

Independent Algal Bloom Removal System

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Abstract - In this study, we propose an independent algal bloom removal system that can remove algal bloom independently through automatic detection of where they are occurring by coordinating a drone, an automated algal bloom removal robot, and a cloud server. Through realization of this system, automatic detection of where algal bloom is occurring and independent removal of algal bloom are enabled. As this system requires automatic detection of where algal bloom is occurring, it is extremely important for the evaluation of this system to assess the performance of the algal bloom determination system which determines if there are algal bloom or not. Therefore, we conducted an evaluation experiment to assess its determination performance. In this paper, we show the result of this evaluation.

Keywords: Internet of Things, Multi robot operation, Algal bloom removal robot, Convolutional Neural Network

1 Introduction

Due to the impact of global warming, increase of algal bloom, which causes deterioration of environment of lakes and marshes, is becoming a problem. An algal bloom is an overgrowth of cyanobacteria (such as *Microcystis*), which is phytoplankton, in lakes and marshes eutrophicated by nitrogen or phosphorus that turns the surface of water into powdery green state. A large growth of algal bloom is so green that it is compared to green paint, and it ruins the view of lakes and marshes. Furthermore, the algal bloom that was blown by wind to the shore can rot and emit strong and bad smell, and when it glows on a lake or marsh used as a water source, it becomes an obstacle to the filtering process that removes trashes from the water, causing the water treatment process to become inefficient. Indeed, the damage caused by toxin in algal bloom is occurring around the world, and health damages and restriction on domestic water caused by its impact on water sources are widely reported. Thus, measures against algal bloom have become an important international issue [1].

Several algal bloom removal devices have been developed. However, these devices require workers to go to where an algal bloom is occurring, carry, install, and retrieve them on a boat. Moreover, the workers must work on the boat and therefore it is dangerous for them. Furthermore, the location of where an algal bloom is occurring changes by time, which requires the device to be moved each time the location

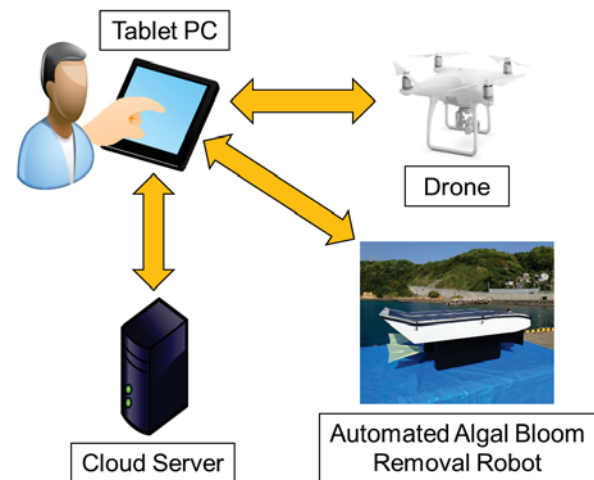


Fig. 1: Overview of Independent Algal Bloom Removal System

changes. And as these devices are large, human resource required for moving is also a problem.

In this study, we propose an independent algal bloom removal system that can remove algal bloom independently through automatic detection of where they are occurring by coordinating a drone, an automated algal bloom removal robot, and a cloud server. The characteristic aspect of this system is the fact that it can detect where algal bloom is occurring automatically by using a tablet PC to coordinate a drone, an automated algal bloom removal robot, and a cloud server in order to independently remove algal bloom (Fig.1).

Through realization of this system, automatic detection of where algal bloom is occurring and independent removal of algal bloom are enabled. Therefore, the problems of troublesome usage of removal devices, dangerous work process, and limited operation area will be solved.

As this system requires automatic detection of where algal bloom is occurring, it is extremely important for the evaluation of this system to assess the performance of the algal bloom determination system which determines if there are algal bloom or not. Therefore, we conducted an evaluation experiment to assess its determination performance. In this paper, we show the result of this evaluation.

