Visibility of LED Lights with Flicker

Japan Coast Guard
Japan Aids to Navigation Association

Summary

Focusing on the outstanding luminescence property of a light emitting diode (LED), this research explores the potential application of LEDs as a measure to enhance the visibility of Aids to Navigation (AtoN) which are mixed up with their background lights.

It was found that the improvement of AtoN both in conspicuity * and recognizability by employing LED lights with flicker.The most significant enhancement was observed at around one-mile distance when using the lights equivalent to the conventional lantern for three-mile range (the most popular one in harbor areas).

In sum, the LED lights with flicker are promising for the application to AtoNs requiring countermeasures against background lights.

＊ "Conspicuity" described in this paper means the state that something stands out well from its surroundings.

1 Introduction

Flashing lights with flicker are known for having a unique stimulus to the optical sensation of human beings and, as a result, they have better visibility.

On the other hand, LED lights in today's market have an excellent electrical response and are able to produce flashing lights with a crisp square waveform. For example, LED lights with flicker can be easily realized by using a Pulse Width Modulation (PWM) method.

Japan Coast Guard (JCG) and Japan Aids to Navigation Association (JANA) jointly organized a study committee comprising individuals from the community of scholars and maritime fields to focus on the visibility of the LED lights with flicker and to implement the research for the utilization of the LED lights as the lights for AtoN. JCG and JANA hereby report the result thereof.

2 Research Items

(1) Comparison of standard (conventional) LED lights and the LED lights with flicker in terms of visibility. (Conspicuity, recognizability , Irritativeness, and brightness)

(2) Measures to utilize the LED lights with flicker.

(3) Future Tasks

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3 Visibility Experiment

This research includes a visibility experiment to compare the standard LED lights and the LED lights with flicker in the Port of Yokohama as it has ample background lights.

(1) Overview

Date and Time of the Experiment: 16:30 to 20:00 on November 30, 2006

Site: Port of Yokohama

Weather: Clear

Evaluators: 20 men (mean age: 50) with VA examination results from 0.7 to 1.5 (or around 20/30 to 20/15) (with or without correction)

Eye elevation: The elevation of evaluators' eyes was set to a level equivalent to the height of the lights.

Evaluation Ranges: 300 meters, 0.5 nautical mile, 1.0 nautical mile, 1.5 nautical mile and 2.0 nautical miles.

(2) Experiment Method

Two lights mounted on a pier were observed by the evaluators from a ship.Tow lights were lit alternatively.

(3) Emission Requirement for Lights (Figure 1)

Emission conditions for the standard LED lights and the LED lights with flicker were as follows.

Condition A: Two lights being at the same brightness

Condition B: Two lights being at the same luminous quantity

Condition A was achieved by adjusting brightness of the lights in a preliminary experiment by five AtoN engineers at the site.

AtoN engineers: 5 men (mean age: 48) with VA examination results from 0.9 to 1.5 (or around 20/22 to 20/15) (with or without correction)

[Condition A (Same brightness)]

(1) Standard LED lights

a. Light Character: Fl. R. 3 Sec.
b. Duration of light: 0.4 second
c. Luminous intensity in the holizontal direction : 155cd
d. Waveform of lights: See Annex 1

(2) LED lights with flicker

a. Light Character: Fl. R. 3 Sec.
b. Duration of light: 0.4 second
c. Luminous intensity in the holizontal direction :
   511cd at 300 meters, 542cd at 0.5 mile to 2.0 miles
d. Emission frequency of PWM: 10Hz

e. Duty ratio of PWM: 30%

d. Waveform of lights: See Annex 1

[Condition B (Same luminous quantity)]

(1) Standard LED lights

a. Light Character: Fl. R. 3 Sec.

b. Duration of light: 0.4 second

c. Luminous intensity in the holizontal direction: 155cd

d. Waveform of lights: See Reference 1

(2) LED lights with flicker

a. Light Character: Fl. R. 3 Sec.

b. Duration of light: 0.4 second

c. Luminous intensity in the holizontal direction: 511cd

d. Emission frequency of PWM: 10Hz

e. Duty ratio of PWM: 30%

d. Waveform of lights: See Annex 1

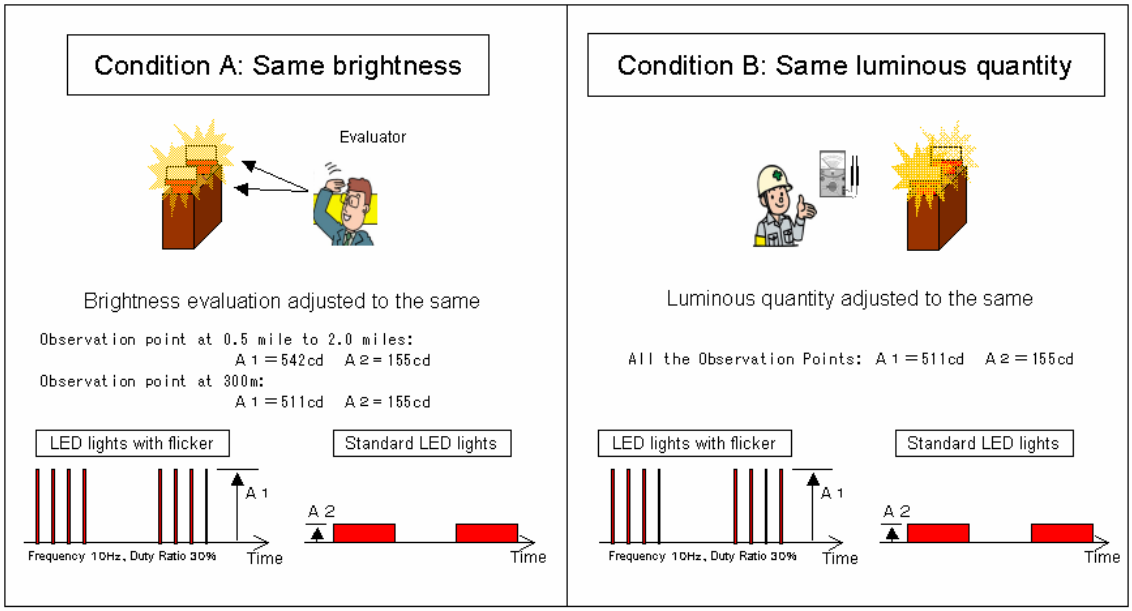


Figure 1: Emission Conditions

(4) Lanterns Used in the Experiment

Annex 2 shows the figures of lanterns used in this experiment.

