Consideration of Utilization of Autonomous Drone for Ship Surveys/Inspections

— Demonstration Experiment in Non-GNSS and Dark Environments —

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1. INTRODUCTION

1.1 Background

In recent years, the application of robotics technologies, such as drones, has become increasingly active in various fields. This trend is also occurring in the maritime industry, and expectations are rising for the effective utilization of these latest technologies in surveys by classification surveyors and in inspections by crew. For this reason, the classification societies were quick to revise IACS UR Z17 in January 2018 to allow the use of Remote Inspection Techniques (RIT) for the inspection of hull structures. Considering this situation, ClassNK also issued the "Guidelines for Use of Drones in Class Surveys" (hereinafter referred to as "the guidelines"), in April 2018 [1]. The guidelines summarize the applicable range and procedures for applying drones to class surveys, the technical considerations for safe operation and the requirements for drone service suppliers. The use of drones for surveys in high places, narrow places, and dark environments such as cargo holds is expected to improve the safety, efficiency, and quality of surveys.

There are two types of drone operation methods. One is "manual flight," in which the operator operates the drone manually, and the other is "autonomous flight," in which the drone flies autonomously by sensing the surrounding environment and estimating self-localization and direction. In the guidelines, the former method of drone operation is covered. This is because the use of autonomous drones onboard a ship requires technologies such as SLAM (Simultaneous Localization and Mapping), but at the time the guidelines were issued, the technology was still in the development stage and it was considered difficult to use them for ship surveys. In recent years, however, technological developments have led to the emergence of drones that can fly autonomously even inside the building [2] [3]. In other industries, the utilization of such drones for infrastructure inspection and patrol security are being considered [4] [5].

1.2 Research Objective

Currently, in an environment surrounded by steel plates such as cargo holds, GNSS do not penetrate and the geomagnetic field is not stable, so ship surveys/inspections by manual flight require operators with advanced piloting skills. On the other hand, autonomous drone can be operated without depending on the skill of the operator. However, as mentioned above, the guidelines do not cover autonomous drones, so technical requirements for the use of autonomous drones for ship surveys need to be developed.

The inside of a ship is a non-GNSS environment and has many dark sections. Therefore, in addition to the technical requirements for autonomous flight, it is important requirement to be able to perform surveys/inspections even in dark environments where no lighting is provided. Therefore, it is important to install lighting, select a camera, and tune the camera so that it can photograph images of sufficient quality even in dark environments.

In recent years, there has also been progress in the development of technology to make effective utilization of the images photographed by the camera. For example, the technology to process camera images into 3D point cloud data and orthophoto has already been established, and the effective utilization of such technology is expected to improve the efficiency and quality of surveys/inspections.

In order to maximize the benefits of using autonomous drones, it is important to use them flexibly without sticking to the existing survey/inspection scheme. Therefore, the Society has been extracting technical requirements for drones that can fly autonomously and stably in non-GNSS and dark environments such as cargo holds and has been studying survey/inspection schemes suitable for ship survey when using autonomous drones.

In this paper, we describe the results of flight experiments conducted in inside of building where is non-GNSS and dark

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environment as same as ship inside environment, whose aim is to validate the automatic flight performance and photographic quality of the drone in non-GNSS and dark environments. An autonomous drone that has Visual SLAM is used, which simultaneously estimates 3D information about the environment and the position and direction of the drones from images photographed by a camera instead of GNSS (see Photo 1).

