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Emission Frequency/Duty Ratio of PWM Flashing on LED Lights with Flicker

Japan Coast Guard
Japan Aids to Navigation Association

Summary

Recently, a light emitting diode (LED) has been used as a light source of Aids to Navigation (AtoN). This research examined how to enhance the visibility of AtoN using a technology which finely controls LED lighting.

Specifically, we obtained the result that LED lights with flicker are effective against background lights of AtoN. Basic survey results have already been confirmed by a visibility experiment carried out at the Port of Yokohama in November 2006. This survey research technically pursued them and made a selection of appropriate duty ratio/emission frequency to enhance the visibility of AtoN lights.

1 Introduction

Aids to Navigation (AtoN) such as light houses and lighted buoys have recently been mixed up with illuminations at growing seaside areas and are sometimes not clearly visible.

This situation is that even if lights for AtoN in front of their background lights are at the visible illuminance level, they are not visible due to ambient background lights or it takes a long time to be visible.

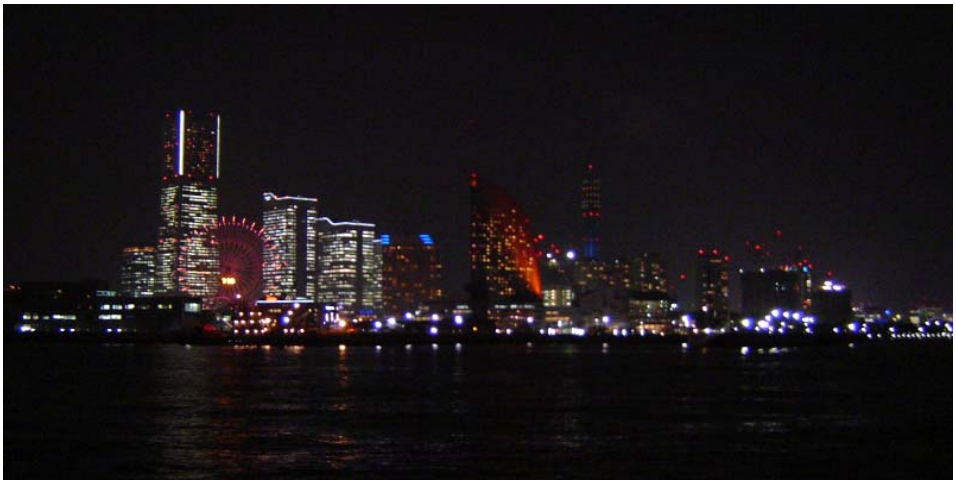


Photo 1. Background city lights at Port of Yokohama

Under the circumstances, the Japan Coast Guard (JCG) and the Japan Aids to Navigation Association obtained a survey result that lights with flicker are effective against background lights of AtoN.

In the visible experiment carried out at the Port of Yokohama in November 2006, it was confirmed that lights become excellent at conspicuity and recognizability even with background lights by producing flashing lights using a Pulse Width Modulation (PWM) method with a light emitting diode (LED) as the light source and this was defined as “PWM LED Lights with Flicker”.

Fig 1 shows a flashing pattern of PWM LED Lights with Flicker:

