DEVELOPMENT OF HYPERSPECTRAL IMAGING SYSTEM FOR COASTAL ZONE STUDIES

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ABSTRACT:
Seagrass and seaweed beds play very important ecological roles such as spawning, nursery and feeding grounds for many marine organisms. However, they are sensitive to environmental changes and human impacts. Coastal zone monitoring of seagrass and seaweed beds is indispensable for their conservation. Although satellite data are used for coastal zone monitoring, atmospheric effects on the satellite data degrades classification of habitats. Low altitude observations using UAV can avoid such atmospheric effects. Hyperspectral image data are a powerful tool for detection of seagrass and seaweed beds. Thus, we develop a hyperspectral imaging sensor and a UAV as a platform of the hyperspectral sensor for habitat mapping in coastal areas, especially, mapping seagrass and seaweed species.
The hyperspectral imaging sensor developed by this study is designed to be light weight for payload and low cost for wide use,. The sensor scans an area and acquires data using optical fibers and swing mirror. Spectral data of a target ground or sea-surface are gathered at one side of optical fibers bundle. At the other side of optical fibers bundle, the spectral data are sequentially sent to optical fibers, which connected micro-spectrometer, by the swing mirror. The swing mirror is controlled by a stepping motor and the swing speed of the mirror is variable. Maximum eight micro-spectrometers manufactured by Hamamatsu Photonics are prepared. Each micro-spectrometer is connected optical fiber. One micro-spectrometer is used for sky light monitoring, and the other micro-spectrometers are used for spectral data of target earth surface. The total weight of the hyperspectral image sensor is less than 3kg.
We are developing two types of UAV as the platform for the hyperspectral imaging sensor. One is an unmanned airplane with fixed wings (UAS) and other is a multi-copter type drone. We planed the unmanned airplane for the large area survey and the multi-copter for the sea truth data at small area.

1. INTRODUCTION

Seagrass and seaweed beds play very important ecological roles such as spawning, nursery and feeding grounds for many marine organisms[1)]. However, they are sensitive to environmental changes and human impacts[2)]. Coastal zone monitoring is necessary for the conservation of seagrass and seaweed beds[3)]. Satellite data are used for the coastal zone monitoring[4)]. There are large atmospheric effects at the satellite data, and low altitude observations using UAV have the benefits of small atmospheric effects. Hyperspectral image data are powerful tools for determination of not only land plants but also marine macrophytes such as seagrass and seaweed species on the shallow bottom. Thus, we are developing a hyperspectral imaging sensor on UAV for the environmental study of coastal zone. At the 36th ACRS in 2015, we presented the outline of hyperspectral imaging sensor.
There are two type of observing requests: one is long flight range to target broad area and the other is easy operation and low cost to target near and narrow area. The first and the second requests led us to use an automated and unmanned airplane driven with a gasoline engine (Unmanned Aircraft System: UAS) and a multi-copter (Drone) driven with electric motor and battery, respectively. In our project, the members of the Japan Aerospace Exploration Agency (JAXA) develop an automated and unmanned airplane. We attached the floats with the UAV of aircraft type for taking off and landing at the seawater for the coastal zone monitoring. Innovation of this multi-copter type UAV is that it can land on not only the land but also the sea surface thanks to waterproof housing.
This paper introduces present development of the hyperspectral sensor and a multi-coper for environmental study of coastal zone

2. DEVELOPING SENSOR SYSTEM

A hyperspectral measurement system is made up about six years ago, and it could observe only nadir and the observed data were on flight line. New hyperspectral image sensor under development can get area data using a swing mirror. The spectral data of target earth surface are gathered by lens at one side of optical fibers bundle. At the other side of the optical fibers bundle, the spectral data are conducted to be given to optical fibers, which connected to micro-spectrometer, by the swing mirror. The swing mirror is controled by stepping motor and the swing speed of the mirror is variable. Hamamatsu Photnics manufactured micro-spectrometers with high performance (Mini-Spectrometer C12880MA-10) upon our special request. Five micro-spectrometers are installed. Each micro-spectrometer is connected to one optical fiber. One is used for sky light information and the others are used for spectral data of target earth surface. The total weight of the hyperspectral image sensor including waterproof case is less than 3.0 kg. Figure 1 shows the outline of the developed hyperspectral imaging system. The system using a swing mirror consisted of the following elements[5)-12)];