Luminous intensity in the horizontal direction of each lantern was as follows.

Standard LED lights: 155cd

LED lights with flicker: 511cd/542cd (switchable)

Table 1 shows the specification of LEDs used in this experiment.

Table 1: LED Spacifications.

Item	Color	Standard	Manufacturer	Remarks
LED	Red	NO5FVWAC-23 5mmφ Transparent Bullet LED Viewing Angle: 23°	NANOTECO Corporation	Chromaticity and Spectrum are shown in Annex 3

(5) Evaluation Items of Visibility Experiment

Evaluation Items comprise conspicuity, recognizability, “irritation” by flicker and brightness of the lights.

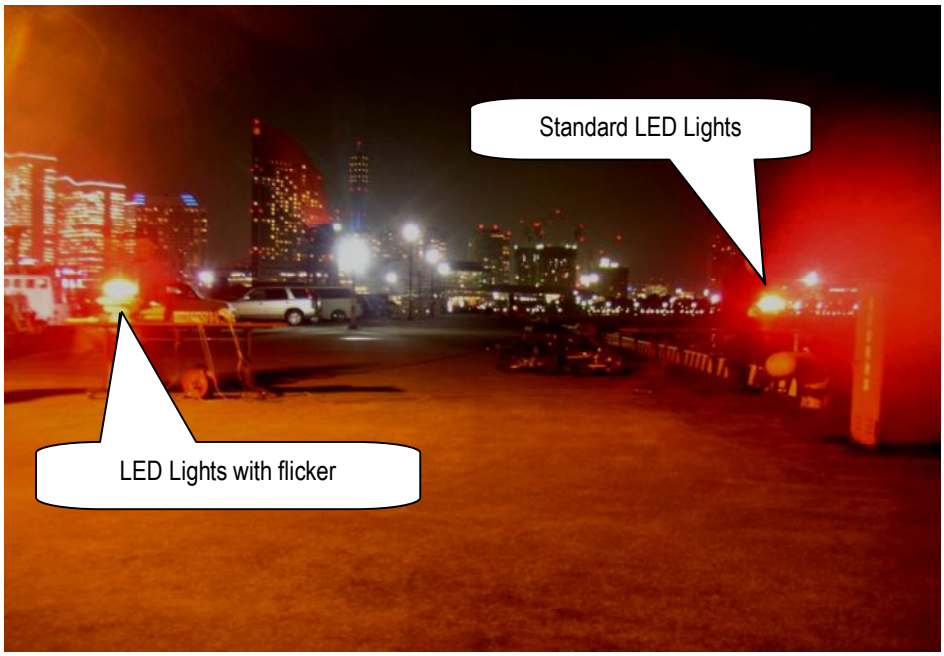
Conspicuity: The LED lights were comparatively evaluated under the condition with background as to which one is more attracting attention of evaluators (i.e. outstandingness and/or detectability.)

Recognizability: The LED lights were comparatively evaluated as to which one is more distinguishable from the other lights inclulding background lights of AtoN.

“Irritation” by flicker: A psychological effect (flickering effect) that may be imposed on ship crews by the lights with flicker was evaluated (by including a question asking whether the evaluator feel obnoxiousness when he/she see such flickering lights while operating vessels.)

Brightness: Two LED lights were evaluated as to which light looks brighter .

