EEP15/11/5

Simulation for Establishment of Visible Light Communications technology

Japan Coast Guard

1. Introduction

(1) History, etc.

Visible Light Communications is the most advanced communications technology using "Visible Light", which is "the data communications method by which light from a lighting apparatus light source is modified".
The characteristics include:

a. No regulations apply as for radio communications such as limitations to frequency bands.
b. The original location of data (light) is easily recognizable.
c. Safe and trustworthy to use as wiretapping is not easily conducted.
d. Lights in homes, etc., which are already everywhere, could be used by the devices to set up a network.
e. Harmless to the human body and electronic devices.

The purpose of the Visible Light Communications Consortium (hereinafter referred to as "VLCC") is to research, develop, plan, standardize and widely disseminate this high-speed, safe and ubiquitous telecommunications system from Japan for Communications by using waves of visible light (brightness of the light) while using a visible light element for lightings, signals, digital displays and notices, etc., and was founded in November 2003 by the collaborators of the Industry-Academia-Government.

We have been studying the possibility of utilizing the technology of Visible Light Communications (hereinafter referred to as "Visible Light Communications Technology") for transmitting information from the aids to navigation. "Lighthouse Sub Project" (hereinafter "Project" is referred to as "PJ"), as a part of the Social System PJ, was established by joining VLCC on September 2007 and originated by getting information from VLCC during 2006.

Effectiveness in reducing collisions by small vessels such as pleasure boats and fishing boats, etc. (prevention of collisions with aids to navigation and between vessels, etc.) has been the issue for Lighthouse Sub PJ till last year, in which Visible Light Communications Technology is applied for breakwater light or lighted buoys, etc. to transmit information to vessels, or between vessels to communicate and transmit information. As a part of the effort, a long distance communications test was conducted successfully as the furthest communications ever tested in the world at the 2 km point with a speed of 1,022 bps*1, and at the 1 km point with a speed of 1,200 bps with the information transmitted by LED lanterns (LED light). As a result, the possibility of communication by image sensor*2 was confirmed in this comprehensive evaluation at Kujukuri Hama, Chiba prefecture, in October 2008.

*[1] Bits per second. A unit of measurement used in data transfer. It can be used, for example, in communications circuits. 1 bps means 1 bit of data is transferred per second. The 'bit' is the basic unit of information in computing, usually denoted by 0 and 1.

*[2] Image sensor. A large conglomerate of photodiodes works as a device that is used mostly in digital cameras. The photodiode is often referred to as a pixel with the benefits including "having multiple communications channels (the same number of pixels) which makes one-to-multiple communications possible", "easy to spot the location of the origin of the transmission (light)" and "long-distance communications", etc.

(2) Activities, etc. in 2009

The main objective focusing on the technology for Lighthouse Sub PJ for this year and later is to define the possibility of accurate data transmission (data including location, weather and condition of devices between lighthouses and vessels, and isolated information or information, etc. regarding prevention of collision between vessels), by capturing the source light with an image sensor while vessels are rolling over the seas, and is the key between lighthouses and vessels, and between vessels to communicate successfully.

There are some unknown technological issues such as vibration and tracking (tracking of origination of light) in order to utilize Visible Light Communications during rolling and pitching motions. It is concluded that the rolling and pitching motions of vessels on the actual seas should be examined and analyzed to study the possibilities. We have gained a sense of the possibility of effective communications in the moderate rolling and pitching motions according to the images of the lights of the vessels which were anchored at night, the vessels navigating the course during the daytime and aids to navigation, which were taken by the "Tsushima, aids to navigation evaluation vessel", in May 2009.

A demonstration test evaluating Visible Light Communications was conducted in our circulating water tank using a model vessel prior to the test on site.
The main purposes of the simulation were to get a sense of the conditions of vessels under rolling and pitching motions, to see the possibility of Visible Light Communications and to validate the effectiveness of a tracking function for an image sensor on rolling and pitching vessels.

The simulation methods and other factors using an actual vessel could be considered when there was a possibility of utilization as a result of this simulation. But the demonstration test would be conducted again when the possibility was not found while analyzing functions and capabilities that may not be sufficient.

