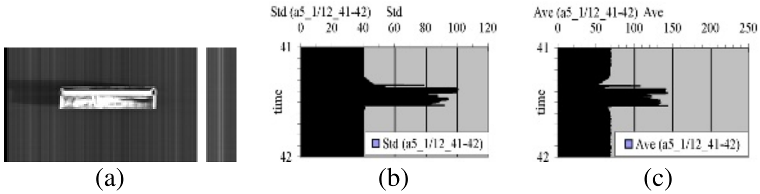


Fig. 2. Std. and Ave. of bright color vehicle-1

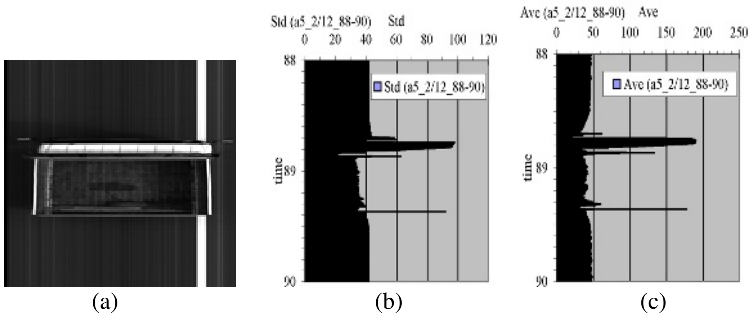


Fig. 3. Std. and Ave. of bright color vehicle-2

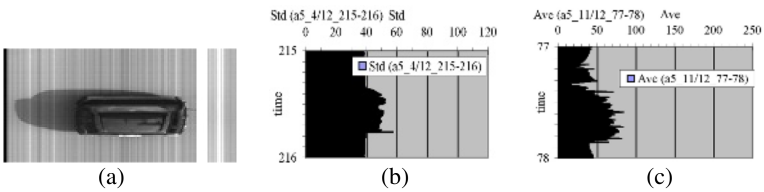


Fig. 4. Std. and Ave. of dark color vehicle-3

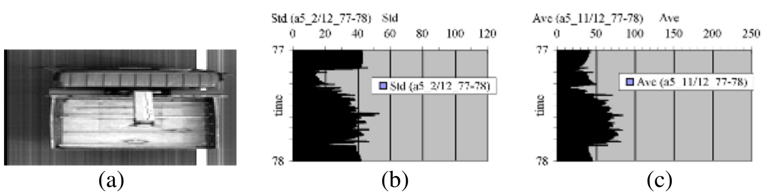


Fig. 5. Std. and Ave. of bright color vehicle-4 at under-exposure

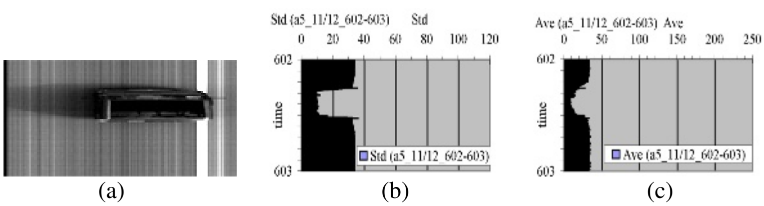


Fig. 6. Std. and Ave. of dark color vehicle-5 at under-exposure

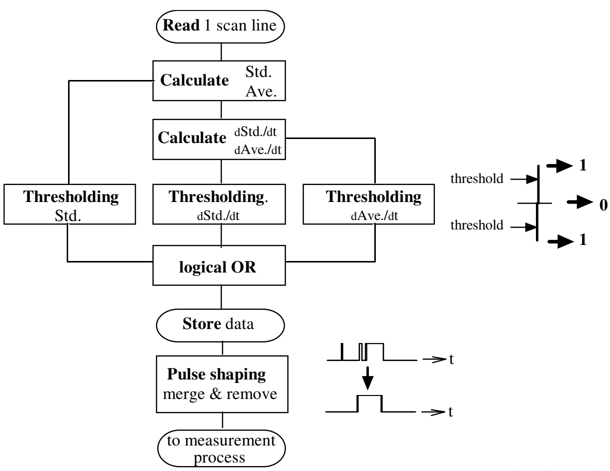
4 Outline of Method

4.1 Measures for Vehicle Detection

We use statistical pixel value of a scan line to detect vehicle. As mentioned above, standard deviation of road surface keeps constant even if daylight slightly changes. Standard deviation is efficient to detect bright color vehicles. Average of road surface depends on a daylight change, so average itself is not enough for measure. We use a change of average as a measure that is less-sensitive about daylight change. We also use a change of standard deviation to improve performance for detecting front and rear edge of vehicles.