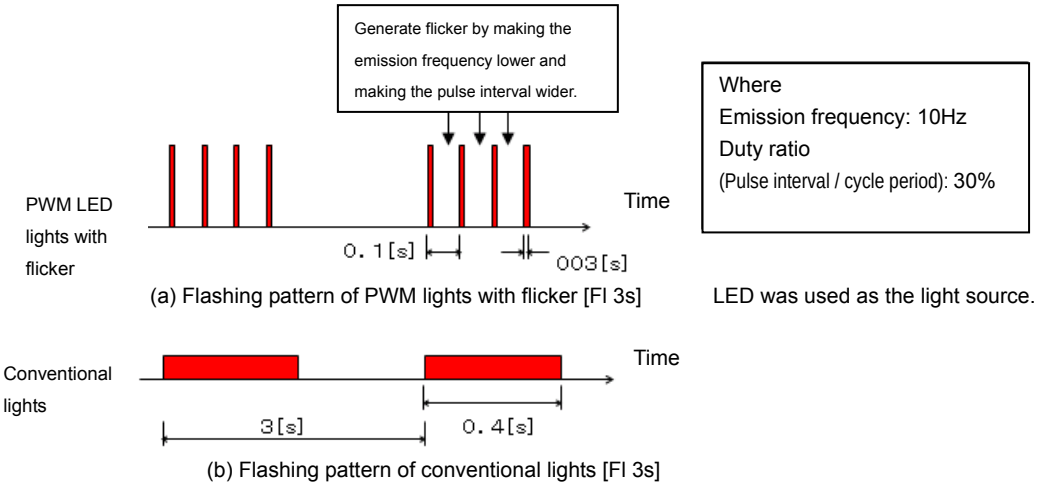


Fig 1. Flashing pattern of PWM LED Lights with Flicker

2 Emission Frequency/Duty Ratio

Since effects on conspicuity and recognizability of PWM LED Lights with Flicker depend on the emission frequency and duty ratio, it is necessary to set them properly.

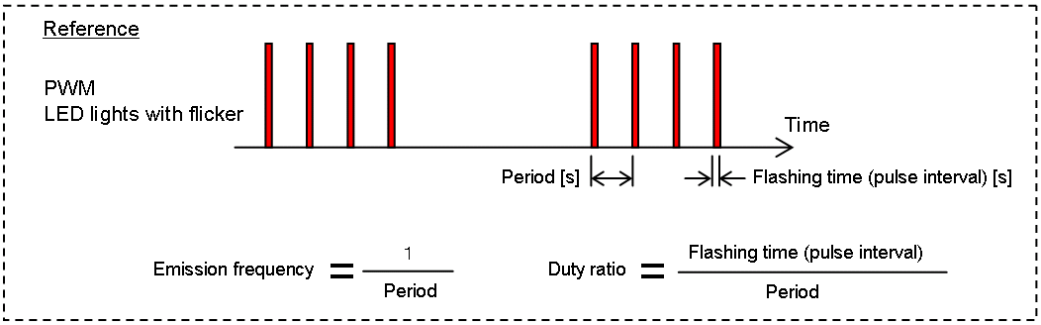
Since the setting of duty ratio is connected directly with the lantern size and manufacturing cost, it is important from the viewpoint of design and manufacturing of lanterns. If duty ratio is set lower, lantern size should be larger to obtain required luminous intensity and its manufacturing cost becomes higher. Therefore, it is preferable to set duty ratio as high as possible.

PWM LED Lights with Flicker should not be confused with “ultra quick light which repeats 240 to 300 flashes per minute” (pulse repetition frequency: 4 to 5 Hz) provided by IALA Recommendation E-110 for the Rhythmic Characters of Lights on Aids to Navigation (May 1998) and the “irritation” by flicker should be taken into account.

This survey research conducted a visible experiment and a laboratory

experiment to verify appropriate emission frequency/duty ratio of PWM LED lights with flicker.

Since the evaluation result of recognizability showed the same trend as that of conspicuity at the visibility experiment in the Port of Yokohama, this survey research focused on conspicuity.



3 Visibility Experiment

3.1 Experiment Method

(1) Date and Time: 19:30 to 20:30 on 3 October 2007

(2) Site: Yamatake, Chiba Pref. (Kujukurihama)

(3) Evaluators: 40 persons consisting of JCG staff and technicians of lantern manufacturers

(4) Specifications of lanterns used in this experiment

Table 1 shows the specifications of lanterns used in this experiment:

Table 1. Specifications of lanterns used in this experiment

Item	Luminous method	Color/Light source	Luminous intensity in the horizontal direction
Test lantern (for PWM LED lights with flicker)	PWM Frequency: 10 to 25 Hz (variable) Duty ratio: 10 to 90 % (variable)	Red LED NO5FVWC-23 manufactured by NANOTECO Corporation	Varied according to duty ratio* 10%: 500cd 20%: 250cd 30%: 167cd 40%: 125cd 50%: 100cd 60%: 83cd 70%: 71cd 80%: 63cd 90%: 56cd
Reference lantern (for conventional lights)	Current control	Same as above	50cd

*Luminous intensity in the horizontal direction of the test lantern was varied according to the duty ratio so that luminous quantity in one light of the test lantern becomes the same as that of the

reference lantern.