1) Micro-spectrometers: Five (in this case) micro-spectrometers are used in the sensor. One is used for the sky light information and four micro-spectrometers are used for spectral data of target earth surface. The spectral response range, the spectral resolution and the weight are 340-850 nm, 10 nm and 5 g, respectively (Fig. 3).
2) Lenses: Two optical lenses for the visible and near infrared are installed in the system. One is the telescopic front of the system and another is faced to the swing mirror (Figs. 2 and 3).
3) Swing mirror: A swing mirror is installed to scan the ground along a direction perpendicular to the flight direction. The mirror is controled by a stepping motor and the swing speed of the mirror is variable (Figs. 2 and 4).
4) Optical fibers: To make small size system of the hyperspectral image sensor, we use a bundel of optical fibers to guide light path compactly. The bundle consisted of 16 times 16 fibers at front end, and 16 times 17 fibers at swing mirror end. At the swing mirror end of optical fibers, 17 columns were connected to one micro-spectrometer. 6 fibers connected to 3 micro-spectrometers and 10 fibers were extra at the machine (Fig. 2).
5) Diffuser of skylight radiation: The skylight radiation transmitted from the optical fibers is scattered in diffuser for reducing the intensity. The spectral profile of the skylight radiation is measured when the diffused light is transmitted to the spectrometer (Fig.7). While low altitude observation is capable even under cloudy condition, the real-time observation of skylight radiation is required because of the temporally, spatially unstable radiation condition. One optical fiber transmits skylight radiation collected by a diffuser attached on the upper side of the UAV to the spectrometer.
6) GPS sensor: Position information is acquired by a GPS sensor (Fig. 7). An acquisition period is 0.1 sec. The position and time information obtained by GPS is sent to a data logger.
7) Embedded CPU system and data logger: Embedded CPU system for managing the data logger and swing mirror motor is located at the data logger board. The data from the four spectrometers and the GPS sensor are integrated and, then, stored in a 32 GB flash memory (Fig. 3). The Embedded CPU system and data logger board is connected with micro-spectrometers board.
8) Battery: A lithium ferrite battery, 12 V and 14 A*hrs, is the power source for the hyperspectral sensor system. Since the current consumption is less than 1A hr^{-1}, continuous observation is possible for 14 hours without changing battery (Fig. 3).
9) Wired remote controller: Preset parameters, a start/stop switch for data acquisition is out of waterproof case, and we can switch on or off after boarding the platform. (Fig. 7)
10) Movie camera: A drive recorder for an automobile (Model KNA-DR300, Kenwood Corporation, Japan) is used for obtaining footprint images automatically (Figs. 2and 5).
11) Tablet for system control: A tablet displays profiles of the observed spectral data and input sensor parameters, e.g., the exposure time and data acquisition period optionally.
12) Waterproof case: The hyperspectral measurement system was setup in waterproof case (Figs. 6 and 11).

3. DEVELOPING SENSOR PLATFORM

In our project, for suitable height observation and cost reduction, we want use unmanned aerial vehicle (UAV) at the platform. Multi coper is easily for operating and the cost is reasonable. By the way, large area observations are difficult by the multi-copter, because the speed of multi-coper is limited and operating time is short for the battery capacity. At the large area observation, the UAVs of aircraft type are suitable, because the speed of operation is very high and operating time also long using gasoline. We determined that both type of UAV would be used.

3.1 UAV of Aircraft Type

JAXA started the developing aircraft type UAV from fifteen years ago. At our project starting time, proto-type model already established. Of course, the UAV used about 200 - 300m runway, and it was difficult to find the runway at the

target coastal zone. We thought at sea, it was easily to find the runway for the UAV and wanted to take off the UAV from seawater. For the reason, we decided to develop the UAV of aircraft type with the floats to start from seawater. In our project, improvement of the proto-type UAV system to improve reliability/safety/stable automatic navigation capability for the hyper spectral imaging observation, and to attach the floats with the UAV for taking off and landing at the seawater.
In September 2017, the hyper spectral imaging observation at coastal zone at Sado Island using the aircraft type UAV were performed and we got successful results. The specifications of the aircraft type UAV are listed in Table 1, and the images of the UAV at Sado Island are shown in Figs. 8 -12.