The structure of the remainder of this paper is as follows. In Section 2, we show the difference between related works and this study. In Section 3, we show the details of this system. In Section 4, we show the results of evaluation experiment

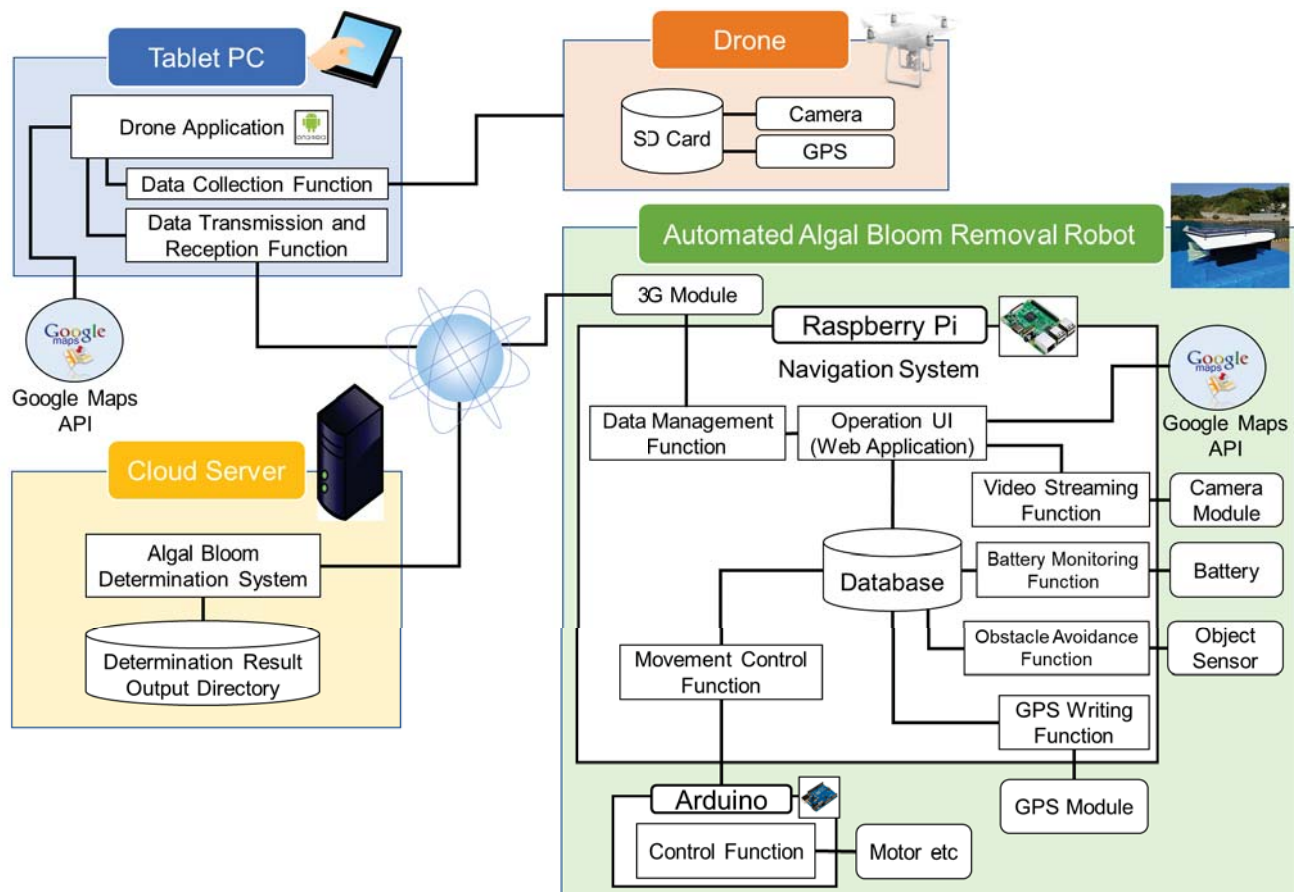


Fig. 2: System Configuration of Independent Algal Bloom Removal System

using this system to assess the performance of the algal bloom determination system. In Section 5, we present our conclusion.