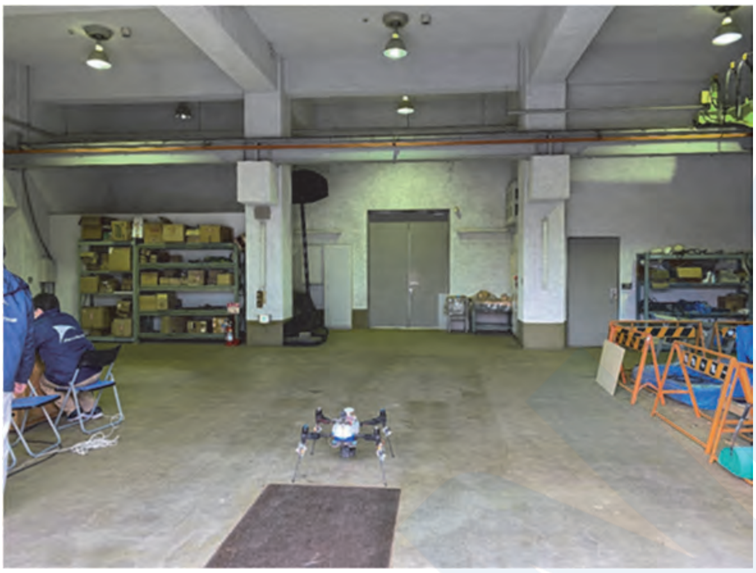

Photo 1　Exterior view of the materials storage area

2.　EXPERIMENT SUMMARY

2.1　Equipment and Experimental Environment

In general, there are three methods of recognizing self-localization without depending on GNSS [6].

① Using vision sensors which recognize from images

② A method using a laser ranging system such as LiDAR

③ A method of sending location information to the drone through external sensing.

The advantages and disadvantages of each method are shown in Table 1.

Table 1　Types of sensors for autonomous flight and their advantages and disadvantages [6]

	Advantage	Disadvantage
①Vision Sensor	・Low cost ・Small size / light weight (miniaturization is possible) ・Location can be determined even on a flat surface if there are features.	・Accuracy tends to drop at long distances ・Difficult to detect flat surfaces and water ・Weak in dark environments
②LiDAR	・Capable of ranging even on featureless flat surfaces (in the case of large size) ・High accuracy even over long distances ・Capable of acquiring 3D information in all directions	・High cost ・Large size/weight (difficult to miniaturize) ・Difficult to acquire position information on a continuous plane
③External sensing	・Acquire information with high accuracy according to the environment	・High cost of installation ・Disconnection of communication with the drone can be dangerous

Drones that use LiDAR can achieve autonomous flight even in environments such as cargo holds. However, LiDAR is expensive, making it difficult to adopt in situations where cost effectiveness is not readily apparent. Therefore, in this experiment, we used the drone equipped with a Visual SLAM using a stereo camera as a vision sensor that can be developed more inexpensively than LiDAR (see Photo 2). The drone recognizes its own position and direction by simultaneously estimating the 3D information of the environment and the self-localization and direction of the drone by capturing feature points from the images acquired by the stereo cameras in multiple directions.

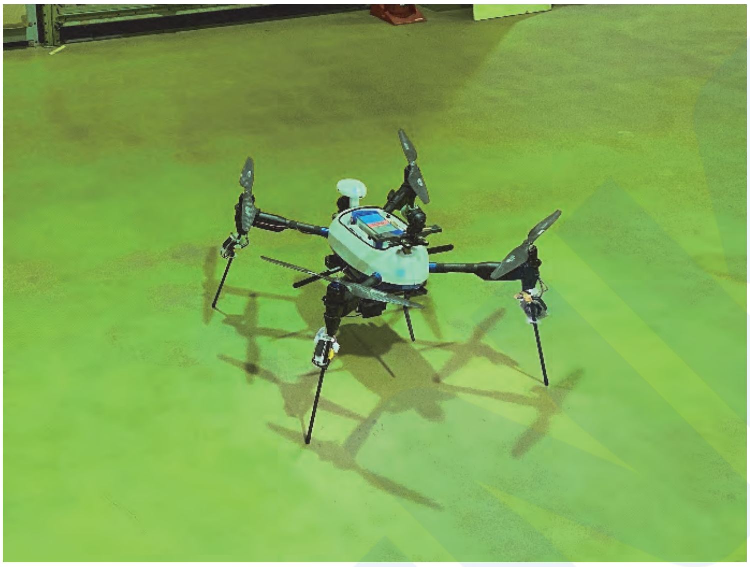

Photo 2 Autonomous drone equipped with vision sensor

Since the vision sensor does not work appropriately in the dark environments, a 100W lighting system was installed under the propeller to provide the necessary amount of light for the vision sensor. Photo 3 shows the scene before and after the lighting.

(a) Before turning on the light (b) After turning on the light

Photo 3 Experimental environment

2.2 Validation of Automatic Flight Performance of the Drone

As mentioned earlier, the vision sensor does not work appropriately in the dark environments, so it is necessary to equip the drone with an appropriate lighting system so that it can capture the surrounding feature points. Therefore, we actually flew the drone equipped with a 100W lighting system in a dark inside environment to validate whether the vision sensor was working appropriately.