3.2 UAV of Multi-Copter Type

Recently, a multi-copter type of UAV is being developed in a rapid pace. Thus, we decided to develop a multi-copter as a platform of the hyperspectral imaging sensor that enable easy operation at low cost. We are developing the multi-copter in collaboration with Prodrone Co., Ltd., Japan. The multi-copter also has the ability of autonomous flight. This system is applied for mapping seagrass and seaweed species around Sado Island and Izu Oshima in summer of 2016 to obtain the hyperspectral data for coastal zone monitoring. The specifications of the multi-copter are listed in Table 2, and the images of the multi-coper are shown in Figs. 13 -16.
Innovation of this multi-copter is that it can land on not only the land but also the sea surface thanks to waterproof housing. This innovation permits us to observe underwater bottom from the sea surface without sun glint (Fig. 16). Next strong point is an automated navigation system that enables to acquire hyperspectral data of 100% cover on target area with designed overlap between observation lines, while manual operations are used at the take-off and landing times. The automated navigations are used by the waypoints system. The hyperspectral measurement system in the waterproof case attached to the multi-copter could be beneath the sea surface without leaking (Fig. 16).
Recently, Multi-copter operational company were increased, and we can hire the company. In September 2017 at Sado Island observation, we used the multi-copter that was belonged one company for the hyperspectral observation, and listed the photos of the observation as Figs.17 and 18.

4. HYPER SPECTRAL OBSERVING RESULTS

Our project started at 1 October 2012, ant will be ending at 31 March 2016. The observations of hyperspectral image sensor operated from 2013 to now. Places of the observations were Erimo Cape in Hokkaido, Shizugawa Bay in Miyagi, Ryotsu Bay at Sado Island in Niigata, Memezu Beach and Akinoura at Oshima in Tokyo, Sotoura at Shimoda in Shizuoka, and Hamana Lake in Shizuoka.
Hyper spectral sensor on multi-copter was operated in Izu Oshima Island in Tokyo prefecture on 25 and 26 February, 2016. Flight courses and sea truth data are shown in Fig. 19. The flights were very stable, and automated navigation system performed perfectly (Fig. 19-22) and the results were presented at PITTCON 2017[13)]. In the target coastal zone, sea bottom surfaces were mainly covered with red *Gelidium* algae bed, Coralline algae bed, rock bed and sand bed. *Gelidium* species are commercial algae for food and health industry while Coralline algae aren't commercial ones. The hyper spectral imaging sensor performed very well to get good spectral reflectance of sea bottom surfaces. Natural color composite image could be produced by using the hyperspectral data (Fig. 20). Spectral patterns of three representative bottom beds were also obtained (Fig. 21). Using the hyperspectral data, we can get classification results (Fig. 22). The results are used for "Using plan of Gelidium" at Oshima area.
Our developed multi-copter and hyperspectral system was applied to costal observations off Shirase in Sado Island in the Sea of Japanese from July 25 to August 5 in 2016, and in Izu Oshima Island facing the Pacific Ocean from September 5 to 12 in 2016.

5. ACKNOWLEDGMENT

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Table 1 Specifications of Aircraft Type UAV

Developer: JAXA and Tokai University	Body material: Fiber-Reinforced Plastic (FRP)
Size: 2.7m (Length) X 4.2m (Wing span)	Engine: 2 stroke, gasoline 150cc
Weight: 55 kg	Payload: 5kg
Speed: 90 – 130km/hour	Operational altitude: < 500m
Navigation System: Automatic by GPS	Operating Time < 6 hours
Specialty 1: Taking off and landing at water	Specialty 2: Automated navigation system