(6) Experiment Site



(a) Installation of Lights

(b) Lights from the Evaluators' Points of View

Figure 2: Experiment Site

Experiment Site: Port of Yokohama

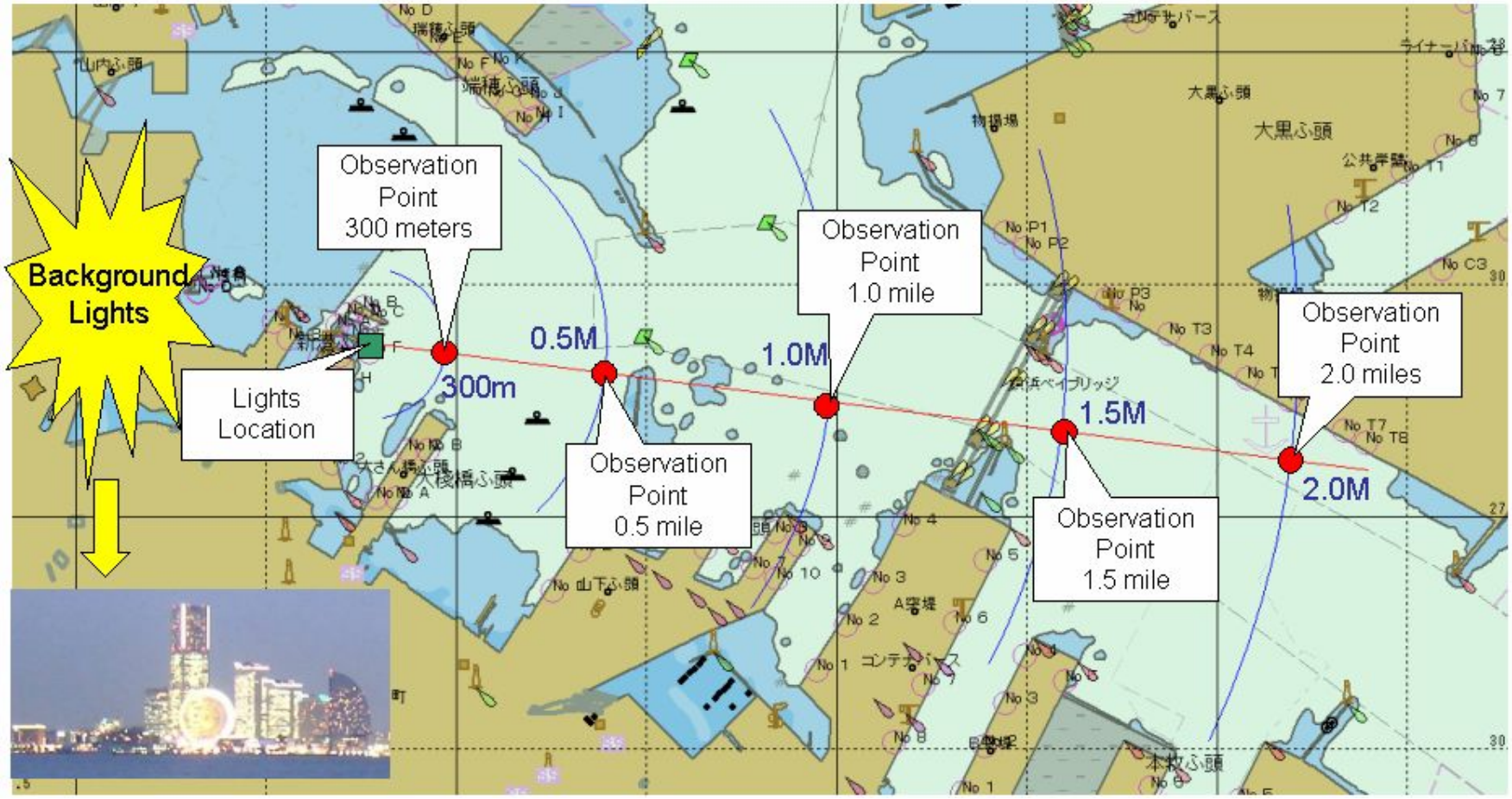


Figure 3: Locations of Lights and Observation Points

4 Results

(1) Conspicuity and Recognizability

For conspicuity and recognizability evaluations, a point system was used. The system counts the answer “LED lights with flicker is better” as 1 point, the answer “Both LED lights appear to be the same” as 0 point, and “The standard LED lights is better” as -1 point for the respective ranges. Average points (i.e. Σ(evaluation points x number of evaluators)/number of evaluators) were then calculated for the respective ranges with the aggregated points. Figure 4 shows the average scores plotted on a graph.