Data for roll and pitch angle and acceleration obtained from the demo may be similar to that of the actual vessels, but wave cycle and vessel's motion cycle have to be in compliance with the similarity rule*[3] due to the size of the model vessel (the cycle would be shorter than for an actual vessel), which has been agreed upon by Lighthouse Sub PJ. The distance from the light source to the model vessel is a max. of approx. 30 m in the circulating water tank which makes approx. 390 m in the actual sea according to the scale of the model vessel (one- thirteenth). This distance is within the range of monitoring aids to navigation, but on the other hand, an agreement was made prior to the test about the fact that it is not an appropriate distance for general users to collect information.

*3 Similarity rule. The standard by which criteria for the model must be compromised due to the similar behavior of the model and the actual object (original shape, originals). " Inertial force" and "gravity" would be the predominant factors in physical law in this case, thus "Froude's Similarity" is to be followed. The scale of the model is one-thirteenth and the t is motion cycle which indicates time and **t** indicates the time of actual vessel that can be calculated as follows: The time of actual vessel is 3.6 times more than the model that is described as √13.

$$\mathbf{t} - \sqrt{13} \cdot t$$

2. Simulation of Visible Light Communications in a circulating water tank

2-1 Objective, etc.

This test was conducted based on the data of wave monitoring in Tokyo bay by changing the direction of the waves against the model to see the possibility of the communications.

As mentioned earlier, there was a concern for the sensor on the model vessel of tracking origination of light (tracking function), following capability (recovery function) after loss (receiving failure) and etc., since the motion cycle for the model is shorter than that of the actual vessel. The long-period waves, which don't occur too often in Tokyo bay, were added to the action of the demo in order to create the conditions as similar as possible to the actual sea to reflect the motions of the model vessel.

2-2 Date

December 24th (Thurs) , 2009, 13:00 to 17:00
Prior test to this demo was conducted to check procedure or problems, etc. for the test, on December 4th.

2-3 Location

Circulating water tank at Japan Coast Guard Research Center

2-4 Attendants

Japan Coast Guard Research Center, VLCC administration, Toshiba Corporation, Casio Computer Co., Ltd., NEC Corporation

2-5 Simulation methods, etc.

(1)Connect the PC which controls the demo on the gauge trolley and the camera panhead, image sensor and video camera with cables, respectively, which are mounted on the pole pod on the model vessel. Image sensor and PC are prepared by the attendants.

(2)Place the light source (location of signal －lighting and communications control unit) in the appropriate location. The light source is set by the respective attendants.

(3)Create waves to roll and pitch the model, and check the receiving status.
The laboratory measures wave cycle and wave height. Motion cycle is measured manually and the roll and pitch angles are calculated based on video images or the angle of view of the image sensor (vertical) and the recorded images.

(4)Gather the results from each attendant.

See Fig. 1 for simulation diagram, Fig. 2 shows positioning.

Simulation diagram (Circulating water tank at Japan Coast Guard)