4.2 Vehicle Detection

Fig. 7 shows flow of vehicle detection. In order to detect vehicles in each scan line, we use three measures for detection; standard deviation, change of standard deviation and change of average. We tentatively determine vehicle in a scan line when these measures are larger than or smaller than the designated thresholds. We add a flag of which 1 as including vehicle or 0 as not including vehicle, to the scan line number. These flagged line information are unified by logical OR, then merged by the duration between 1s, and replaced 1 to 0 by the isolation. After detection process, this information is send to measurement process to count traffic.



$Ave(t)$: *average of pixel value at line t*

$$\text{Ave}(t) = \frac{1}{n}\sum_{x=0}^{n} I(x,t)$$

$Std(t)$: *standard deviation of pixel value at line t*

$$Std(t) = \sqrt{Std(t)^2},\ Std(t)^2 = \frac{1}{n}\sum_{x=0}^{n} I(x,t)^2 - \text{Ave}(t)^2$$

n : *resolution of space domain*

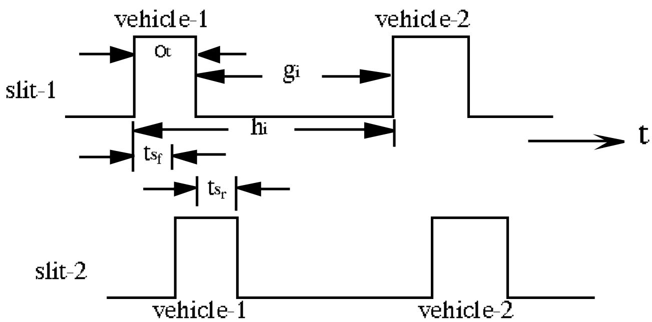
$I(x,t)$: *pixel value*

Fig. 7. Flow of vehicle detection

4.3 Traffic Flow Measurement

In Fig. 8, pulse duration corresponds to occupancy, pulse spacing corresponds to time between two cars and interval between a leading edge of a pulse and next leading edge of a pulse corresponds to time headway. Time difference of a leading edge of a pulse (front edge of vehicles) or a trailing edge of a pulse (rear edge of vehicles) between the slits corresponds to a time required passing through the slits. We can get occupancy; **Ot**[sec], time between two cars; **gi**[sec], time headway; **hi**[sec] and time difference of its appearance at each slit; **ts**[sec]. Spot speed; **vt** is calculated by **vt=ds/ts**[m/sec], because distance between slits; **ds**[m] is already known.

An equivalent film running speed of the camera; **vslit** is derived from line capturing speed; **cslit**[line/sec] (or scanning time of a line) and resolution of the camera; **rt**[m/line], and as follows **vslit=rt·cslit**[m/sec]. Therefore modification coefficient for restoring non-extended and non-contracted slit image of vehicles; **k** becomes **k=vt/vslit**. Vehicle length; ℓ is estimated by ℓ**=ot·rt·k**[m] using occupancy, resolution and modification coefficient. We also obtain traffic volume; **Q**, rate of flow; **q**[/h], occupancy: **Qt**[%], time mean speed; $\overline{v_t}$ [m/sec], average time headway; $\overline{h}$ [sec], average time between two cars; $\overline{g}$ [sec], as macroscopic traffic flow parameters for designated period.



Ot: occupancy
gi: time between two cars
hi: time headway
ts: time difference of its appearance at each slit
(**tsf:** leading edge, **tsr:** trailing edge)

Fig. 8. Parameters derived from wave forms

5 Experiment

5.1 Experimental Set-Up

We install two line sensor cameras on a pedestrian overpass at 6.1 meters height from road surface. Both cameras look down to the road surface, and the slits are aligned to latitude direction with 2.6 meters distance between slits. The line sensor camera equipped 10.24[mm]width by 10[mm]length CCD array and 17[mm] focal length optical lens, so range of vision becomes 3.7[m]width by 3.6[mm]length in each line, and resolution of CCD becomes 3.6[mm/pixel]. We fix on a line capturing speed of the camera; 500 [line/sec], or one line scanning time; 2 [ms].

5.2 Measures for Vehicle Detection

In order to adapt detection to some different road surface materials, we study the value about standard deviation and average of pixel value at measurement position, then decide the thresholds.

1) A scan line includes vehicle when Std. becomes less than 30 or larger than 45.
2) A scan line includes vehicle when change of Std. becomes less than -3 or larger than 3.
3) A scan line includes vehicle when change of Ave. becomes less than -6 or larger than 6.