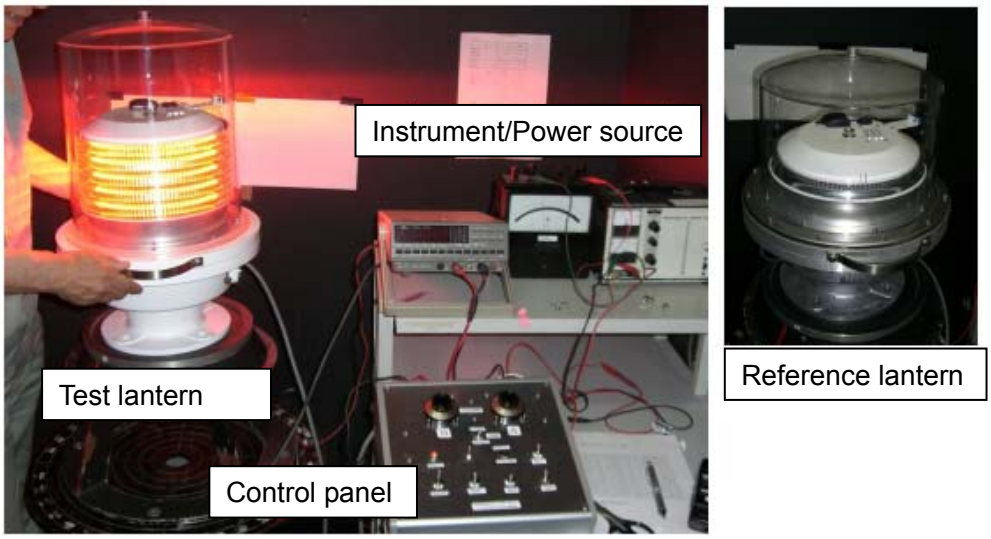


Photo 2. Test lantern/Reference lantern

(5) Allocation of experimental equipment, etc.

Two lanterns were separately allocated on temporary scaffolds built up on the breakwater and evaluated from coastwise distances of 4 km, 5km, 2km, 1km and 300m.

The lights were Fl. 3 Sec. (1 flashing per 3 seconds, red). The luminous quantity was the same as that of the reference one.

Photo 3. Visibility experiment

There was no background city lights which prevent the visibility of the

lights, cloudy day, the wind was north-east 4 [m/s] and visibility range was 25 [km].

(6) Evaluation method

Experiment 1. 【Survey on duty ratio】

The reference lantern (conventional lights: no flicker) and test lantern (PWM LED lights with flicker: Duty ratios varied from 10 to 90 % by 10% and emission frequency was fixed as 10 Hz) flashed synchronously to relatively evaluate the conspicuity of various duty ratios.

Experiment 2. 【Survey on emission frequency】

The test lantern (PWM LED lights with flicker: Emission frequencies varied from 10 to 25 Hz by 1 Hz and duty ratio was fixed as 30%) was only used to relatively evaluate the conspicuity of various emission frequencies by switching two frequencies over time . Lanterns were flashed at one frequency, switched to another frequency when the light rhythm was 3rd to 5th cycle and returned to the original frequency when the light rhythm was 3rd to 5th cycle repeatedly.