This drone can automatically fly along its path by setting waypoints. In this experiment, two flight paths were planned, as shown in Fig. 1. The distance to the detection target of vision sensor was set to 3m for the flight path of the solid line and 8m for the flight path of the dashed line.

Photo 4 shows the automatic flights of the drone. In the situation where this experiment was conducted, it was confirmed that the drone flew stably and automatically along the flight plan as the vision sensor worked appropriately with the lighting system, even in a non-GNSS and dark environments [7].

Figure 1　Flight plan

Photo 4　State of automatic flight

2.3　Validation of the Quality of Video Taken by the Drone

In this experiment, a 20 megapixels camera which is called Sony UMC-R10 [8] was used as the inspection camera. The images taken during the automatic flights are shown in Photo 5. The cracks at the locations indicated by arrows can be sufficiently identified.

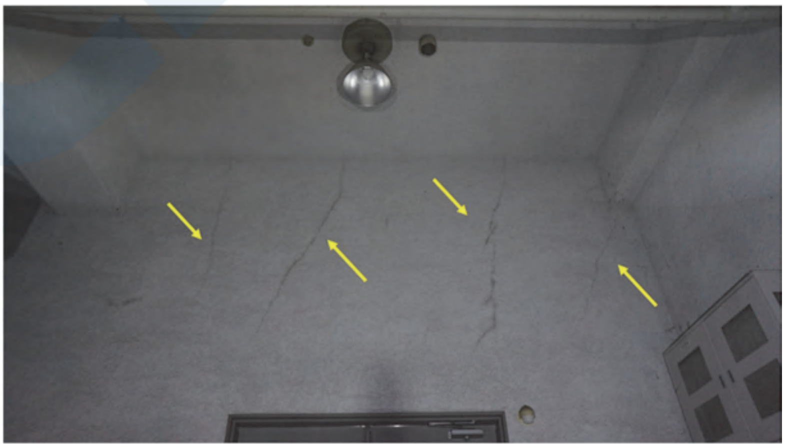

Photo 5　The images taken during the automatic flights

In this experiment, as shown in Photos 6~9, the distance from the photo location was increased to a maximum of 10 meters, and the cracks were confirmed in all cases. In a dark environment such as this experiment, the lighting attached to the drone is the only light source, and the amount of light hitting the photo location decreases as the distance increases. Therefore, as the distance increased, the ISO sensitivity increased, and the noise tended to be amplified.