5.3 Vehicle Detection

We tentatively detect whether a scan line includes or not includes vehicle from three measures. We add a flag of which 1 as including vehicle or 0 as not including vehicle to the scan line. The flagged line are unified by logical OR, then merged by the duration between 1s and replace 1 to 0 by the isolation. Almost vehicles keep more than 0.5 second distance against preceding vehicle, therefore candidates of vehicle within 0.5 second interval are merged as a same vehicle.

Fig. 9 show one minute slit image during 12 minutes shooting and typical example of detection process (whole slit image has 1024 pixel along space axis and 360,000 line along time axis). Fig. 9 (a) shows original slit image, (b) shows histogram equalized slit image for easy to see, (c) shows Std. of scan line, (d) shows change of Std, (e) shows Ave. of scan line, (f) shows change of Ave. (g) shows vehicle detection by three measures, logical OR and merged result respectively.

From human observation, 170 vehicles pass through the upper side camera, and 166 vehicles pass through the lower side camera during 12 minutes. We detect 165 vehicles at upper side, and 163 vehicles at lower side. Correct detection rate becomes 96 % taking into account of redundancy and insufficiency of detection results.

5.4 Traffic Flow Measurement

5.4.1 Correspondence of Vehicles Between Slits

In order to detect vehicle speed, we study correspondence of vehicles between slits. We extract and regard as corresponding vehicle that appears within one second from upper slit to lower slit (faster than 7.8 km/h between slits). We can adapt slow traffic by this interval to longer. In the speed detection stage, we can finally detect 153 vehicles, and detection rate becomes 90 %.

5.4.2 Traffic Flow Measurement

Table 1 represents typical example of occupancy, vehicle speed, vehicle length of detected vehicles with human observation results. Detected speed of vehicles includes