2 Related Works

In Japan, other algal bloom removal devices such as MIZUMORI [2] or Algae Hunter [3] have been developed in the past. However, these devices (hereafter referred to as existing devices) have several problems.

Firstly, the operation of existing devices is troublesome. They require the workers to go to where an algal bloom is occurring, carry, install, and retrieve them on a boat. Thus, usage of existing devices requires large amount of work.

Secondly, operation of existing devices is dangerous for the workers. As the workers must work on a boat, there is a possibility that it may capsizal during the work. Moreover, as algal bloom sometime contain toxin, if a worker fall into the lake or marsh and accidentally drink its water, it may cause health damage.

Thirdly, the existing devices have limited operation area. The operation area of the existing devices is limited to the area around the device. However, the location where algal bloom is occurring changes by time. Thus, the device has to be moved according to this change. And as these existing devices are large, removal of algal bloom using them requires significant amount of human resource to move them.

With this system, automatic detection of where algal bloom is occurring and independent removal of algal bloom are enabled by coordinating a drone, an automated algal bloom removal robot, and a cloud server. Therefore, the problems of the existing devices, namely the troublesome usage of removal devices, the dangerous work process, and the limited operation area, will be solved.

3 Independent Algal Bloom Removal System

3.1 System Requirements

Following is the requirements for the realization of this system.

- Requirement 1: It can automatically detect where algal bloom is occurring by using the drone.
- Requirement 2: The automated algal bloom removal robot can automatically move to where algal bloom is occurring.
- Requirement 3: The automated algal bloom removal robot can automatically return.
- Requirement 4: It is possible to remotely monitor the automated algal bloom removal robot.

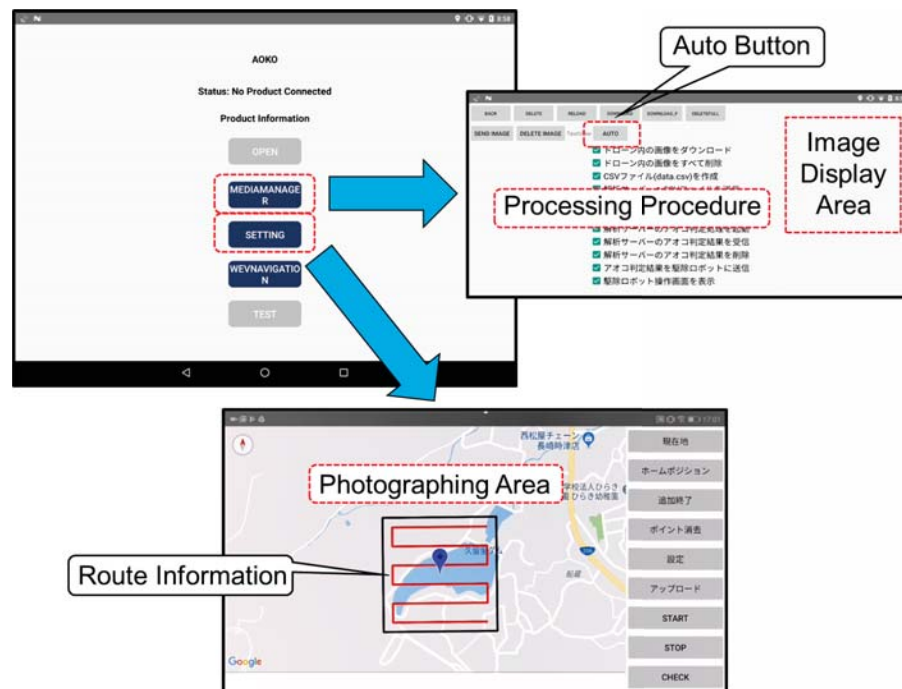


Fig. 3: Drone Application

This study developed a “drone application”, an “algal bloom determination system” and a “navigation system for automated algal bloom removal robot” in order to satisfy these requirements. Note that the drone application was produced as an application for Android OS (DJI Mobile SDK [4]).