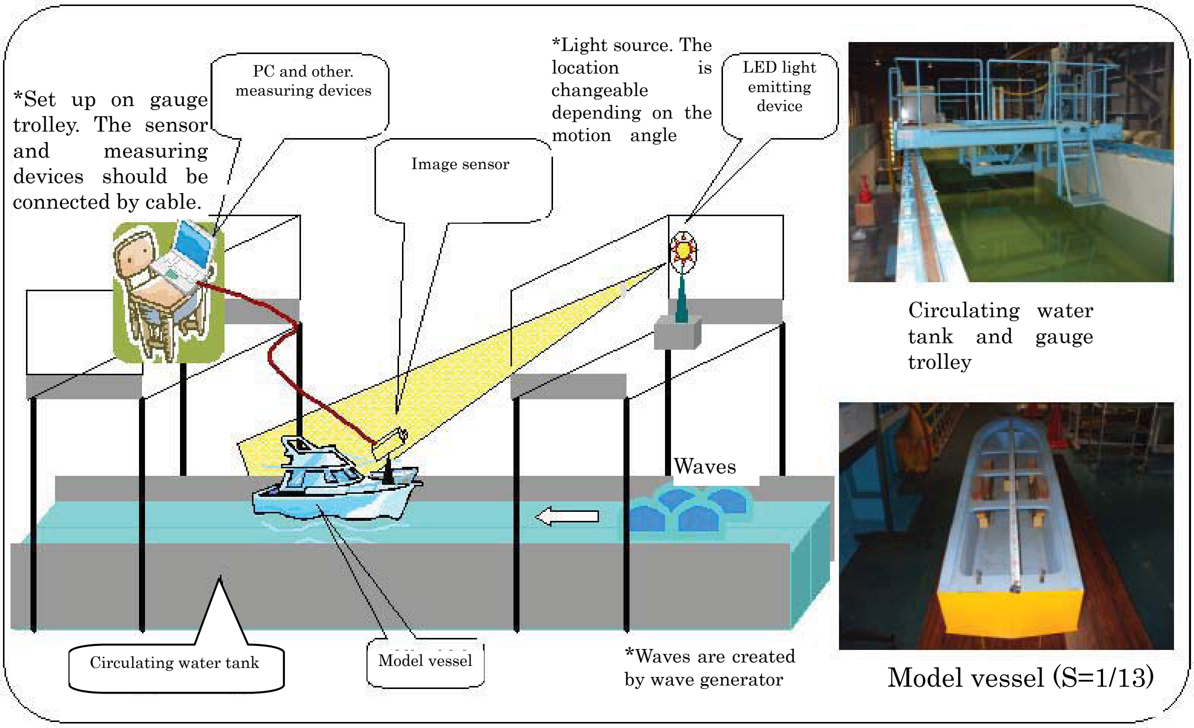

Fig. 1 Simulation diagram

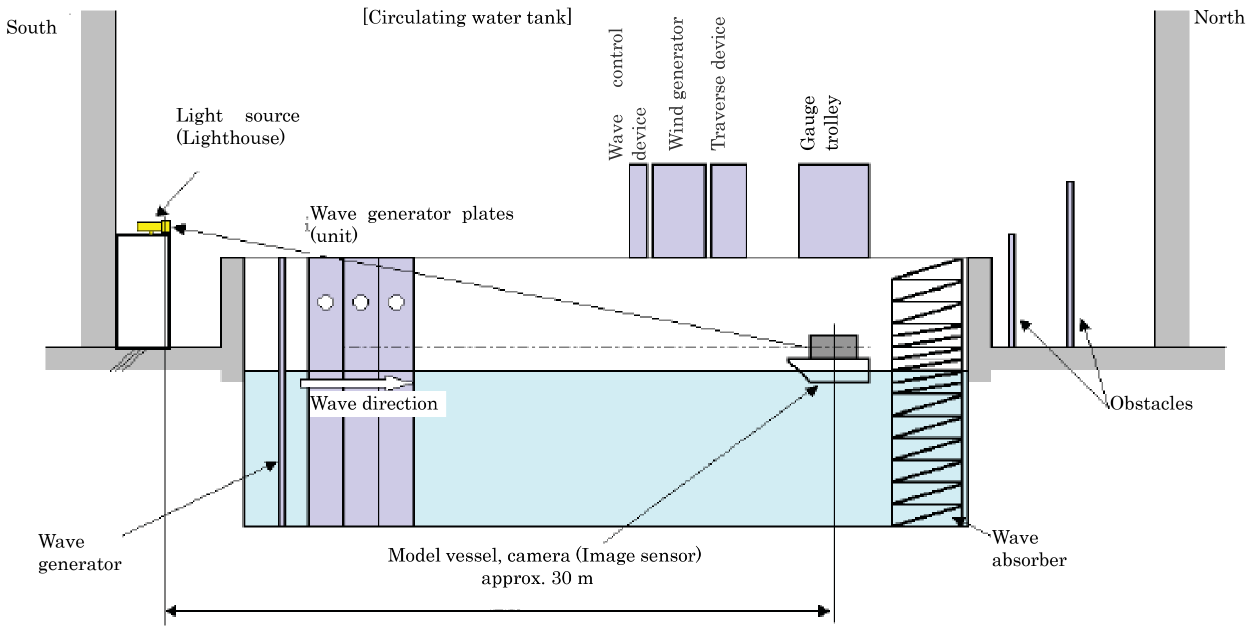

Fig. 2 Positioning

*The bow of the model vessel should point toward the oncoming waves (wave generator) directly under the gauge trolley (45° to the right for the waves with oblique angles) by 4 points fixed positioning. Image sensor tracks the light source (origin of the signal) by the south wall, which is the direction of the waves' approach (origin of the waves). In this case, the light source should be set at about 1.2 m above the floor. The angle of the sensor should be adjusted appropriately to the direction of the light source, since it is above the model vessel. Rolling motion can be measured as it is.

3. Specifications of the model vessel which is used for the simulation

(1) The model of the patrol boat 20 m in length (1/13) with the specifications in Table 1 (extracted from the production specifications)

Table 1 Model vessel specifications

Length (length of water line)	1.5 m
width	0.365 m
Depth	0.187 m
Draught in front	0.093 m
Draught in back	0.049 m
Average draught	0.071 m
Rolling motion cycle	1.05 to 1.09 sec. (equivalent to 3.78 to 3.93 sec. of actual vessel)
Pitching motion cycle	0.35 to 0.51 sec.(equivalent to 1.26 to 1.84 sec. of actual vessel)

(2) Adjustment

Weight balance and the motion cycles were adjusted with image sensor, video camera on board, pole pod (produced) and camera panhead (already made) mounted having total weight of 2 kg.

The height of the center of the sensor is set between eye level from the navigation bridge and the maximum height of the navigation bridge. See Photo 1.

Pole pod … 172 g
Camera panhead … 229 g
Video camera … 245 g
} +Image sensor+weight=2 kg

Photo 1 Model vessel

4. The waves which were used for demo

Wave monitoring data (text) from No. 2 Kaihou and Tokyo Light Beacon, which is open to the public, was analyzed in order to make a decision about the wave pattern.

(1) Wave motions of Tokyo bay

