Development of Sensor Network for Ecology Observation of Seabirds

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SUMMARY It becomes so important to observe a wild life for obtaining not only knowledge of its biological behaviors but also interactions with human beings in terms of geoenvironmental investigation and assessment. A sensor network is considered to be a suitable and powerful tool to monitor and observe a wild life in fields. In order to monitor/observe seabirds, a sensor network is deployed in Awashima island, Japan. A sensor platform is useful for early and quick deployment in fields. Atlas, a server-client type sensor platform, is used with several sensors, i.e., infrared sensors, thermometers within a nest and a sound sensor. The experimental results and the first outcome of observation have been reported. Particularly emphasized is that an infrared sensor has detected a leaving and returning of seabirds, and has identified that a leaving and returning is affected by sunrises and sunsets. An infrared sensed data has also shown a chick’s practice before flying to the south. These facts and knowledge have not been clearly obtained by observation of human beings, so have demonstrated the usefulness of sensor networking for ecology observations.

key words: sensor network, ecology, seabird, streaked shearwater

1. Introduction

Streaked Shearwater, Calonectris Leucomelas as an academic name of genus and called as a shearwater for short hereinafter, is a seabird of about 50 cm from a top to a tail, 120 cm of outstretched wings and 0.5 kg of weight, and is listed in IUCN Red List of Threatened Species [1]. Shearwaters come to Japan and Korean Peninsula in Spring, lay only one egg per one breeding pair from June to July, and leave in Autumn to south-eastern Asia and Australia (see Figs. 1 and 2). Breeding place for the Shearwaters is designated as a national sanctuary or protected region in Japan. An ecological activity area of the shearwaters ranges so widely in the Pacific Ocean, and a seabird is a top order of predators in marine organization from plankton to fish. It is, therefore, important to investigate an ecological activity of shearwaters, by which we could obtain knowledge of ecological and geoenvironmental change and assessment.

So far, observations of seabirds have been carried out mainly by human beings (ecologists) with a limited set of equipment. A real-time and on-line observation has not been performed, for which Internet and related technologies can provide a valid and effective tool. We pick up Awashima island, i.e., one of breeding areas, and have developed a sensor network to observe ecology of Streaked Shearwaters. This research has been conducted jointly by a wildlife ecologist...
and Internet researchers. Presented in the following sections are 1) backgrounds and related works of this study, 2) how to construct a sensor network easily and quickly using an Atlas sensor platform, 3) design and implementation of sensors to check and verify ecological assumption, and 4) experimental results and new ecological knowledge obtained by the experiment.

2. Backgrounds and Related Works

2.1 Observation and Field of Streaked Shearwaters

Awashima is a small island, 4.4 km from the west to the east and 6.1 km from the north to the south, located in the north sea of Niigata Prefecture, Japan. There’re a few other islands with Streaked Shearwater’s breeding area in Japan as shown in Fig. 1, but all of them are so far from the mainland of Japan, and Internet facilities such as a broadband access are not available. It is, therefore, thought that Awashima island is the best place to develop a real-time and online observation system.

Sanctuary of Streaked Shearwaters in Awashima island resides on the west side, where steep walls and strong winds are suitable for the birds to make their nests. Almost residents live on the east side, and there’re no human beings in that sanctuary. It was reported that about 1,000 Streaked Shearwaters were observed in 1970, and 2,000 in 1990. But, a consolidated observation has not been done and reported. So, we have started a sensor network for observation of Streaked Shearwaters in Awashima island [2]–[6].

2.2 Current Observation Methods and Their Issues

Wildlife ecologists and researchers have been carrying out observation of seabirds with a very limited set of equipment. The use of sensor network has been reported [7], but it has not been extensively carried out so far.

The bio-logging is a method of logging a history of activities, for which GPS-based data logger is equipped to seabirds [8], [9]. This method is useful to know tracks of seabirds, particularly when seabirds fly around a wide area. But, data logger is so heavy and becomes a load to seabirds. It is, furthermore, difficult to pick up the seabird equipped with a data logger after a long period of observation.

In order to capture leaving and returning of seabirds, a study using a magnet has been reported [10]. In this study, a magnet is equipped to a seabird, and whose detection is observed at the front of a nest. A magnet is not so small, so becomes a load to seabirds. Furthermore, data logger to measure magnet detection is a lot of power consuming, hence only one or two nests can be observed.

Taking these conventional methods and their issues above, a sensor network is proposed for ecology observation in seabirds breeding fields. An advantage of a sensor network can also be found since it does not have an impact to environment and seabirds while human-beings’ observation may violate ecological nature and cause threats to seabirds.

In this study, infrared sensor is particularly proposed to capture leaving and returning of seabirds, whose method does not need any equipment to be loaded to seabirds.

3. Proposed Sensor Network for Seabirds Observations

3.1 Overall Structure of Sensor Network

Conventional observation systems for ecology are almost built with hardware-based data gathering and storing. Such a system is expensive, a lot of power consuming and difficult to be set up. A sensor network is a good solution to this problem, particularly for fields of ecology and biology observation where an easy and quick deployment is at most important.

There’re mainly two types of configurations for sensor networking. The first type is an ad-hoc network, where no centralized server is given and each sensor node will communicate autonomously. The second type of sensor networking assumes a server which connects all sensor nodes and provides, e.g., a storage of sensed data, computation, and interconnection with Internet and so on. We adopted the second type of configuration since 1) all data should be collected to a server, 2) configuration of sensor nodes can be pre-designed, i.e., autonomous routing is not necessary.