3.2 Basic System Configuration

This system consists of a drone, an automated algal bloom removal robot, a cloud server, and a tablet PC that coordinates them. The drone application, the algal bloom determination system, and the navigation system for automated algal bloom removal robot we developed are installed on the tablet PC, the cloud server, and the automated algal bloom removal robot, respectively (Fig.2). Note that the automated algal bloom removal robot is equipped with a Raspberry Pi, and the navigation system is installed on this Raspberry Pi.

This system photographs the occurrence situation of algal bloom from the sky by setting the photographing area for the drone on the tablet PC, which enables the drone to fly automatically in the set photographing area. The resulting aerial photographs are sent to the cloud server together with the positional information of the locations of the photographs via the tablet PC. At the cloud server, image recognition is conducted using Convolutional Neural Network (CNN) [5] in order to identify the locations where algal bloom is occurring. The identified occurrence locations of algal bloom are sent to the automated algal bloom removal robot via the PC tablet, and the removal of algal bloom is conducted independently based on the information of the occurrence locations of algal bloom. Following the completion of algal bloom removal, the

automated algal bloom removal robot returns to the home position automatically.

3.3 Prototype System

3.3.1 Tablet PC

The drone application is installed on the tablet PC (HTC Nexus 9, Android 7.1.1 [6]). With this system, coordination between the processes of the drone, the automated algal bloom removal robot, and the cloud server is possible through only the operation of the drone application installed on the tablet PC (Fig.3). The drone application consists of two functions, namely “data collection function” and “data transmission and reception function”. Following is the details of these two functions.

- Data Collection Function

When the map in this drone application (Google Map) is tapped, the photographing area (300m×300m for the prototype), for which the point that was tapped is the center, is set automatically. Note that, Google Maps API [7] is used to display the Google Map. When the photographing area is set, the positional information of the photographing location, as well as the route information, is calculated automatically. When this route information is sent to the drone, the drone flies automatically according to the route information and photographs the occurrence situation of alga blooms from the sky. The aerial photographs the drone took are saved on the SD card in the body of the drone. Note that the flight altitude and the speed of the drone can be specified when sending the route information to it. Moreover, as the drone (Phantom4 PRO [8]) is equipped with GPS, the positional information

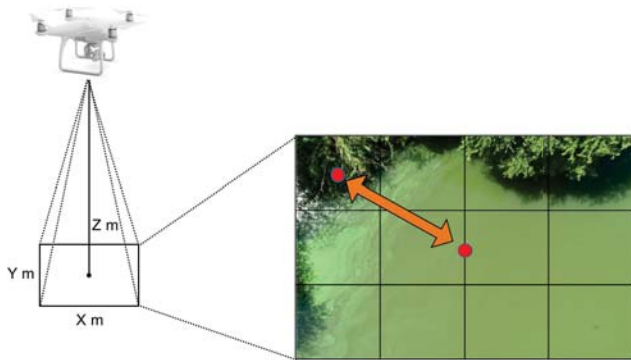


Fig. 4: Diagram for Divided Image Location Coordinate Calculation

(latitude/ longitude) of the photographing location is recorded as EXIF information on the aerial photographs taken by the drone.

- Data Transmission and Reception Function

When the “Auto” button on the drone application is tapped, the aerial photographs saved on the SD card in the body of the drone are sent to the tablet PC. After they are sent to the tablet PC, the aerial photographs saved on the SD card are deleted. Based on the aerial photographs taken by the drone, a CSV file for determining the occurrence of algal bloom is created. The file names of the aerial photographs and the positional information (latitude/ longitude) of their photographing locations are saved on this CSV file, with one line corresponding to one location. Following this, the aerial photographs and the CSV file are sent to the cloud server. After they are sent to the cloud server, the aerial photographs and the CSV file saved on the tablet PC are deleted.