According to the wave monitoring data (2007) throughout the year at the fort on the sea (Daini-Kaiho), which is located near the entrance to the Tokyo bay, the annual average significant wave height*[4] was about 38.8 cm and the significant wave cycle*[5] was about 3.64 sec. According to the monthly average wave height, the highest was in March, which was 45.2 cm, and lowest in June, which was 32.2 cm. The wave cycle was shortest mostly in the winter and tends to be longer in the summer, but it fits roughly between 3.4 sec. and 3.8 sec.

*[4] Significant wave height. The average wave height of the one-third largest waves measured by a wave height meter for a certain period of time (10 to 20 minutes) and represented as the highest one-third number of waves (H1/3) as well.

*[5] Significant wave cycle. Referred to as the cycle of significant waves as described above and represented as the cycle of the highest one-third number of waves (H1/3) as well.

The annual average significant wave height is about 28.5 cm, and 2.7 sec. for the cycle according to the data (2008) collected at Tokyo offshore fixed light, which is located at the head of the bay. The average highest wave of the year is 32.6 cm in May. The average lowest is 24.6 cm in September. The annual average wave cycle is about 2.7 sec. all year around, and the wave is smaller than at Daini-Kaiho.

Considering that there are waves higher than the average and shorter cycles than the average, the data used by the demo was only an average value of significant waves (this value is the average of the highest one-third for a certain period of time), but by creating a pattern of waves for the demo test, the average value of data was adopted for fixed wave height and a cycle in the tank.

The setting for the wave height was 50 cm maximum and 3.6 sec. for the cycle (equivalent to the actual sea conditions), but the cycle of 7.2 sec., which is 2 times longer, was added to the demo (2.0 sec. at the wave generator) considering the tracking function of the image sensor. 100 cm wave height (equivalent to the actual sea conditions) was added as a reference since pitching motion is less trembling than rolling motion.

(2) Wave pattern

The wave pattern at the simulation is shown in Table 2. The actual wave height would be 13 times more than that of the demo with the model being one-thirteenth the size of the actual vessel, and the wave cycle would be $\sqrt{13}$ times according to the similarity rule.