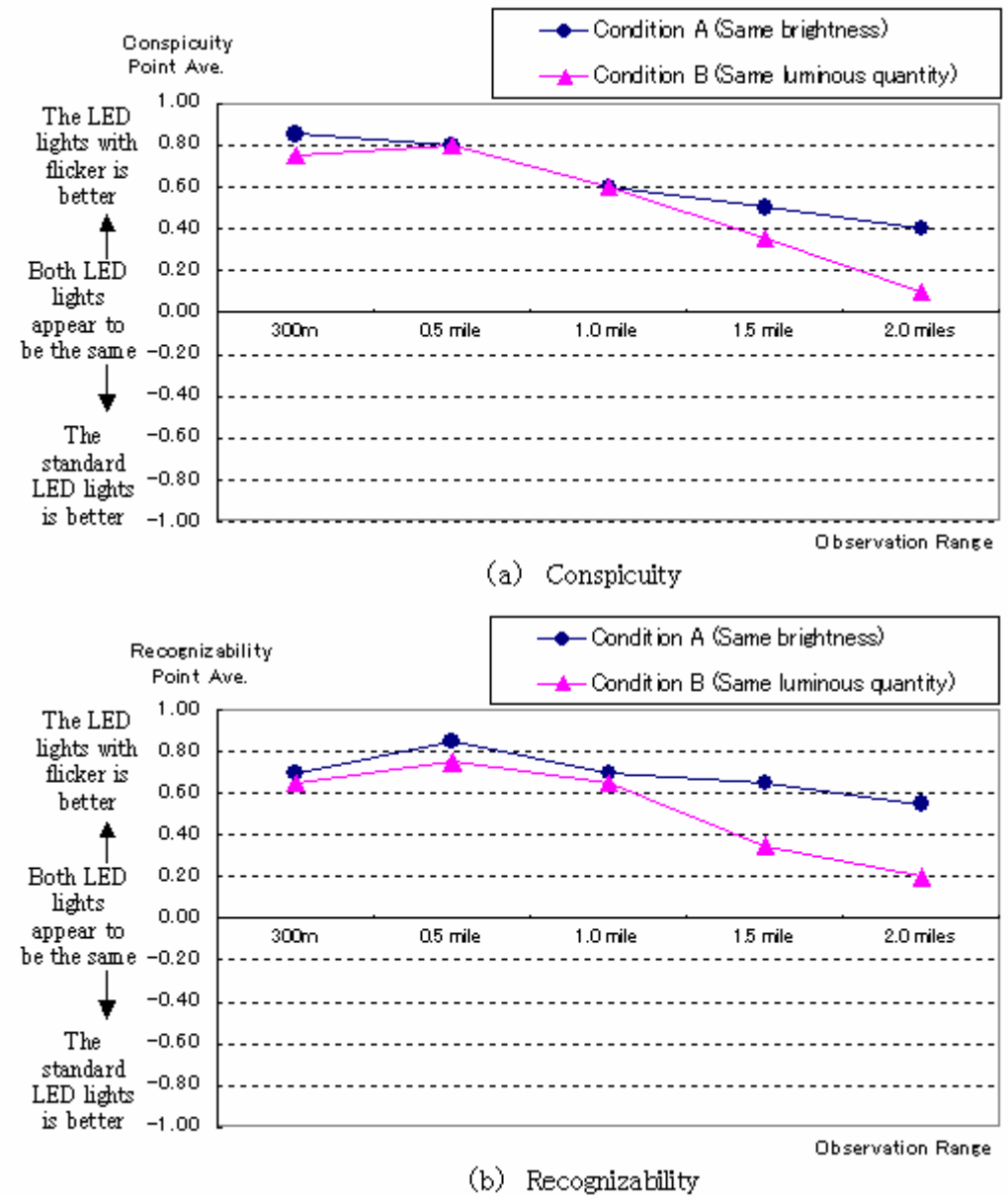


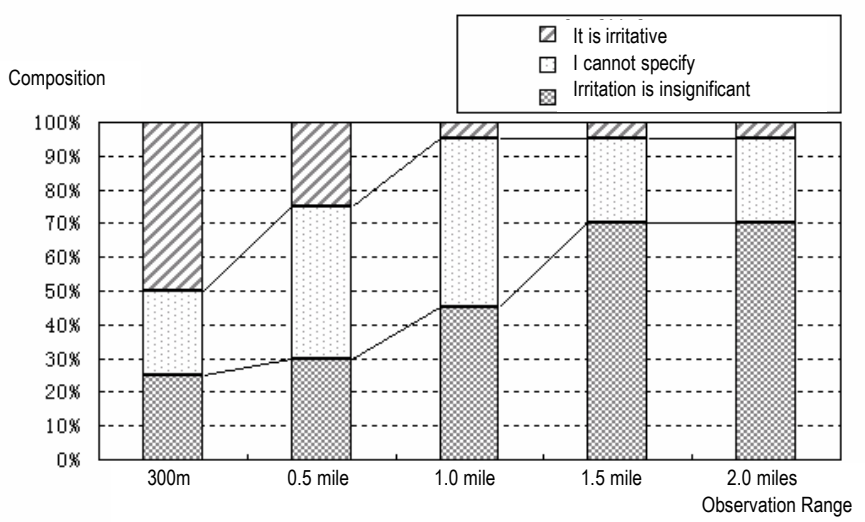
Figure 4: Averages Points of Conspicuity and Recognizability Evaluations

Both evaluations shared the same trend , that is the LED lights with flicker added more superiority as the evaluation point got closer to the light source. The LED lights with flicker outperformed within one mile, and were proved to be less effective at the range of 1.5 mile and at 2.0 miles under the predefined Condition B (same luminous quantity).

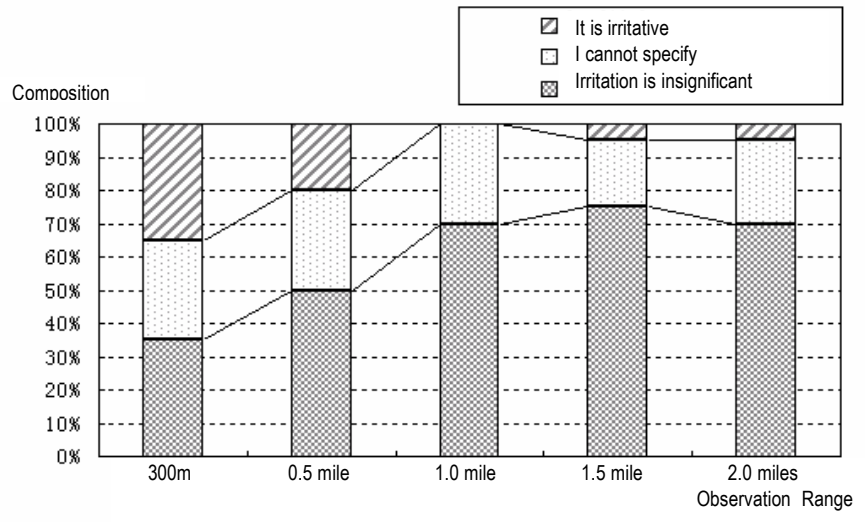
The results under the Condition A (same brightness) the LED lights with flicker had more light quantity, attracted more points than the results under the Condition B (same luminous quantity).

(2) “Irritation” by Flicker

Figure 5 shows the results of the irritativeness evaluation under Conditions A and B in separate graphs.



(a) Irritativeness under Condition A (Same brightness)



(a) Irritativeness under Condition B (Same luminous quantity)

Figure 5: Irritativeness Evaluation

The results show that the proportion of the answer “irritative” increased as the range got closer to the light source. Merely less than 5% (or one evaluator) answered “irritative” at the ranges longer than 1.0 mile, whereas the same answer was still less than 50% at the shortest range of 300 meters in this evaluation.

Also, the evaluation results under the Condition A (same brightness) and the Condition B (same luminous quantity) exhibit difference in 300-meter range, whereas both evaluations were conducted under the identical luminous intensity setting. The unidentified cause of this difference was presumably changes in other conditions such as observation distance or elapsed experiment time. In addition, the glare of the lights might play a significant role in the evaluation in the shorter ranges.

(3) Brightness

As for the brightness evaluation under the Condition B (same luminous quantity), the point system mentioned above was also used Figure 6 shows the average scores plotted on a graph.