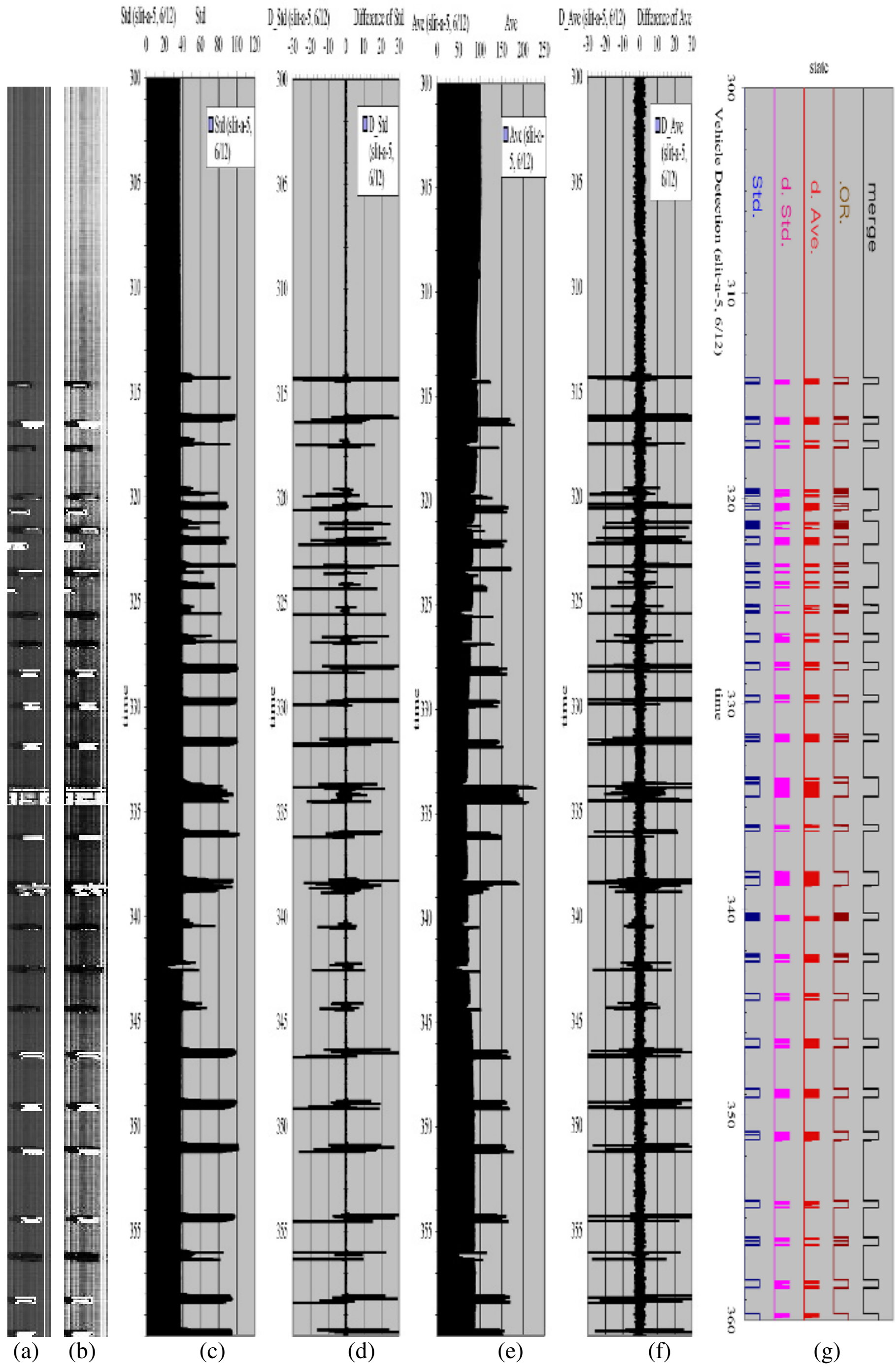


Fig. 9. Typical detection result of vehicles (5~6 minute or 30,000 line data during 12 minutes measurement)

an error of maximum 30km/h. Table 2 represents some traffic flow parameters derived from the measurement. We estimate vehicle length from occupancy and vehicle velocity, then classify vehicles into type of vehicle by length. We regard vehicles less than 2.5 [m] length as a motor cycle, less than 3.4 [m] length as a sub-compact car, less than 4.7 [m] length as a compact car, and longer than 4.7 [m] as a regular car. We classify the objects less than 1 [m] or longer than 12 [m] into irregular. Classified results show estimated lengths of many vehicles are longer than the manually detected results, due to the effect of shadow.