Table 2. Wave pattern

Wave direction*	Wave height (wave generator) cm	Wave height (equivalent to actual sea) cm	Wave cycle (wave generator) sec.	Wave cycle (equivalent to actual sea) sec.
Pitching	0.77	10	1.0	3.6
Pitching	1.92	25	1.0	3.6
Pitching	3.85	50	1.0	3.6
Pitching	7.69	100	1.0	3.6
Pitching	0.77	10	2.0	7.2
Pitching	1.92	25	2.0	7.2
Pitching	3.85	50	2.0	7.2
Pitching	7.69	100	2.0	7.2
Rolling	0.77	10	1.0	3.6
Rolling	1.92	25	1.0	3.6
Rolling	3.85	50	1.0	3.6
Rolling	0.77	10	2.0	7.2
Rolling	1.92	25	2.0	7.2
Rolling	3.85	50	2.0	7.2
Oblique	3.85	50	1.0	3.6

*Angle of the bow against the waves' approach. Front against pitching, 45^{o} against oblique, 90^{o} against rolling.

5. The points of exercising simulation (per attendants)

5-1 Toshiba Corporation

(1) Names and positions

- Position: Infrastructure Systems Div., Highway & Traffic Systems Engineering
- Name: Shigeto Shimada (representative), Hideki Ueno, Minoru Fujita, Yoshiyuki Sato, Minoru Matsuura

(2)Carry in devices

- Visible Light Communications control unit, 1
- Visible Light Communications light source, 1
- Visible Light Communications receiver (CMOS camera and inbound processing device), 1
- Total weight of the apparatus on the model vessel: Camera 200 g, lens (25 mm) 100 g
- Cable and tools, 1 set
- Length of the USB cable between camera and PC: 1.8 m, power cable for camera: 2 m

(3)Carry in devices are shown in photos 2 and 3

Photo 2. Visible Light Communications control unit

Photo 3. Visible Light Communications receiver (CMOS camera and inbound processing device)

5-2　Casio Computer Co., Ltd.
(1) Positions and names
- Position:　Research & Development Center, Development Center
- Name:　Norio Iizuka (representative), Tomohisa Ishikawa

(2) Carry in devices
- Visible Light Communications control unit,　1 (all in one with light source, compact size)
- Visible Light Communications light source　(all in one with the control unit)
- Visible Light Communications receiver (CMOS camera and PC), 1Cable and tools, 1 set

(3) Carry in devices are shown in photos 4 and 5

Photo 4 Light source: Chip LED with button cell, 3x3x1 cm

Photo 5 Sensor module with USB port, about 10x6x1.5 cm

5-3 NEC Corporation
(1) Positions and names
- Position:　System Platforms Research Labs

- Name: Shuji Suzuki (representative), Hiroshi Yagi

(2) Carry in devices

- Visible Light Communications control unit, 1
- Visible Light Communications receiver (CMOS camera and PC), 1
- Cable and tools, 1 set

6. Motion conditions of the model vessel

(1)The view from the windows on the side of the circulating water tank is shown in Photos 6, 7 and 8.

Photo 6 Rolling motion (L: camera looks down, R: camera looks up, the same applies hereinafter) Wave cycle 1 sec. (equivalent to about 3.6 sec. in actual sea), wave height 1.92 cm (about 25 cm in actual sea)