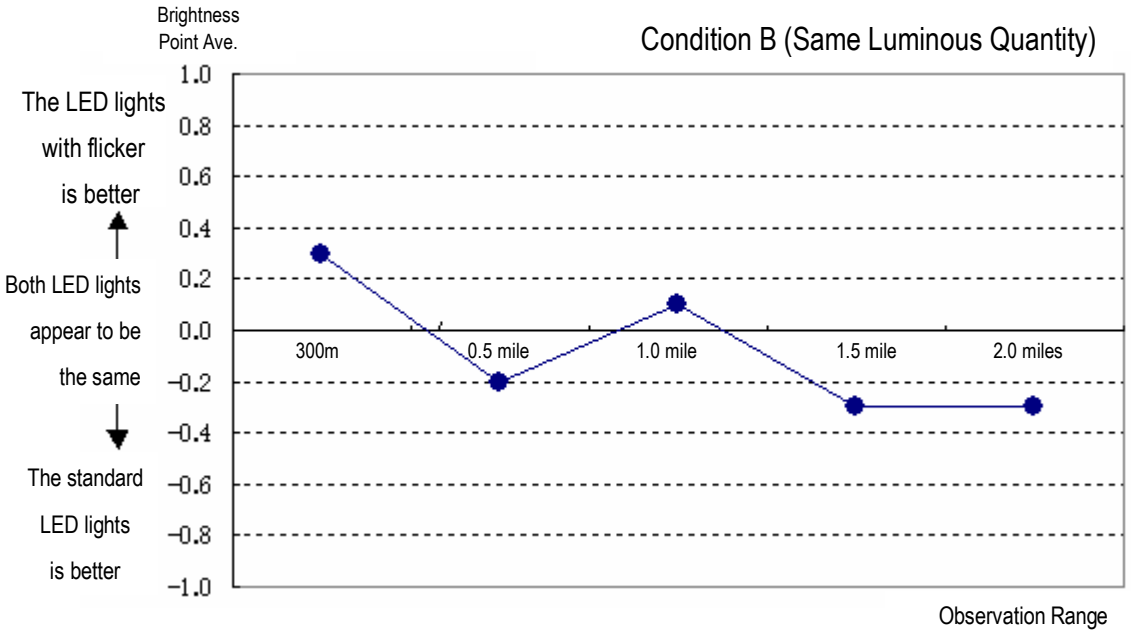


Figure 6: Comparison between the LED lights with flicker (Fl 3s) and the standard LED lights (Fl 3s) in terms of brightness

The evaluation results revealed the tendency that the LED lights with flicker appeared to be darker than the standard LED lights as the distance increased. However, the evaluation point for the LED lights with flicker still stands at -0.3 point (or 7 out of 10 evaluators answered “Both LED lights appear to be the same”) at 2.0 miles , indicating that the brightness of the LED lights with flicker was still at the level equivalent to that of the

standard LED lights.

Figure 7 shows the result of the comparison between the LED lights with flicker (Fl 3s) and the LED lights (Fixed). The comparison was implemented as a part of a preliminary experiment to determine the Condition A (same brightness) for this experiment. The same point system as mentioned earlier was used for the preliminary experiment results retrieved from five evaluators participated. Figure 5 shows the average scores plotted on a graph.

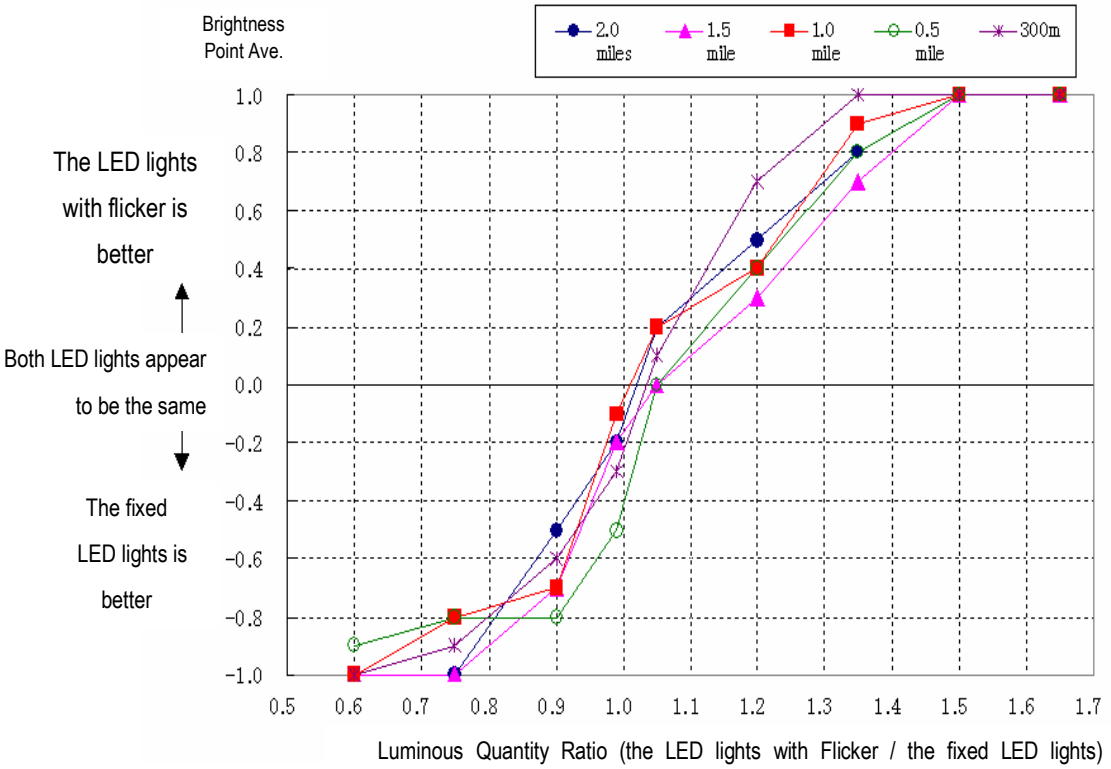


Figure 7: Comparison between the LED lights with flicker (Fl 3s) and the LED lights (Fixed) in terms of brightness

The LED lights with flicker at 99 % luminous quantity of the LED lights (Fixed) was evaluated as “slightly darker” whereas the LED lights with flicker with 105 % luminous quantity of the LED lights (Fixed) was evaluated as “slightly brighter” in all the ranges where evaluation was implemented for the preliminary experiment.

5 Conclusion

The following are the findings with respect to the characteristics of the LED lights with flicker which have been identified in comparison to the standard LED lights.