Table 2 Multi-copter (Drone) Specifications

Maker: PRODRONE (Japanese company)	Rotor Type: Hexacopter
Specialty 1: Water-Resistant	Specialty 2: Automated navigation system
Motor Distance: 600mm	Propeller Distance: 432mm
Weight: 5.5kg	Height Size: 750mm
Maximum speed: 76km/hour	Flight Time: 10-50min
Flight Possible Wind Speed: < 10m/sec	Battery: 22.2V 12000mAh
Flight Possible Elevation: < 5000m	

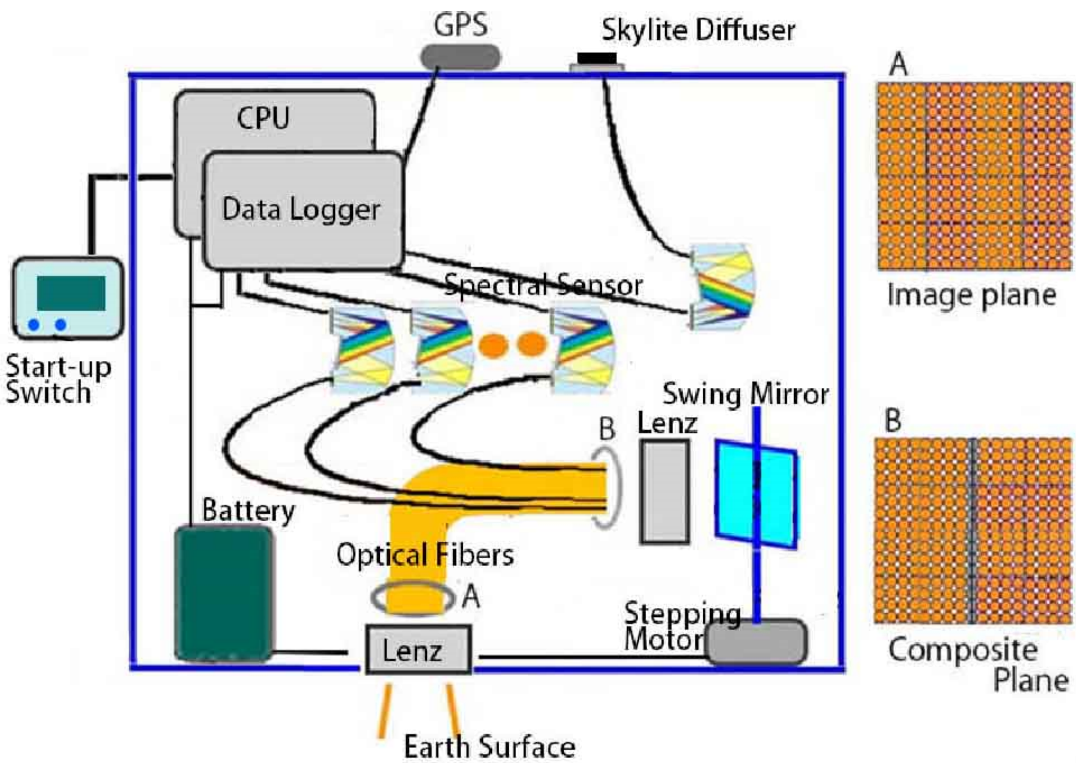

Fig. 1 Outline of the developed hyperspectral imaging system using glass fibers and a swing mirror