After sending the aerial photographs and the CSV file to the cloud sever, the drone application starts the algal bloom determination system of the cloud server. Please see Section 3.3.2 for the detail of this algal bloom determination system. The drone application regularly checks the determination result output directory until the algal bloom determination system of the cloud server identifies where algal bloom are occurring, in other words until there is an output of the algal bloom determination result. When the determination result is outputted to this directory, the occurrence locations of algal bloom are sent to the tablet PC from the cloud server. Note that after sending the occurrence locations of algal bloom to the automated algal bloom removal robot, the drone application starts the navigation system for the automated algal bloom removal robot. Please see Section 3.3.3 for the detail of this navigation system for the automated algal bloom removal robot.

3.3.2 Cloud Server

The cloud server is equipped with the algal bloom determination system (Sakura no VPS + CentOS + Python) . “Sakura no VPS” is a commercial cloud service in Japan. The algal bloom determination system uses CNN for image

recognition in order to determine the locations algal blooms are occurring. Following is the detail of the algal bloom determination system.

First, the algal bloom determination system starts image division program. The size of one divided image is equivalent of the size of the mesh for setting the movable area of the automated algal bloom removal robot using its navigation system (5m×5m for the prototype system). Next, the location coordinate in relation to each areal photograph taken by the drone is calculated using the CVS file for algal bloom determination. The calculation result is saved on the text file. Following is the detail of the calculation method of location coordinate.

As the photographing area changes according to the angle of view in relation to the water surface, this system places the camera to the bottom of the drone (perpendicular to the water surface). Thus, the location coordinate of each areal photograph corresponds with the coordinate of the central point of the areal photograph. As shown in Fig.4, the location coordinate of each divided image is calculated in relation to the central coordinate of the areal photograph.

Next, the algal bloom determination system determines if there are algal blooms or not on each divided image using CNN. CNN is one of neural networks that calculate through multiple layering of convolution layers or pooling layers [5]. Please see Section 4 for the detail of the determination method. The algal bloom determination result is saved on the text file. Note that on this text file, the location coordinates of the divided images that were judged to be “With algal bloom” are saved. Finally, the algal bloom determination result, in other words the locations where algal blooms are occurring, is sent from the cloud server to the tablet PC. After sending it to the tablet PC, the text file of the algal bloom determination result on the cloud server is deleted.

3.3.3 Automated Algal Bloom Removal Robot

The automated algal bloom removal robot is equipped with a single-board computer called Raspberry Pi (Raspberry Pi 2 model B), and the navigation system (PHP + Python + Apache + HTML + JavaScript + MySQL) for the automated algal bloom removal robot is installed on this Raspberry Pi. Fig.5 shows the user interface of this navigation system. The navigation system is constructed as a Web application by installing Web server on the Raspberry Pi. Moreover, as the Raspberry Pi is connected to a camera module, a GPS module, a battery, an object sensor, and a 3G module, it can remotely monitor the automated algal bloom removal robot by using the information from these attachments. Following is the detail of this navigation system.

This navigation system first takes the photographing area of the drone, divides this area into a mesh, sets the mesh area as the movable area, and displays this movable area on the map of the navigation system (Google Map). When displaying this movable area, it also displays the occurrence locations of algal blooms using the determination result of the algal bloom determination system. Moreover, it obtains the current location of the automated algal bloom removal robot and set