Since the number of combinations of two frequencies is too many, 120, combinations which showed almost same evaluation results in the prior laboratory test were omitted and the rest of them were narrowed down to the following 37 combinations shown in Table 2:

Table 2. Frequencies to be compared in the visibility experiment (○)

Hz	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
10			○					○			○		○			○
11					○		○			○		○			○	
12					○			○			○		○			○
13						○			○			○		○		
14							○				○		○			○
15									○					○		
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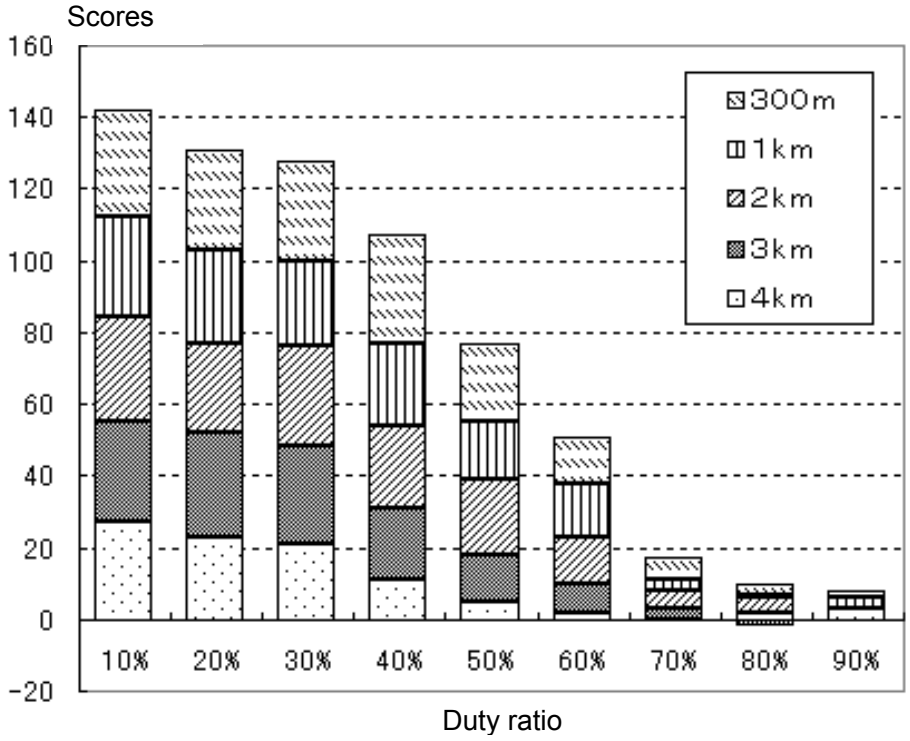
Since some frequencies are too long to fit their pulse trains into the

duration of light, this experiment set out the flashing within 0.4 seconds and coordinated so that luminous quantity becomes the same at frequencies to be compared with.

3.2 Results

Experiment 1. 【Survey on duty ratio】

Compare the test lantern (PWM LED lights with flicker) and reference lantern (conventional lights without flicker) and evaluate as +1 when the conspicuity of the test lantern is higher than that of the reference one and -1 when the conspicuity of the reference lantern is higher than that of the test one. The evaluation results (total scores) are shown in Fig. 2.



*Evaluators: 40 persons, Evaluation distances: 5 places, Range of score: +/-200

Fig 2 Evaluation results on duty ratio

On the ground that the higher the duty ratio is set, the smaller the lanterns become and the lower the manufacturing cost becomes, scores were multiplied by the duty ratio to be revised. Table 3 shows the results. Cost-effective duty ratios were 30 to 50 %.

Table 3. Revision of score

Duty ratio	Score	Score x Duty ratio
10%	142	14.2
20%	131	26.2
30%	128	38.4
40%	107	42.8
50%	77	38.5
60%	51	30.6
70%	17	11.9
80%	8	6.4
90%	7	6.3

Experiment 2. 【Survey on emission frequency】

Evaluate as +1 when the conspicuity of the low frequency is higher than that of the high one and -1 when the conspicuity of the high frequency is higher than that of the low one. The evaluation results (total scores) are shown in Fig. 3.