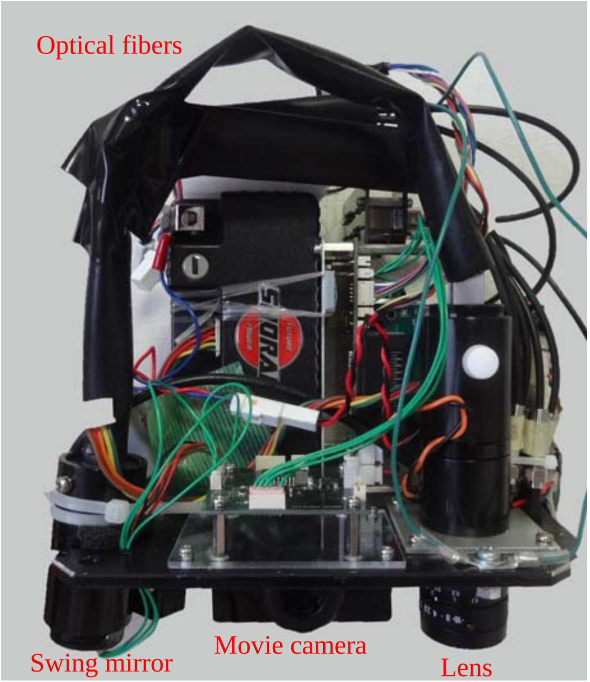

Fig. 2 Front side photo of
the hyperspectral image sensor

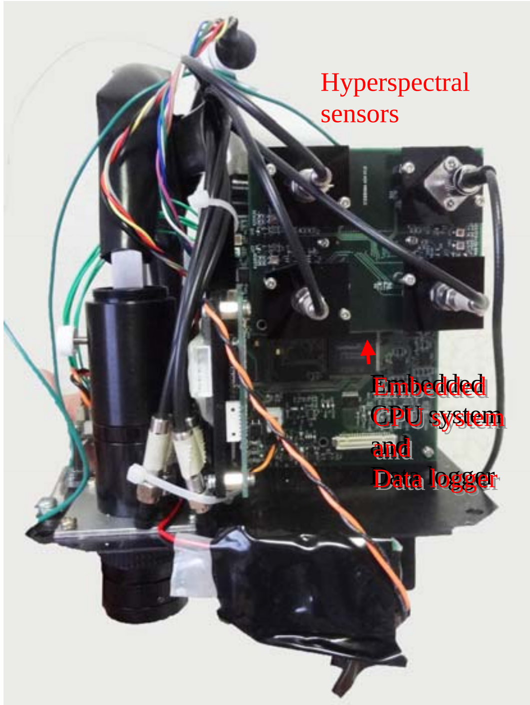

Fig. 3 Left side photo of
the hyperspectral image sensor

Fig. 4 Right side photo of
the hyperspectral image sensor

Fig. 5 Bottom side photo of
the hyperspectral image sensor

Fig. 6 Waterproof case for multi-copter

GPS

Diffuser
of skylight
radiation

Start-up switch and display
of condition

Fig. 7 GPS, Skylight diffuser and Switch

Fig. 8　Aircraft type UAV with 2 floats for the taking off and landing at water (Front)

Fig. 9　Aircraft type UAV with 2 floats for the taking off and landing at water (Side)

Fig. 10 Observation holes at the aircraft body

Fig. 11 The sensor set in the aircraft body (Front)

Fig. 11　The sensor set in the aircraft body (Side)

Fig. 12　Just taking off from sea surface

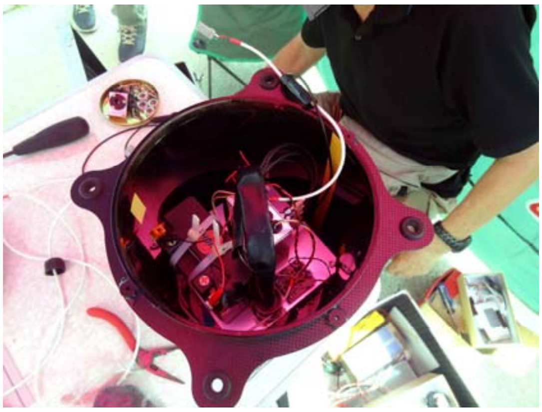

Fig. 13 Setting the hyperspectral imaging sensor

Fig. 14 The hyperspectral sensor with multi-copter

Fig. 15 Observation on coastal zone in Izu Oshima Island

Fig. 16 Observation on the sea bottom from the sea surface

Fig. 17 The sensor was mounted with ordinary multi-copter

Fig. 18 Observation on coastal zone in Sado Island mounted with ordinary multi-copter