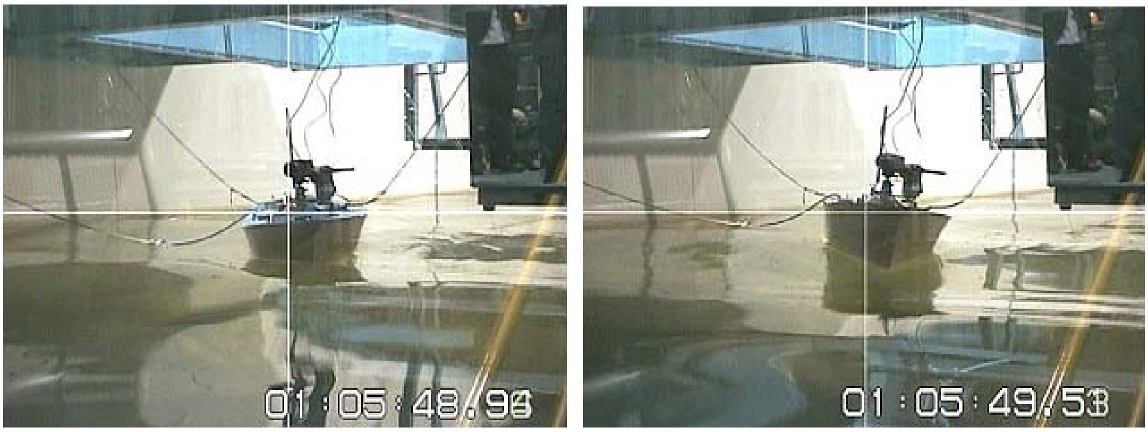

Photo 7 Waves from oblique (same)

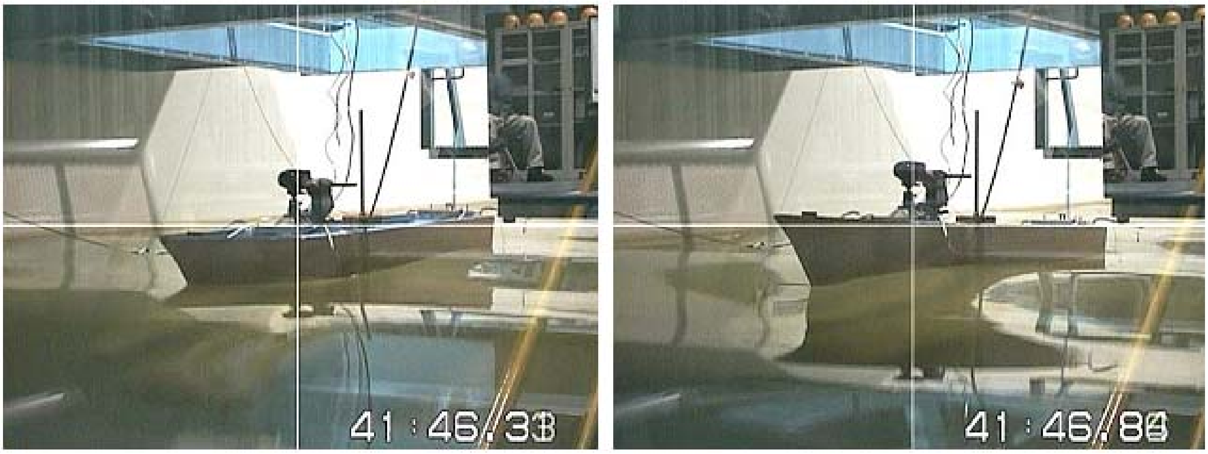

Photo 8 Pitching motion

Wave cycle 1 sec. (equivalent to about 3.6 sec. in actual sea), wave height 3.85 cm (about 50 cm for the same)

(2)The view from the camera on the model vessel is shown in Photos 9 and 10

Photo 9 Rolling motion (L: camera looks down, R: camera looks up)

Wave cycle 1 sec. (equivalent to about 3.6 sec. in actual sea), wave height 1.92 cm (about 25 cm for the same)

*Dotted lines indicate the location of the light source (same as follows). If the angle of view (about 30°) of the pitching motion of the mounted camera is taken into consideration the rolling for the same would be 13° to 14°.