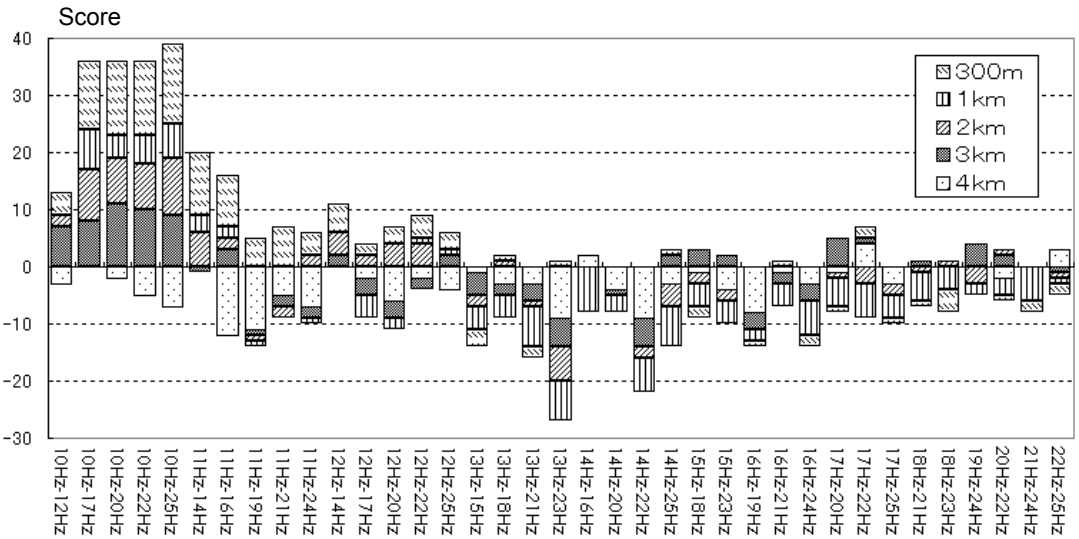


Fig 3 Evaluation results on emission frequency

In this experiment, the frequency with the highest conspicuity was 10 Hz. 11 Hz or higher frequencies did not show any remarkable tendency.

4 Selection requirement of emission frequency/duty ratio

If both emission frequency and duty ratio of PWM LED lights with flicker are set to low, the light pulse train may not be visible as one light (continuous light). Therefore, lower limits should be set for the selection of emission frequency and duty ratio.

In order to make a light pulse train visible as one light (continuous light), the light pulse interval should be set within the time of visual afterglow.

The time of visual afterglow is 0.15 second as provided in “IALA Recommendation E-110 for the Rhythmic Characters of Lights on Aids to Navigation (May 1998)”.

In this survey research, the light pulse train of PWM LED lights with flicker was visible as one light by many of evaluators when its pulse interval was shorter than 0.1 second.

This result shows optimum values compared with 0.15 second as provided in “IALA Recommendation E-110 for the Rhythmic Characters of Lights on Aids to Navigation (May 1998)” while they vary between individual evaluators.

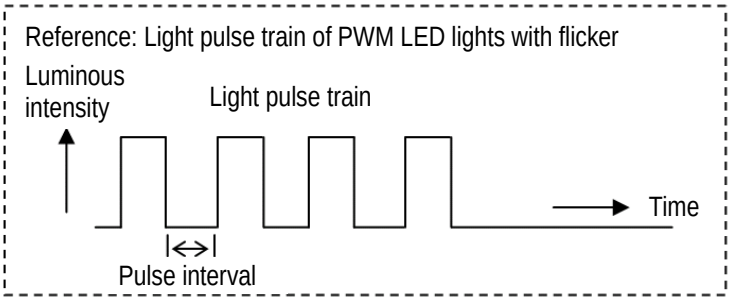


Table 4 shows pulse intervals of PWM LED lights with flicker when emission frequencies are 50 to 20 Hz (by 1 Hz) and duty ratios are 10 to 90% (by 10%). Combinations of emission frequencies and duty ratios when the pulse interval is shorter than 0.1 second are as shown in Table 4. This is the selection requirement of emission frequency and duty ratio.