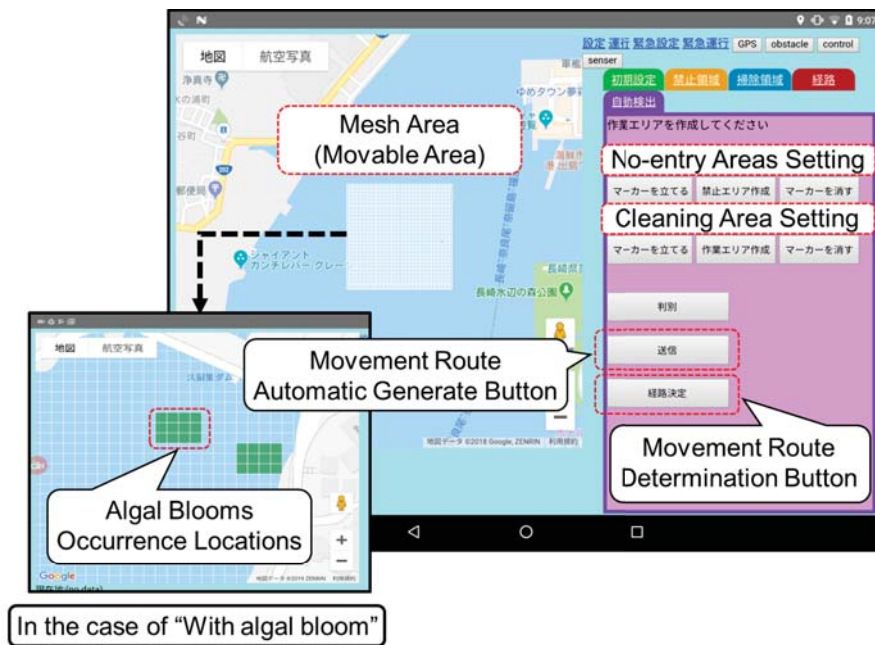


Fig. 5: User Interface of Navigation System for Automated Algal Bloom Removal Robot

that location as the home position. Next, it sets the cleaning area based on the algal blooms occurrence locations information, and it also sets no-entry areas if necessary. Following this, it automatically generates the movement route of the automated algal bloom removal robot based on the information of the home position, cleaning area and no-entry area. A search algorithm A^* [9] is used for the generation of the route. The automated algal bloom removal robot moves and removes algal blooms following this movement route, and returns to the home position upon completion. Note that the camera view of the automated algal bloom removal robot, its remaining battery and positional information can be checked on this navigation system.

On the other hand, this navigation system also has the manual mode. Thus, it is possible to switch to the manual mode when there is an emergency and control the automated algal bloom removal robot manually. Thus, the system user can conduct every operation of the automated algal bloom removal robot by using this navigation system on a tablet PC.

4 Algal Bloom Determination Method and Its Evaluation Experiment

This section discusses the algal determination method of the algal determination system, its evaluation experiment and the evaluation result.

4.1 Algal Bloom Determination Method using CNN

The CNN model for this system is based on AlexNet [10], which is a representative CNN model for categorizing images. The algal bloom determination is classified into the following two classes: “With algal bloom” and “Without algal bloom”.

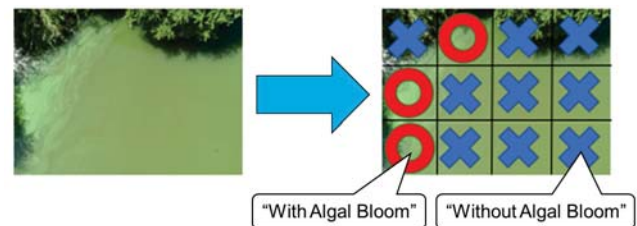


Fig. 6: View of Algal Bloom Determination using CNN

Fig.6 shows the view of algal bloom determination using CNN. Note that precision, recall and F-value are used as the evaluation indexes of the algal determination method.

4.2 Data Set and Evaluation Experiment

The RGB images (areal photographs) used for the evaluation experiment were taken by actually flying the drone over the kururi dam located at togitsu in Nagasaki. The flight altitude of the drone was uniformly set at 20m from the water surface, and the camera was pointed directly below (perpendicular to the water surface) to take photographs.