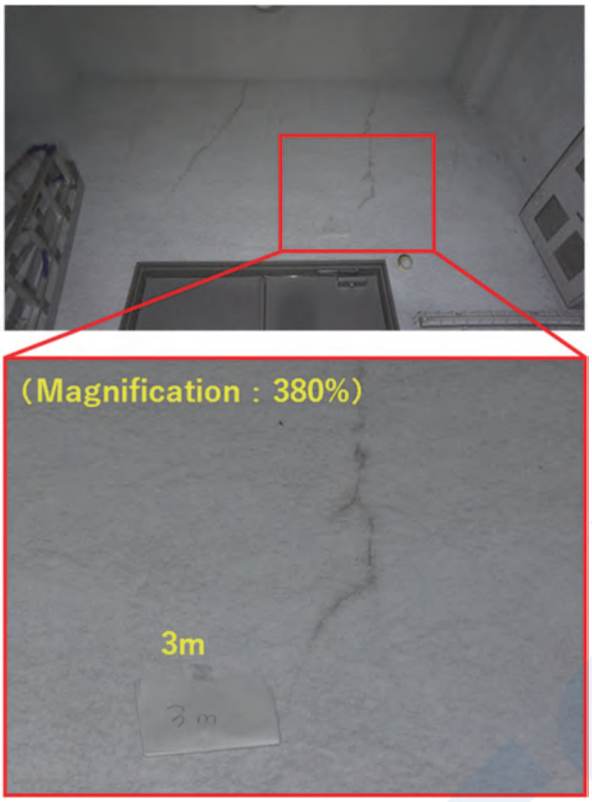

Photo 6　Image taken from a distance of 3m

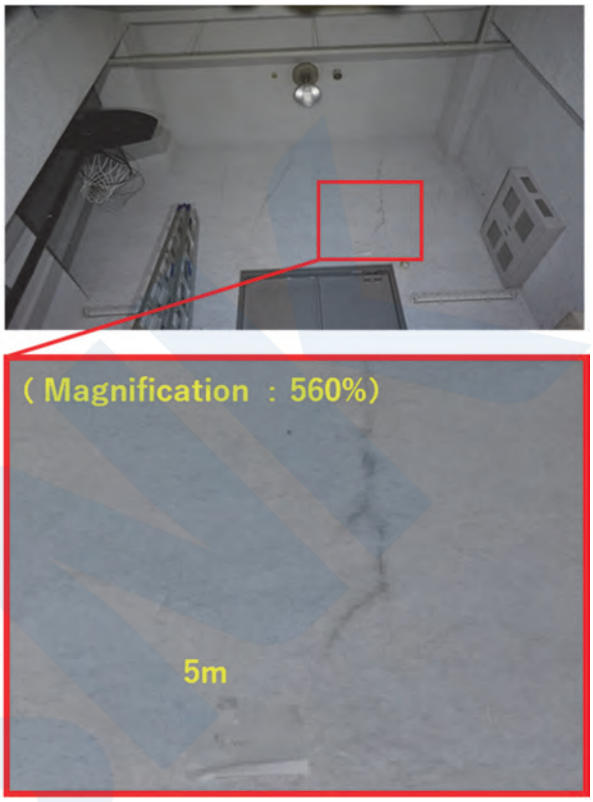

Photo 7　Image taken from a distance of 5m

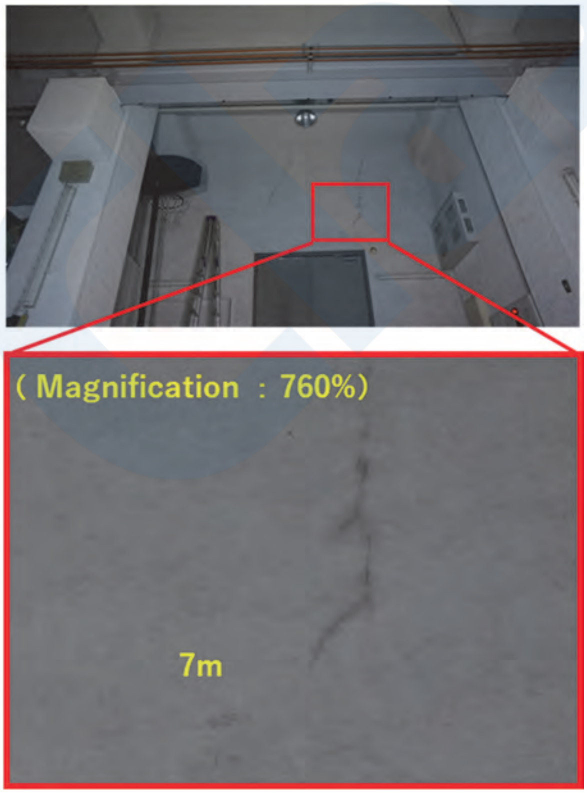

Photo 8　Image taken from a distance of 7m

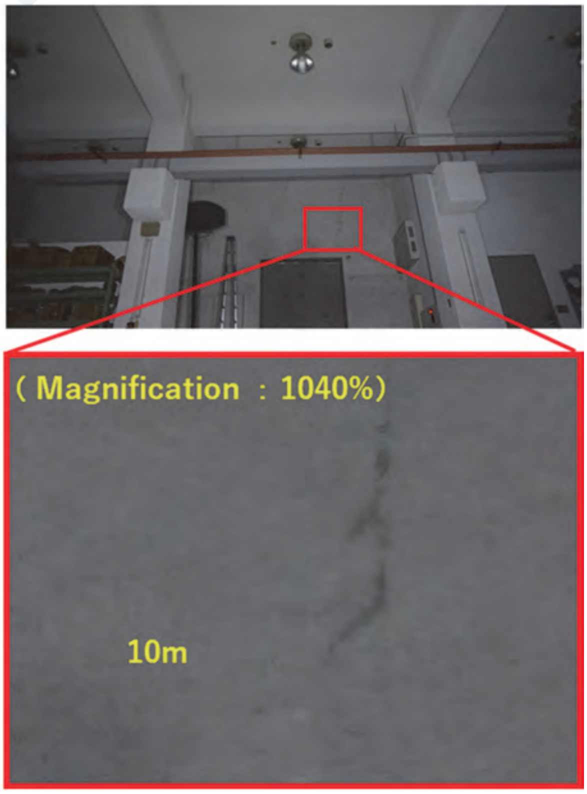

Photo 9　Image taken from a distance of 10m

2.4 Study of the Effective Utilization of Images Photographed by Drones

2.4.1 Processing into 3D Point Cloud Data and Orthophotos

If autonomous drones can be operated with simple operations, the information necessary for surveys/inspections can be easily obtained. For example, if crew can use an autonomous drone, they can take images of the inside of cargo holds during the time when the ship is waiting to enter port. The recorded images can then be used as effective advance information. In addition, technology has already been developed to generate 3D data from the recorded images, and by using this technology, it will be possible to efficiently grasp the situation inside the cargo holds.

SfM processing were performed to generate a 3D model using the images taken during automatic flights. SfM processing is a technique that estimates the positions of multiple images taken by a camera and generates a 3D model of the entire object from the disparity of each image to the same point [9]. The accuracy of the generated 3D model requires a sufficient overlap ratio (the ratio of overlapping parts in a series of images taken by a drone in automatic flight), because it depends on the overlap ratio of the images. In this experiment, the images necessary for SfM processing were acquired by continuously shooting at