Table 4. Combinations of emission frequencies and duty ratios when the pulse interval is shorter than 0.1 second

Emission frequency	Duty ratio	Pulse interval
5Hz	60% or higher	0.080s or shorter
6Hz	50% or higher	0.083s or shorter
7Hz	40% or higher	0.086s or shorter
8Hz	30% or higher	0.088s or shorter
9Hz	20% or higher	0.089s or shorter
10Hz or higher	10% or higher	0.090s or shorter

5 Laboratory experiment

The lower the emission frequency is and the lower the duty ratio is, the higher the conspicuity of PWM LED lights with flicker becomes. However there are lower limits of emission frequency and duty ratio which can be used for PWM LED lights with flicker. Therefore, a laboratory experiment was conducted to survey optimum emission frequency and duty ratio.

5.1 Experiment Method

(1) Date and Time: 13:00 to 17:00 on 21 February 2008

(2) Site: Japan Coast Guard (JCG) Research Center

(3) Evaluators: 7 persons consisting of JCG staff

(4) Specifications of equipment used in this experiment

Table 5 shows the specifications of equipment used in this experiment:

Table 5 specifications of equipment used in this experiment

Equipment	Specification	Model	Manufacturer
Experimental light source	Red LED (5mm)	OSHR5111A-TU	OptoSupply International limited
ND filter	Attenuation rate: 1/10	—	—
Controller	Analog I/O PC card Analog I/O BNC terminal block	DA16-8/2(CB)L ATP-8L	CONTEC Co., Ltd.
Control software	PWM Frequency: 5 to 25 Hz (variable) Duty ratio: 10 to 90 % (variable) Number of ports: 2	Original	JCG Research Center

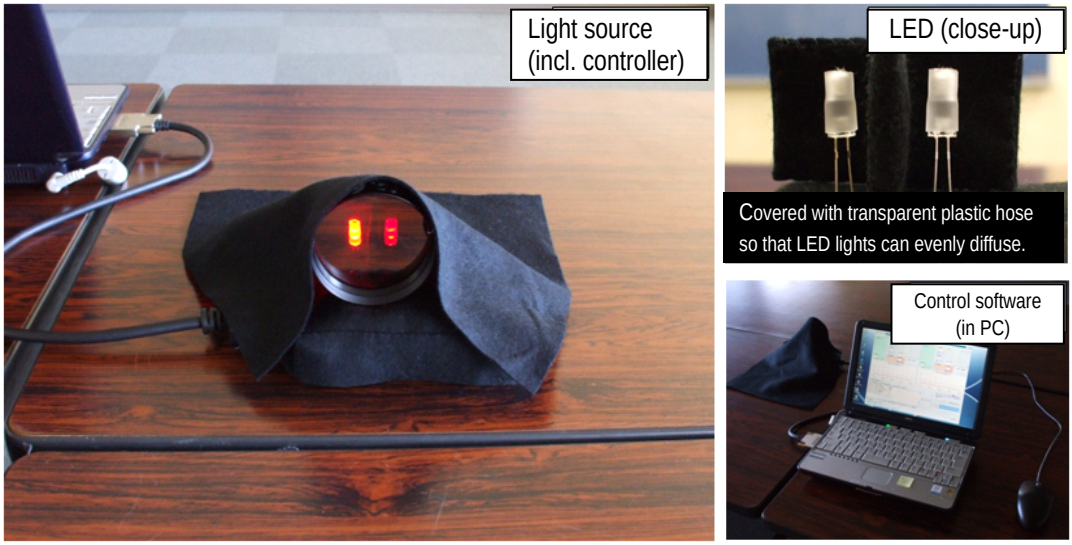


Photo 4. Equipment used in the laboratory experiment

(5) Allocation of experimental equipment, etc.

An experimental light source consisting of two LEDs was allocated on the meeting room of JCG Research Center and evaluated from distances of 3.5 to 4.5 m.

LED lights were Fl. 3 Sec. (within 0.4 second, red). The luminous quantity of LED was the same as that of the reference one.

Experimental conditions are as follows:

- Interior illuminance: 55 to 65［lx］
- Luminous intensity of experimental light source (LED):
  0.974×10^{-3} to 8.82×10^{-3}［cd］
- Brightness of experimental light source (LED):
  3.82 to 34.7［cd/m^2］(using ND filter)
- Chromaticity of experimental light source:
  x=0.6755 y=0.3118（minimum）
  x=0.6812 y=0.3188（maximum）
- Corneal illuminance of evaluators: 5.6×10^{-4}[lx]
  (Distance was regarded as 4m for the calculation.)
- Background brightness: 33.05［cd/m^2］

(6) Evaluation method

Two couples of emission frequencies and duty ratios were selected each time and two LEDs of the experimental light source flashed alternately to relatively evaluate the conspicuity.