(Conspicuity and Recognizability)

(1)The good influence of flicker effect was enhanced more in shorter ranges, and very high improvement level (i.e. six out of ten evaluators answered that the LED lights with flicker was “superior”) was achieved within 1.0 mile.

(2)The improvement effect was not significant (i.e. six out of ten evaluators answered , “Both LED lights appear to be the same”) at 1.5-mile and 2.0-mile ranges in case of luminous quantity equivalent to the LED standard lights for 3-mile range (155cd.) However, a tendency to increase its effect with additional luminous quantity was identified.

(“Irritation” by flicker)

(1)Majority answered the irritativeness was "insignificant” at the range from 1.0-mile to 2.0-miles.

(2)The irritativeness increased as the observation point got closer to the light. However, the evaluator answered “irritative” remained less than 50% at 300-meter range.

(Brightness)

The LED lights with flicker appeared to be slightly darker at longer ranges when the luminous quantity was equal to that of the standard LED lights, the extent of which is nominal (i.e. three out of ten answered “The standard LED lights is better” and remaining seven answered “Both LED lights appear to be the same,") and which should be rather construed as the both LED lights were appeared to be the same with almost the same amount of luminous quantity.) However, this experiment being a fieldwork where detailed conditions such as atmospheric permeability could not be controlled, the findings should be confirmed by laboratory experiments where certain conditions are easily achievable in order to attain more accuracy to the findings.

The research was implemented in an area of Port of Yokohama because it had ample background lights. An evaluation experiment at surface level was conducted at ranges from 300 meters to 2 miles with lanterns equivalent to the conventional lights for 3 miles for the investigation of the anti-background effect thereof. This research confirmed that the conspicuity and recognizability of the LED lights with flicker were superior to the standard LED lights. The superiority was significant at ranges within one mile. In addition, the irritativeness (obnoxiousness) caused by the flicker had insignificant effect to its practical use. Furthermore,

the brightness of the LED lights with flicker was proved to be the equivalent of the brightness of the standard LED lights with almost the same luminous quantity. Finally , the increment in the peak luminous intensity of the LED lights with flicker resulted in a significant improvement at the cost of more irritativeness at shorter ranges.

6 Possible Measures to Utilize LED Lights with Flicker.

LED lights with flicker have a significant possibility for the application to AtoNs requiring measures against background lights. On the other hand, a bright light with flicker may also cause irritativeness.

The available operational range and irritativeness level of the light with flicker vary depending on the frequency and duty ratio of PWM. Furthermore, the size and price of the lantern vary depending on the duty ratio of PWM.

Therefore, the utilization of LED lights with flicker requires appropriately configured luminous intensity, frequency and duty ratio of PWM.

7 Future Tasks

(1) Confirmation of the brightness of the LED lights with flicker

In the field test, the LED lights with flicker were proved to have the luminous quantity equivalent to the standard LED lights, and to appear to be the equivalent brightness compared to the standard LED lights. However, it is needed that the confirmation of the results in laboratory tests where reproducibility of various conditions is available.

(2) Method for the measurement of effective luminous intensity for lights with PWM

Since the calculation method of effective luminous intensity for the lights with PWM has not established yet the evaluation of luminous intensity must be continued.

(3) Determination of the appropriate duty ratio and frequency of PWM

Along with its superior conspicuity and recognizability, the LED lights with flicker also imposes irritativeness, which calls for appropriately assigned frequency and duty ratio.

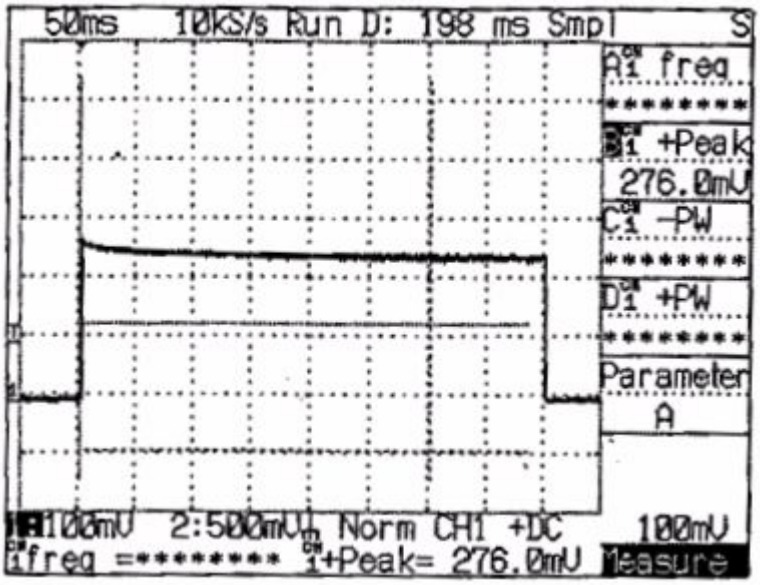
(4) Study on the application of the LED lights with flicker

Based on the study in the item(3) the scale of the light (luminous range) and the specific applications for AtoN must be determined.

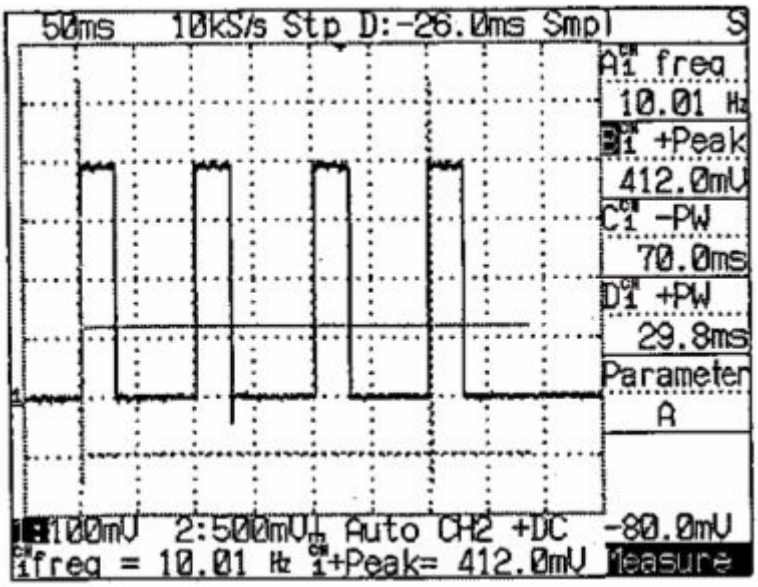
(5) Other applications of the LED lights with the PWM

This research focused on the LED lights with flicker using PWM lighting method. However, PWM lighting method facilitates the modulation of the light and therefore application to the other character of light “fixed and flashing light” (FFl),will be studied.