Table 1. Example of vehicle detection result

Vehicle No.	Correspond Vehicle		Occupancy [sec]							Vehicle speed [km/h]								Mod. Coef_cient		Vehicle length	
Slit-1	No. at Slit-2		Detected			Human observatiom				Detected			Human observation			Error		Detected	Observed	Detected	Observed
	Front edge	Rear edge	slit-1	slit-2	Average	Slit-1	slit-2	Average	error [%]	Front edge	Rear edge	Average	Front edge	Rear edge	Average	[km/h]	[%]			[m]	[m]
1	1	1	0.362	0.368	0.365	0.374	0.362	0.368	-0.8	46.8	45.2	46.0	42.3	45.2	43.7	2.3	5.2	6.2	5.9	4.8	4.6
2	2	2	0.284	0.296	0.290	0.278	0.274	0.276	5.1	60.8	55.5	58.1	55.5	57.2	56.4	1.8	3.2	7.9	7.6	4.8	4.4
3	3	3	0.238	0.248	0.243	0.234	0.226	0.230	5.7	67.0	61.7	64.4	60.8	64.8	62.8	1.6	2.5	8.7	8.5	4.5	4.1
4	4	4	0.210	0.216	0.213	0.198	0.186	0.192	10.9	58.9	56.3	57.6	52.5	57.2	54.9	2.8	5.0	7.8	7.4	3.5	3.0
5	5	5	0.374	0.388	0.381	0.350	0.346	0.348	9.5	47.4	43.7	45.6	43.2	44.2	43.7	1.9	4.3	6.2	5.9	4.9	4.3
6	6	6	0.290	0.282	0.286	0.318	0.318	0.318	-10.1	54.8	58.0	56.4	57.2	57.2	57.2	-0.8	-1.4	7.6	7.7	4.6	5.2
7	7	7	0.210	0.212	0.211	0.214	0.214	0.214	-1.4	54.8	54.0	54.4	55.5	55.5	55.5	-1.2	-2.1	7.4	7.5	3.3	3.4
8	8	8	0.276	0.276	0.276	0.278	0.270	0.274	0.7	56.3	56.3	56.3	55.5	58.9	57.2	-0.9	-1.5	7.6	7.8	4.4	4.5
10	10	10	0.218	0.340	0.279	0.350	0.338	0.344	-18.9	92.6	37.7	65.2	36.7	38.9	37.8	27.4	72.5	8.8	5.1	5.2	3.7
11	11	11	0.392	0.394	0.393	0.398	0.390	0.394	-0.3	39.7	39.3	39.5	38.9	40.5	39.7	-0.2	-0.5	5.3	5.4	4.4	4.4
12	12	12	0.306	0.300	0.303	0.370	0.358	0.364	-16.8	40.5	41.8	41.2	40.5	43.2	41.9	-0.7	-1.7	5.6	5.7	3.5	4.3
13	13	13	0.382	0.386	0.384	0.382	0.382	0.382	0.5	40.5	39.7	40.1	40.5	40.5	40.5	-0.4	-1.0	5.4	5.5	4.4	4.4
14	14	14	0.278	0.278	0.278	0.282	0.274	0.278	0.0	40.9	40.9	40.9	40.5	42.3	41.4	-0.5	-1.1	5.5	5.6	3.2	3.3
15	15	15	0.680	1.070	0.875	0.678	0.670	0.674	29.8	41.8	13.5	27.7	41.4	43.2	42.3	-14.6	-34.6	3.7	5.7	6.9	8.1
16	16	16	0.948	0.930	0.939	0.950	0.926	0.938	0.1	38.9	42.7	40.8	38.9	44.2	41.5	-0.7	-1.8	5.5	5.6	10.9	11.1
17	17	17	0.314	0.314	0.314	0.318	0.314	0.316	-0.6	43.7	43.7	43.7	45.2	46.3	45.7	-2.1	-4.5	5.9	6.2	3.9	4.1
18	18	18	0.454	0.466	0.460	0.458	0.454	0.456	0.9	47.4	44.2	45.8	42.3	43.2	42.7	3.1	7.2	6.2	5.8	6.0	5.5
19	19	19	0.382	0.382	0.382	0.386	0.382	0.384	-0.5	42.7	42.7	42.7	42.3	43.2	42.7	0.0	0.0	5.8	5.8	4.6	4.7
20	20	20	0.370	0.382	0.376	0.342	0.338	0.340	10.6	49.8	46.3	48.1	45.2	46.3	45.7	2.3	5.1	6.5	6.2	5.1	4.4
21	21	21	0.386	0.412	0.399	0.382	0.378	0.380	5.0	49.2	42.3	45.7	42.3	43.2	42.7	3.0	7.0	6.2	5.8	5.2	4.6
23	23	23	0.410	0.436	0.423	0.378	0.378	0.378	11.9	42.3	37.0	39.6	38.1	38.1	38.1	1.5	4.0	5.4	5.2	4.8	4.1
24	24	24	0.434	0.456	0.445	0.398	0.382	0.390	14.1	42.3	37.7	40.0	36.0	38.9	37.4	2.6	6.8	5.4	5.1	5.1	4.2
25	25	25	0.316	0.328	0.322	0.310	0.306	0.308	4.5	54.8	50.5	52.6	51.2	52.5	51.8	0.8	1.5	7.1	7.0	4.8	4.5
26	26	26	0.314	0.322	0.318	0.290	0.286	0.288	10.4	51.8	49.2	50.5	48.6	49.8	49.2	1.3	2.7	6.8	6.7	4.6	4.0
27	27	27	0.378	0.386	0.382	0.358	0.346	0.352	8.5	48.6	46.3	47.4	45.2	48.6	46.9	0.5	1.1	6.4	6.4	5.2	4.7
28	28	28	0.332	0.338	0.335	0.306	0.302	0.304	10.2	50.5	48.6	49.5	49.8	51.2	50.5	-1.0	-1.9	6.7	6.8	4.7	4.4
29	29	29	0.356	0.802	0.579	0.334	0.330	0.332	74.4	50.5	13.0	31.7	47.4	48.6	48.0	-16.3	-33.9	4.3	6.5	5.2	4.5
30	30	30	0.788	0.782	0.785	0.734	0.726	0.730	7.5	42.3	43.7	43.0	42.3	44.2	43.2	-0.2	-0.6	5.8	5.9	9.6	9.0

Table 2. Traffic flow measurement result and classified type of vehicles by length

	Traffic volume	Rate of traffic flow [/h]	Time occupancy	Aveeage time [sec] between two cars	Average time headway [sec]
Manual	168	840	0.074	3.90	4.20
Experiment	153	765	0.084	4.33	4.73

Average time headway [sec]	**Vehicle speed** [km/h] Average	Max. speed	Min. speed
4.20	46.2	108.0	29.7
4.73	47.5	108.2	27.0

shorter than 1 m		**Type of vehicles**			longer than 12 m
Irregular	Bike	Sub-compact	Compact	Standard	Irregular
0	4	19	110	20	0
2	4	8	77	56	6

6 Conclusion

We propose a traffic flow measurement method using double slit camera. We detect vehicles at each scan line from three measures. We also count vehicles, occupancy, time headway and time between two cars. We detect vehicle speed and estimate vehicle length by double slit configuration. We classify vehicles into type of vehicle by length.

In order to improve detection, we have to prepare fine exposure slit image and consider countermeasures against effect of shadow from the vehicles. We also have to add a measure for detection using likelihood of vehicle from consistency and continuity of a line profile.

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