regular intervals during automatic flight and setting the overlap ratio to be more than 70%. The 3D model is output as 3D point cloud data consisting of many point clouds. The 3D point cloud data can also be processed and orthorectified to obtain orthophotos, which are 2D models. In this experiment, we generated 3D point cloud data and orthophoto from images taken from the two flight paths shown in Fig. 1.

2.4.2 Validation of Effectiveness of 3D Point Cloud Data

Figure 2 shows the generated 3D point cloud data. It shows that the data taken from two different flight paths were successfully combined into one 3D point cloud data, and the object can be confirmed from various angles.

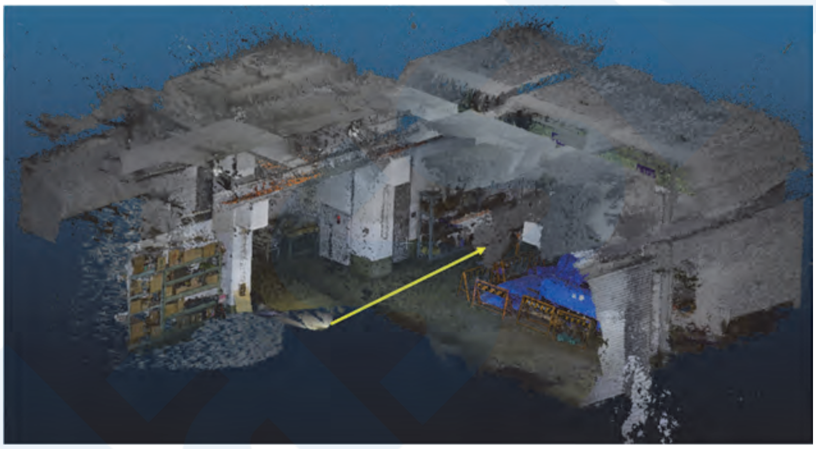

Figure 2　Composite view of 3D point cloud data

Figure 3 is an enlarged view of a portion of the 3D point cloud data when viewed from the direction of the arrow in Fig. 2. When the details are checked, the point clouds become sparse as shown in the lower part of Fig. 3, due to the data has been processed to point clouds.

Thus, while the 3D model makes it easier to grasp the situation intuitively, the image quality itself is degraded. In the ship survey, 3D point cloud data can be useful for understanding the general condition of the inspection area/section. However, it is needed to check in more detail from the photographed images individually to check the suspected areas.

Since the 3D model contains location information, it can also be used for length measurement. We compared the actual measurements with the 3D point cloud data at the three locations indicated by the lines in Fig. 4. Table 2 shows the measurement results.