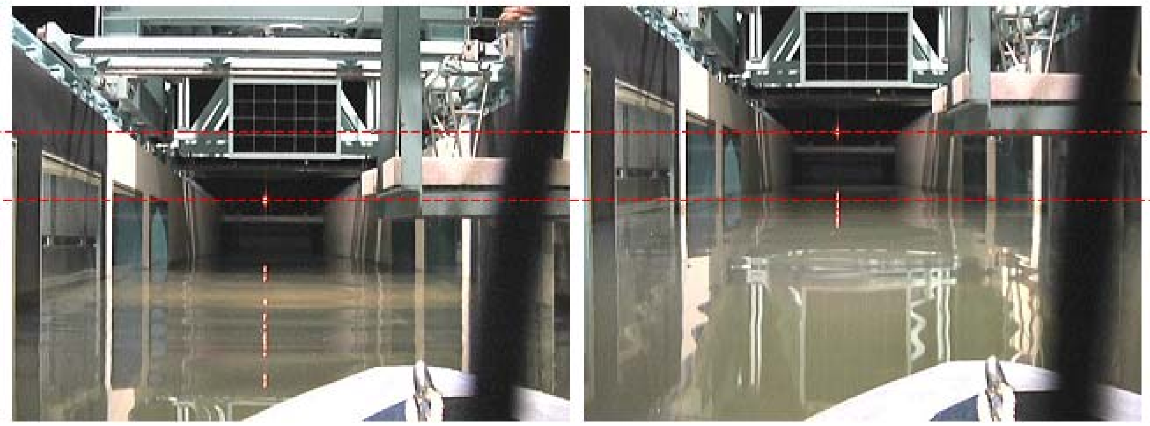

Photo 10 Waves from front (L: camera looks down, R: camera looks up)

Wave cycle 2 sec. (equivalent to about 7.2 sec. in actual sea), wave height 7.69 cm (about 100 cm for the same).

*About 5^{o} of pitch angle was observed

(3) Analysis of roll, pitch and oblique angles

The model vessel created rolling, pitching and oblique motions against waves, which showed angles created by several different wave patterns. The maximum angle was created by tuned motions, which overlapped due to the rolling motion cycle being similar to a natural period. On the other hand, pitching motion was kept down and the result was a small angle despite its equivalence to a 1 m high wave in an actual sea as seen in Photo 10.

When the camera is set up on the actual vessel, make sure that the sensor system is placed such that it will be easy to adjust its angle, and that accessibility of information can be improved by handling the camera by a human being who could be a cushion to the motions.

8. Summary

(1) Result and observations of the simulation

As a result of the demonstration test, we obtained the result that with 1 sec. of wave cycle, the information wasn't lost till 50 cm, which would be in the actual sea conditions with pitching motions and the information started getting lost at the height of 25 cm which would be in actual sea conditions, and it was frequently lost at the height of 50 cm which would be in actual sea conditions with rolling and oblique motions though we omit a detailed result from the test participants. This was due to the cycle of the motion of the object (light source) in the sensor display being more frequent than in the actual sea ($\sqrt{13} \fallingdotseq 3.6$ times) according to the similarity rule for motion cycle, even the motion angles and acceleration were reproduced for the model vessel.

This process is only a theory, but the demo with a wave cycle of 2 sec. was conducted as close as possible to the actual vessel conditions in the sea (7.2 sec in the actual sea, which occurs rarely in Tokyo Wan according to the significant wave monthly average value). Little information was lost or not lost with any patterns of waves.

The results show sufficient possibility of practical use as attendants reported on this demo (omission), even though it is still under development.

(2) Issues to be considered

It was a successful communications test for receiving information from a 2 km distance with the light source and receiver fixed on the ground, but information needs to be accessible from at least one nautical mile in the actual sea as well. The equivalent to actual distance of 390 m was calculated based on the test facilities and equipment. And that 390 m may be an appropriate distance for monitoring aids to navigation on the sea and for other purposes, but not enough for vessels that are on the sea to receive information from lighthouses or other objects.

The wave patterns created in the tank were regular to the utmost based on the monthly average data of significant waves. But a number of higher than average waves and irregular patterns occur in the actual seas, thus the actual motions of the vessel could not be produced with the test equipment this time. The effect to the sensor is not easy to estimate for such reasons.

The conclusion is that the test must be conducted at actual sea.

(3) Summary

As the practical application is coming into the view, the VLCC, starting next year, is going to come out with testing methods at actual sea (fixing the sensor on the vessel or human operations, etc.) and deal with applications and newly arrived technological problems. We will search for the possibility of installing Visible Light Communications Technology including for monitoring of aids to navigation, etc. by having specific discussions of interface and content of information between the lantern and the Visible Light Communications control unit, and other usages, etc.

For all the above reasons, we will remain continuously joined with VLCC and test at the actual sea and to participate in other activities by using our vessels and lighthouses.