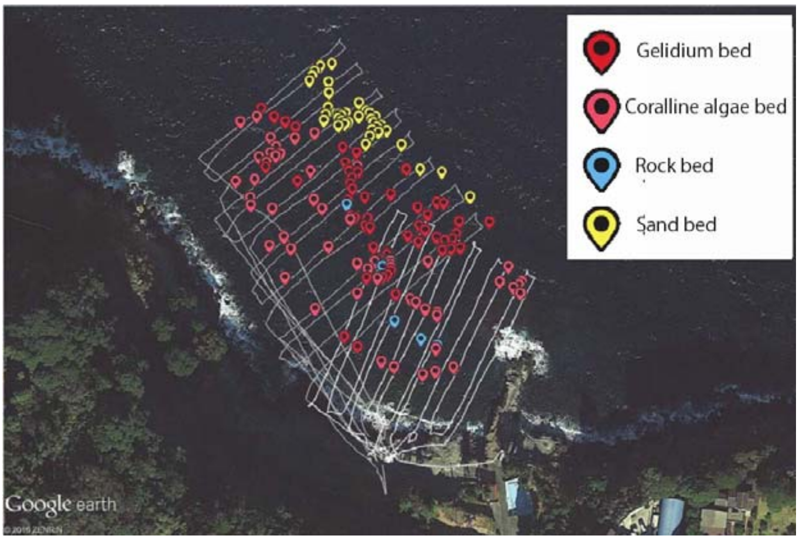

Fig. 19 Trace of flight course (lines) and sea truth data (marks)

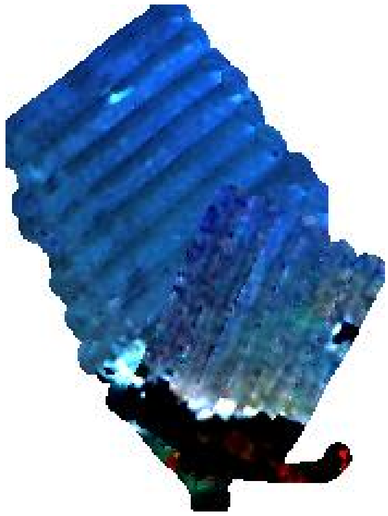

Fig. 20 Natural color composite of hyperspectral sensor.

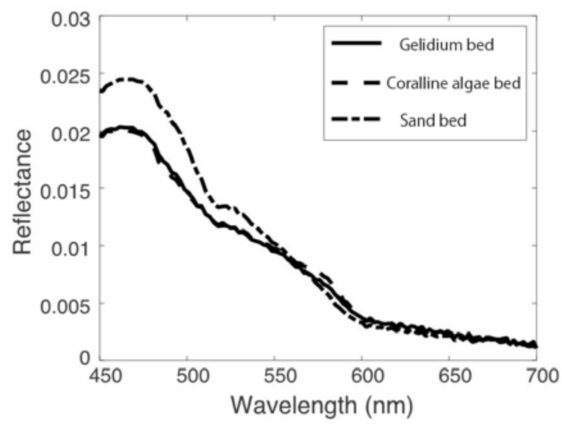

Fig. 21 Spectral reflectance of targets using the hyperspectral imaging sensor

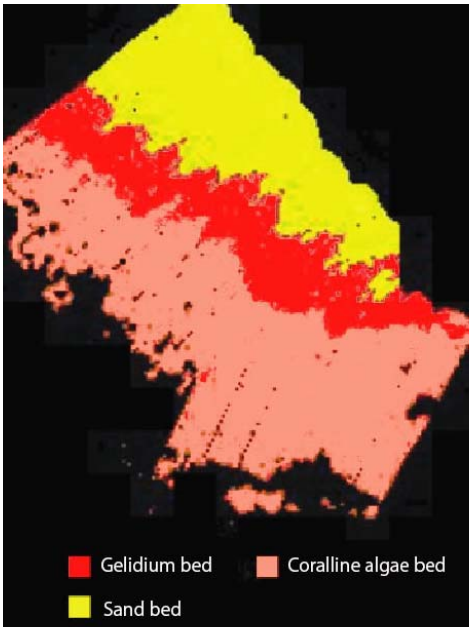

Fig. 22 Classification results of the observation at Izu Oshima Island