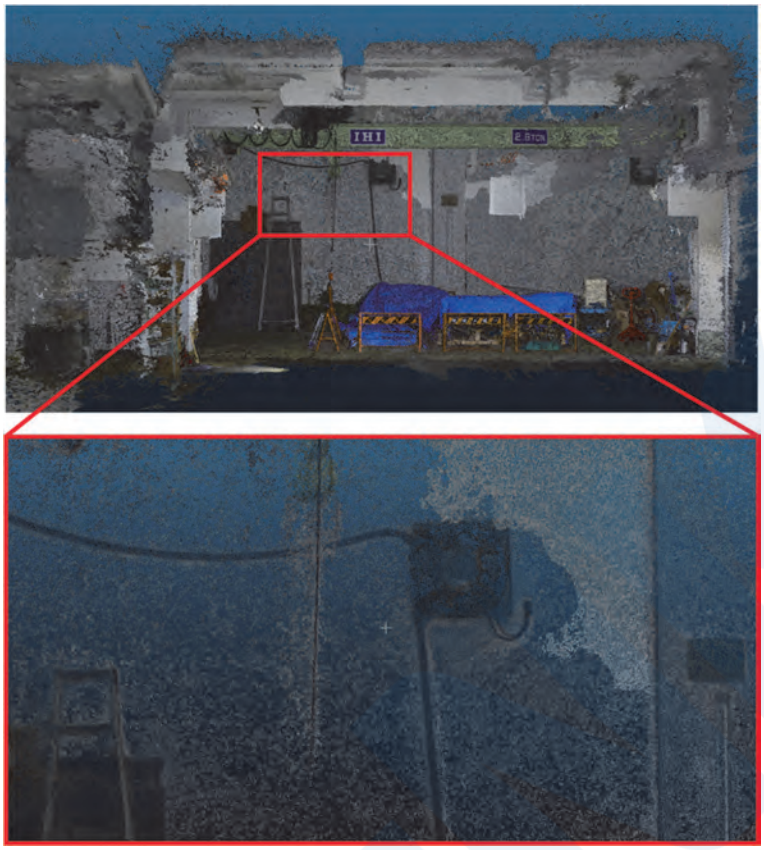

Figure 3　Magnified view of 3D point cloud data

Figure 4　Measured location

Table 2　Comparison of measurement results

	Result of length measurement with 3D point cloud data[cm]	Measured results[cm]	Accuracy[%]
①shelf	209	206	1.46
②Fire hydrant	110	105	4.76
③Barricade	119	121	1.65

Although there is an error in centimeters, it may be useful for measuring the crack length and roughly calculating the extent of damage.

2.4.3　Validation of Effectiveness of Orthophotos

Figure 5 is the orthophoto generated from the images taken in the flight path of the solid line on the left side in Fig. 1, and

Fig. 6 is the orthophoto generated from the images taken in the flight path of the dashed line on the other side.

Figure 5　Orthophoto of the flight path of the solid line

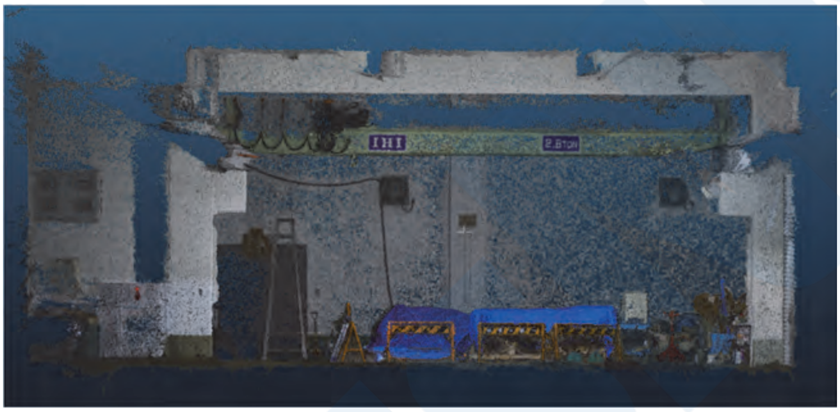

Figure 6　Orthophoto of the flight path of the dashed line

The quality of the orthophoto is close to that of the photographic image, although the image returns from 3D to 2D. Orthophoto cannot capture the situation in three-dimensionally like 3D point cloud data, but the visual information in a plane is improved. Therefore, orthophotos may be more suitable for understanding, for example, the painting condition.

On the other hand, images that show hidden parts of a component from an angle will be lost in the ortho image even though it is reflected in the image taken by the drone since orthophotos are generated by combining photos taken from the front. In this sense, there are advantages and disadvantages.

In addition, there were some parts (black parts) that are not output in the orthophoto. This may be because the orthorectifying is processed on the premise that it is projected onto a single plane, the distortion will be large, when the shape seen from the camera direction is complicated as in this experimental environment, and some parts were failed to convert. As a countermeasure, it is possible to reduce the distortion by generating separate data for each area with different depths.