The data set used for the evaluation experiment is thus: 108 images were created by dividing the RGB images photographed by the drone into the mesh of 3×4 (vertical × horizontal) (With algal bloom: 39, Without algal bloom: 69). These images were increased to 2336 images through data extension. (With algal bloom: 1168, Without algal bloom: 1168). During this data extension, noise processing based on inversion, rotation and Gaussian distribution was conducted using OpenCV [11]. Among the extended 2336 pictures, 70% was assigned as the training data and 20% was assigned as the examination data to conduct the learning in order to create a classification model for determining whether there are algal

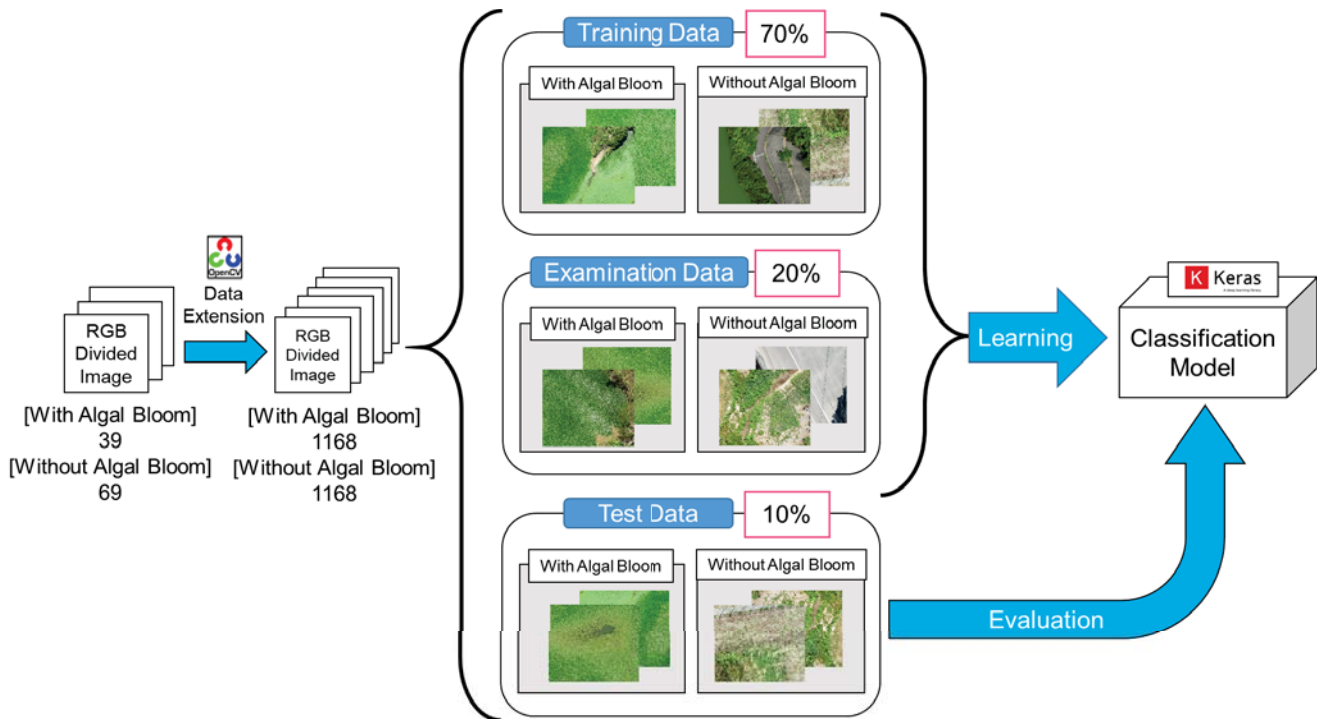


Fig. 7: Evaluation Experiment Flow

blooms or not. The remaining 10% is used as the test data for conducting the evaluation experiment using the created classification model. Fig.7 shows the evaluation experiment flow.