Evaluated combinations of emission frequencies and duty ratios are shown in Table 6. The relative evaluation was conducted in round-robin

system.

Table 6. Emission frequencies and duty ratios evaluated in the laboratory experiment

	Emission frequency	Duty ratio
①	5Hz	60%
②	6Hz	50%
③	7Hz	40%
④	8Hz	30%
⑤	9Hz	20%
⑥	10Hz	10%

5.2 Results

Table 7 shows experimental results:

Table 7. Experimental results in the laboratory experiment

Emission frequency/Duty ratio	Reference: 5[Hz] 60[%]			6[Hz] 50[%]			7[Hz] 40[%]			8[Hz] 30[%]			9[Hz] 20[%]			10[Hz] 10[%]			Total			Score
	○	−	×	○	−	×	○	−	×	○	−	×	○	−	×	○	−	×	○	−	×	
5[Hz] 60[%]				0	1	6	1	0	6	0	0	7	1	0	6	0	1	6	2	2	31	−29
6[Hz] 50[%]	6	1	0				2	2	3	1	2	4	0	2	5	0	2	5	9	9	17	−8
7[Hz] 40[%]	6	0	1	3	2	2				1	3	3	0	2	5	0	2	5	10	9	16	−6
8[Hz] 30[%]	7	0	0	4	2	1	3	3	1				3	3	0	1	3	3	18	11	5	13
9[Hz] 20[%]	6	0	1	5	2	0	5	2	0	0	3	3				2	3	2	18	10	6	12
10[Hz] 10[%]	6	1	0	5	2	0	5	2	0	3	3	1	2	3	2				21	11	3	18

*○: Conspicuity is evaluated as relatively better.
−: Conspicuity is evaluated as relatively equal.
× : Conspicuity is evaluated as relatively worse.
Score is a total of ○(+1) and × (-1).

Highly-evaluated combinations of emission frequencies and duty ratios in the laboratory experiment were: 10 Hz + 10%, 8 Hz + 30% and 9 Hz + 20% in the order of descending scores.

6 “Irritation” by flicker

“Irritation” by PWM LED lights with flicker (emission frequency: 10Hz, duty ratio: 30%) was surveyed in the visibility experiment in the Port of Yokohama in November 2006 and the irritation caused by the flicker had insignificant effect to its practical use. Such irritation was not a problem in this experiment either.

The reason why the irritation was not a problem is because the brightness of LEDs was not glaring and the solid angle of LED lights in the field of vision was small.

Therefore, it seems “Irritation” by PWM LED lights with flicker has insignificant effect to its practical use for Aids to Navigation.

7 Discussions and Conclusion

The irritation caused by PWM LED lights with flicker has insignificant effect to its practical use for Aids to Navigation. Therefore, combinations of emission frequencies and duty ratios of PWM LED lights with flicker which obtain higher conspicuity can be preferentially selected.

The effective luminous intensity of lights and the pulse interval of light pulse train which comprises flashing time, sort of the slit within the duration of the light seem to be elements to enhance the conspicuity. The emission frequency and duty ratio which obtained the highest conspicuity in this survey research was 10 Hz and 10% respectively, and the evaluation level was nearly equal even duty ratio changed to 20 or 30%.

It is preferable to set the duty ratio as high as possible from the viewpoint of designing and manufacturing lanterns. The optimum combination of emission frequency and duty ratio which makes the size of lanterns as small as possible and obtains high conspicuity is 10 Hz and 30%.

PWM LED lights with flicker seem different from conventional LED lights due to the flicker. For the solution to the problem of how to show as expected light character, it is necessary to inform all navigators about the light character avoiding misunderstandings. We propose to append a note “with flicker” to the light character as one of solutions.