2.4.4　Considerations

At this stage, it is difficult to determine whether 3D point cloud data or orthophotos are more suitable for ship surveys/inspections. We will continue to study the utilization of 3D point cloud data in combination with orthophotos, while increasing the number of validation cases, after understanding the characteristics of each. For example, if the aging of the entire area/section can be confirmed by comparing chronological order of 3D point cloud data and orthophotos, it can be expected to be effectively utilized for ship surveys/inspections.

Moreover, it is a great advantage to be able to obtain following three types of data from a single camera:

a)　An image for survey.

b)　A recording images for later confirmation.

c)　A 3D model by post-processing the image.

It will become increasingly important for classification societies to make effective utilization of the data obtained. I would like to continue to study how to utilize the data acquired by the drone.

2.5 Summary

In this experiment, the following was confirmed.

- In a dark inside environment with an approximate volume (D x W x H) of 14 x 15 x 5 (m), we were able to confirm that the drone flew stably and automatically along the planned flight path even in a non-GNSS and dark environments as the vision sensor worked appropriately with the lighting system.
- It was confirmed that images that could sufficiently distinguish the cracks could be taken even in the dark environment. However, the quality of the images taken in dark environment varies depending on the distance between the drone and the photo location due to the illuminance. Therefore, it is necessary to take from an appropriate distance according to the performance of the camera and the illumination level.
- 3D point cloud data and orthophotos were obtained by SfM processing of the images taken by the drone.
- In 3D point cloud data, the 3D model makes it easier to grasp the situation intuitively.
- The image quality itself is degraded by processing into the 3D point cloud data. Therefore, In the ship survey, 3D point cloud data can be useful for understanding the general condition of the inspection area/section. However, it is needed to check in more detail from the photographed images individually to check the suspected areas.
- The length measurement from 3D point cloud data has an error of centimeters. It can be used to grasp the rough crack length and to calculate the extent of damage.
- In the orthophoto, visual information on a large area of a flat surface could be confirmed with a quality close to the photographic image. It may be possible to grasp the painting condition on ships. On the other hand, images that show hidden parts of a component from an angle may be lost in the orthophoto, even though it is reflected in the image taken by the drone.

3. CONCLUSION

In this experiment, we used a drone equipped with a vision sensor and confirmed that stable automatic flight was possible in an inside enclosed area without external lighting. However, since the vision sensor recognizes self-localization based on the feature points of the images captured by the camera, it is necessary to continue to validate whether the sensor can work appropriately in a larger space than this experimental environment. We would like to conduct a demonstration experiment inside a ship to validate the system under conditions closer to actual operation.

ClassNK will engage in relevant study to ensure that the ship surveys/inspections are carried out efficiently and rationally.

REFERENCES

1) ClassNK: Guidelines for Use of Drones in Class Surveys, 2018
2) Skydio, Inc: Skydio2, https://www.skydio.com/skydio-2
3) ACSL: Inspection Industrial Plant (Japanese), https://www.acsl.co.jp/solutions/inspection-industrial-plant/
4) ALSOK: News Release (released 15th July 2020) (Japanese), https://www.alsok.co.jp/company/news/news_details.htm?cat=2&id2=1039
5) Hokkaido Electric Power Co., Inc.: Press Release (released 4th March 2021) (Japanese), https://www.hepco.co.jp/info/2020/1251171_1844.html
6) Aerosense Inc.: Autonomous drone flight experiment for inspecting cargo holds - Confirming inspection methods using autonomous flight in a dark environment with no GPS or other radio signals – (Japanese), https://aerosense.co.jp/pressitems2021/0318
7) Aerosense Inc.: Aerobo Inspection on Dark site with vSLAM and Light (Aerosense Inc.), YouTube, https://www.youtube.com/watch?v=Ov9YtEqZpbI&ab_channel=AerosenseInc.
8) SONY：UMC-R10C，Image Sensing Solutions Europe, a division of Sony Europe B.V，https://www.image-sensing-solutions.eu/UMC-R10C.html
9) Shirotani Eisaku, Kiri Hirohide, Takahashi Junji, Ooishi Tetsu, Muraki Hirokazu, Prospect of Unmanned Aerial Vehicle Usage for Stock Management of Irrigation Facilities, 2015, Volume 83, Issue 10, p839-842 (Japanese)