Annex 1: Waveforms of the LED Lights



(a) Standard LED Lights

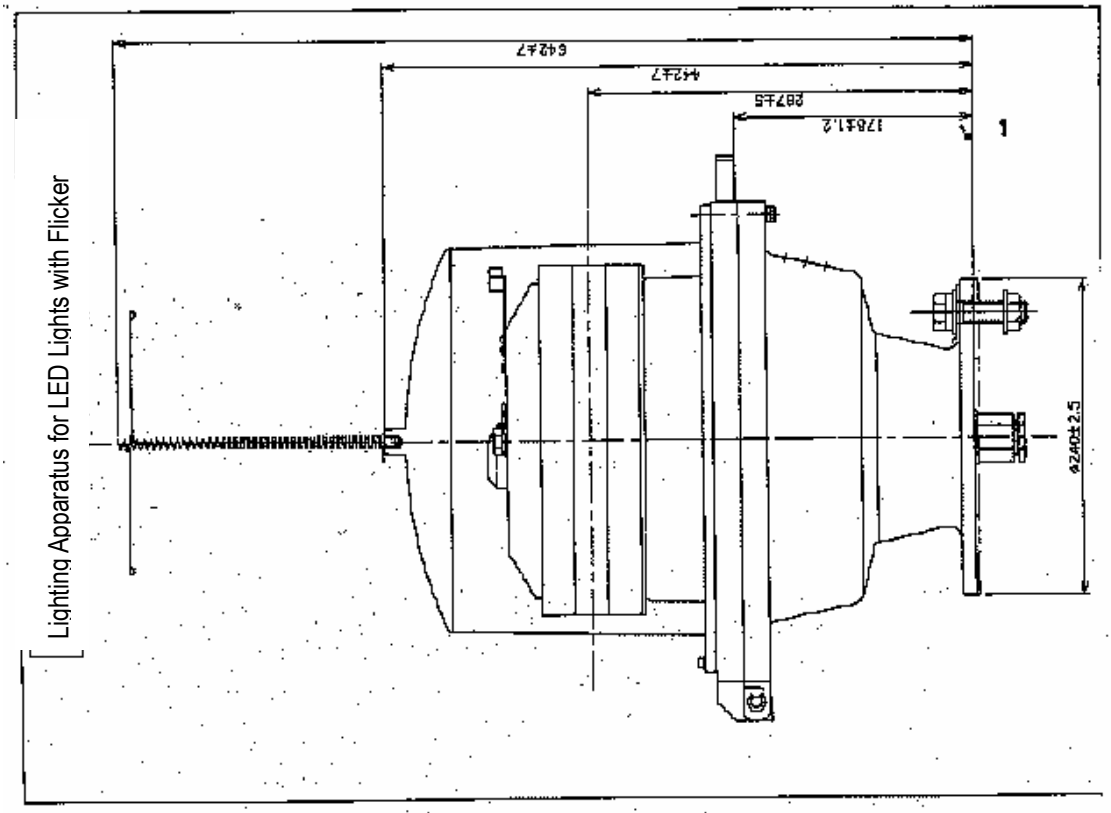


(b) LED Lights with Flicker

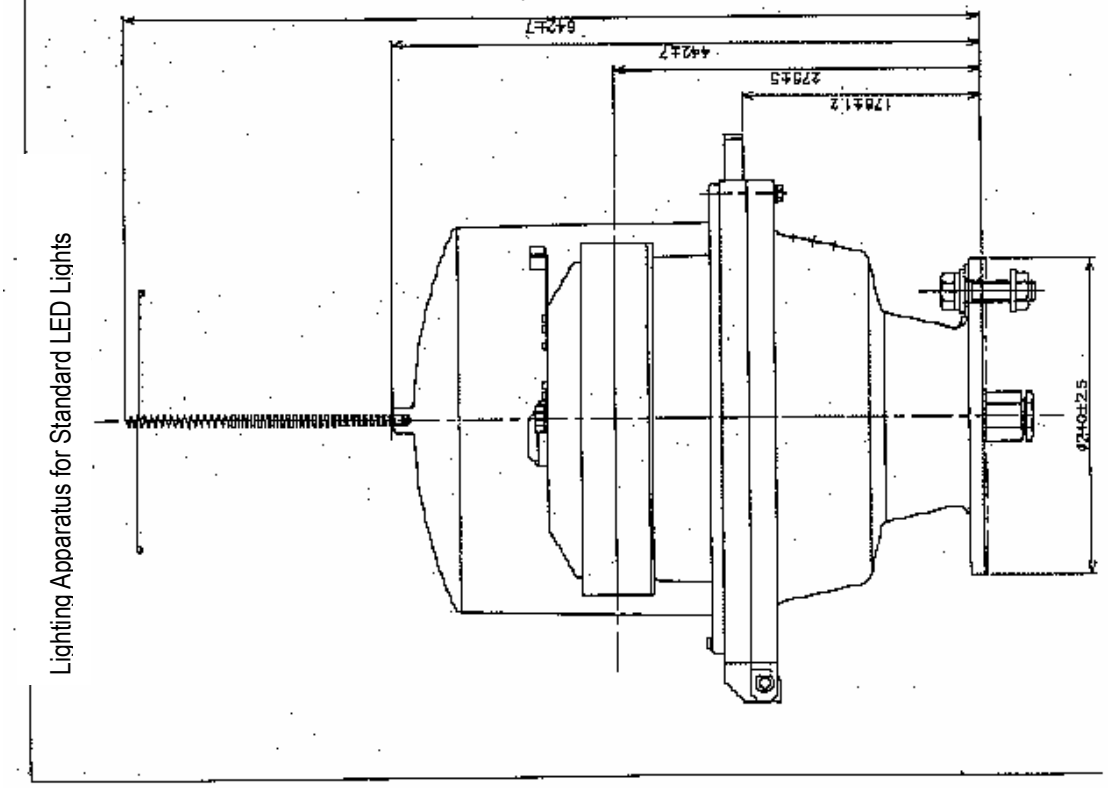
Measurement Device: Topcon photo-cell illuminometer (PI-301)
Measurement Distance: 30cm
Recorder: IWATSU DS-8812
Duration of flashing: 0.4 second