4.3 Evaluation Result

The input images to CNN were resized to 224×224 , which is also the case of the model of AlexNet. The batch size was 256. The learning rate for the optimization is unified at 0.001. Following is the result of the evaluation experiment.

First, Fig.8 shows the transition of the accuracy of algal bloom determination by CNN.

Next, Table 1 shows the result of performance evaluation of algal bloom determination by CNN. For the output layer of AlexNet, which is frequently used for multi class classifications, softmax function is used. However, for binary classifications, sigmoid function is commonly used. Thus, a CNN model that changed the output layer of AlexNet to sigmoid function was used for this experiment. Note that the threshold for the class probability at the output layer for determining whether there is an algal bloom or not is 0.5. This means that when the probability of “With algal bloom” is 0.5 or more, it is determined as “With algal bloom”, and when it is less than 0.5, it is determined as “Without algal bloom”. Moreover, the epoch number is evaluated at 100, which is where the accuracy of the learning converged, and its result is the evaluation of the performance of the model.

As a result, a relatively high accuracy, with precision at 0.78, recall at 0.75 and F-value at 0.77, was obtained. It is inferred that the fact that CNN could capture the characteristic shapes of the target (characteristics such as many curved lines

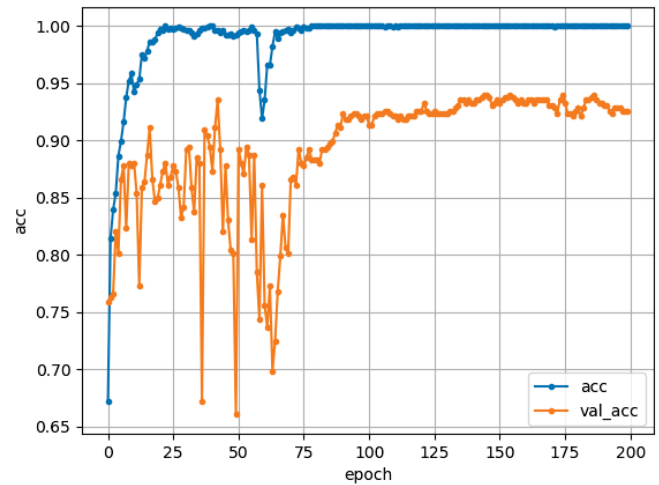


Fig. 8: Transition of Epoch Number and Accuracy of CNN

Table 1: Result of Performance Evaluation of Algal Bloom Determination by CNN

Precision	Recall	F-value
0.78	0.75	0.77

of algal blooms) well led to the relatively high F-value being obtained. However, it is not yet at the level of practical application. Thus in future, further improvement in accuracy, for instance through using an optimal CNN model or a parameter, is required.

5 Conclusion

In this paper, we proposed an independent algal bloom removal system that can remove algal bloom independently through automatic detection of where they are occurring by coordinating a drone, an automated algal bloom removal robot, and a cloud server. Further, as this system requires automatic detection of where algal bloom is occurring, it is extremely important for the evaluation of this system to assess the performance of the algal bloom determination system which determines if there are algal bloom or not. Therefore, we conducted an evaluation experiment to assess its determination performance. As a result, a relatively high accuracy, with precision at 0.78, recall at 0.75 and F-value at 0.77, was obtained.

The future challenges include a proposal of algal bloom determination system using near infrared images. Near infrared ray is a short infrared ray with wavelength at approximately 0.72 to 2.5 micrometers. Chlorophyll contained in plants absorbs visible light in the process of photosynthesis. However, it reflects near infrared ray. Therefore, the wavelength region of near infrared ray has strong reflection from plants but hardly has any reflection from water surface, which enables clear distinction between plants and water surface. Proposal of an algal bloom determination system using near infrared images in order to determine the occurrence areas of algal blooms and improve the algal bloom determination performance is the challenge for the future.

Acknowledgment

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