Annex 2: Lanterns for the Experiment

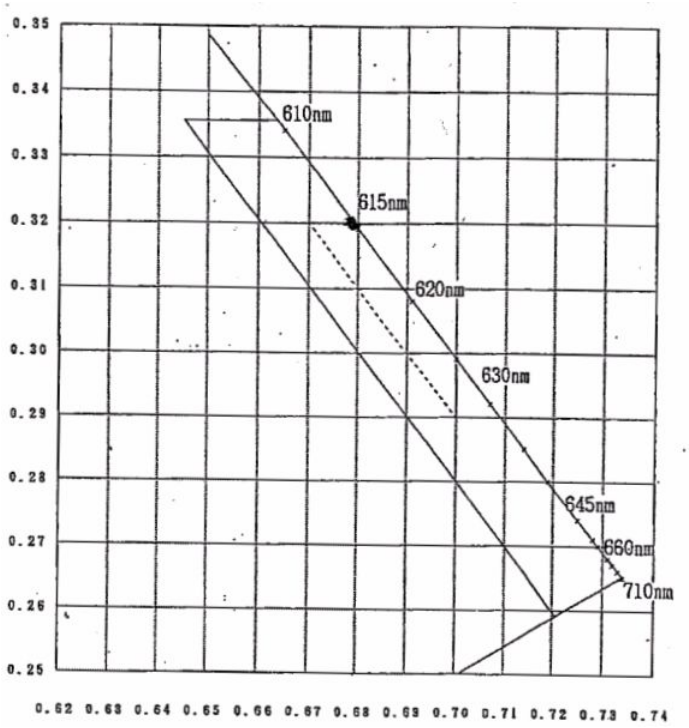
Lighting Apparatus for LED Lights with Flicker



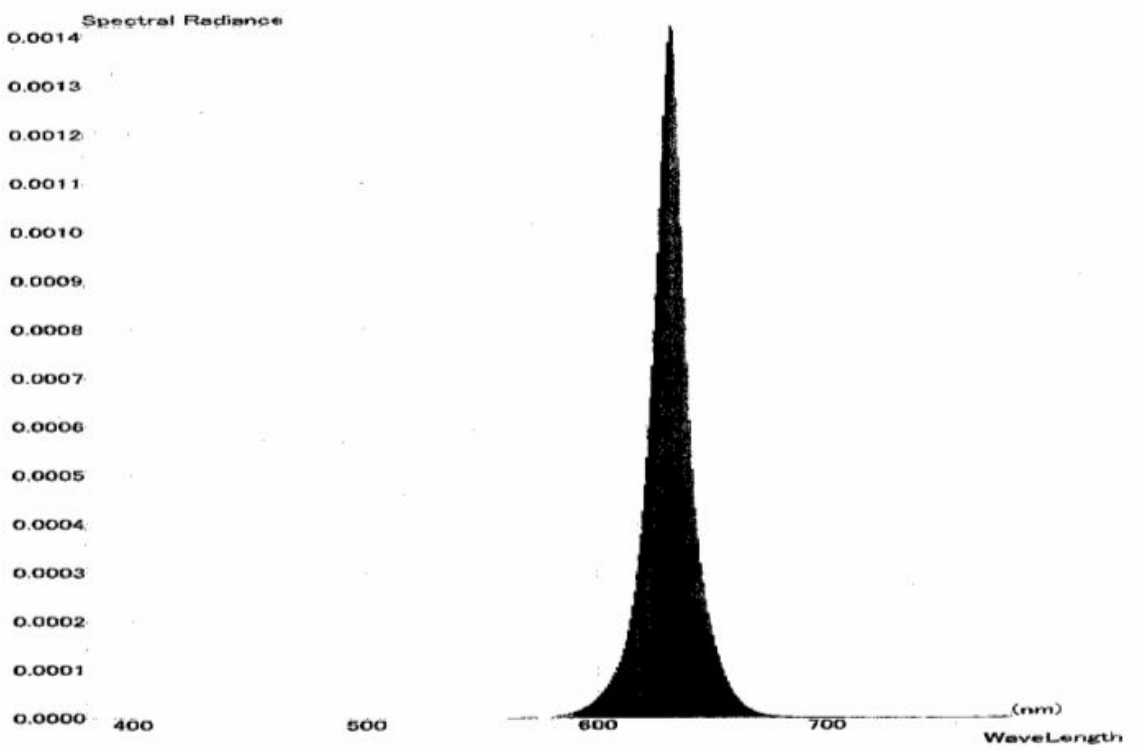
Lighting Apparatus for Standard LED Lights



Annex 3: Chromaticity and Spectrum of Red LED Used in the Experiment



(a) Chromaticity [x=0.679, y=0.320]



(b) Spectrum