Figure 3 shows an overall structure of a sensor network developed in Awashima island. Atlas is a server-client type sensor platform being developed by Nagaoka University of Technology and Network Application Engineering Laboratories Ltd. in close relationship with University of Florida [11]–[13]. Various sensors can be connected to an

Fig. 3 An overall structure of sensor network to observe shearwaters.
Atlas sensor node, by which sensed data is then transmitted to an Atlas server. The Atlas server stores received data and can be accessed from Nagaoka University of Technology through the Internet.

3.2 Atlas Sensor Platform

A sensor platform will further facilitate this deployment by providing built-in data transfer between sensor nodes and a server. One can connect sensors to a sensor node, and then get data at a server.

Figure 4 illustrates an overview of an Atlas sensor platform. Two types of sensors can be supported by Atlas at present, 1) ON/OFF or Open/Short data and 2) analog or voltage data. One does not need to manipulate or program the Atlas node. ON/OFF data of one bit and analog data of 10 bits sampling can be sent to the Atlas server with specified intervals. The Atlas node supports up to 7 analog interfaces and 16 ON/OFF interfaces. The Atlas node is also quite small, 6.5 cm width × 6.5 cm length × 2.5 cm height, and is designed for a few power consuming. It can be operated by a solar battery, but is powered by commercial electricity in Awashima island.

Up to 16 Atlas nodes can be connected to one Atlas server. The Atlas server is nothing but a software package built over Java, and can be operated over any type of Java platform. In Awashima island, we use a Linux server for reliability and economic efficiency. With this Atlas sensor platform, several sensors and equipment have been installed in Awashima, whose functions are presented in the next section.

3.3 Ecological Assumptions and Sensors to Check and Verify those Assumptions

3.3.1 Infrared Sensors to Detect Leaving/Returning of Individual Shearwater

Ecological behavior of Streaked Shearwaters has still not been 100% investigated. For example, a shearwater is considered to fly around over thousand kilometers looking for a food. Once he/she leaves a nest, it is uncertain when he/she returns to the nest. A study of ecologists suggests that 1) he/she will fly during a night to avoid threats from animals, e.g., cats and human beings, and 2) he/she will utilize a wind to fly. But these have not yet been checked and verified yet. The purpose of an infrared sensor is to catch a leaving and returning of Streaked Shearwater.

An infrared sensor itself is the same as that for detecting human beings for security and so on [14]. We have found that such an infrared sensor can also detect the presence of seabirds. Figure 5 shows the detection area of an infrared sensor. A detection area for human beings, the left figure, is about 5 m, whereas a detection area for seabirds, the right figure, is narrowed to 2.5 m to 2 m by installing a sensor within a plastic case. This narrowed detection area is necessary and important since a sensor is expected to detect shearwaters just in the front of a nest.

3.3.2 Sound Sensor to Detect Leaving/Returning of Group of Shearwaters

It is also important to monitor a group of Streaked Shearwaters, since they leave and return as a group, and the time of their leaving and returning seems to be the same. We recorded a sound of shearwaters when they leave and return, and found that they sing with so strong sounds. After an analysis, it is identified that a frequency of these sings is typically 5.3 kHz (See Fig. 6(a)), which will be useful to distinguish their sound from background noises of sea waves. A circuit for filtering 5.3 kHz was designed and installed between a microphone and an Atlas sensor node. An output of this filtering circuit, as a voltage, is captured by an Atlas node. Figures 6 (a) and (b) show characteristics of a filtering circuit and how the circuit detects a typical sings of shearwaters.

In order to analyze data of sound sensors, which will be expected to show roughly the number of shearwaters, a wind, i.e., a direction and strength, needs to be measured. There’s a measurement equipment of the Meteorological Bureau at the east side of Awashima island, but a wind is so local phenomenon and is different between the east and west of the island. We have installed a weather sensor which can record a direction and strength of a wind [15].

3.3.3 Thermometer within a Nest to Observe Chick’s Metabolism

A chick of shearwaters has to wait for a quite a long time before parents give a food. According to ecological assumptions, it is considered that a chick is keeping its base...
metabolism as low as possible during that period. A thermometer within a nest provides the amount of activity, whereby metabolism of a chick could be derived.

3.4 Installation of Sensor Network

Figure 7 shows the field and nests of Awashima island where sensors are installed. We have installed:

- 8 infrared sensors at the front of 8 nests to detect a leaving/returning of seabirds,
- 5 thermometers within 5 nests and one to monitor an outdoor temperature, and
- One sound sensor and one network camera at a power supply station, i.e., close to nests.

A network camera is directly connected to the Internet, whereas three Atlas nodes have been used to connect sensors, i.e.,

- One Atlas node connects 8 infrared sensors,
- One Atlas node connects 6 thermometers, and
- One Atlas node connects one sound sensor.

Although Atlas node can support multiple types of sensors per a node, one type of sensors is connected to one node since this is the first experiment in the field and the simple implementation is considered safer for observation.

Three Atlas nodes are fed with 5 [V] DC converted by 100 [V] AC power. AC power and Ethernet cables are provided for about 50–60 [m] from the power supply station to the area of the nests. The area is located in the west side of Island, so there expected so heavy rain and wind. In order to prevent rains, a waterproof power cable is used and junctions are carefully protected. A normal CAT5 cable is used for Ethernet. Atlas nodes and associated devices, e.g., DC converter, are installed in a plastic case to prevent rains. These installations have been done for only two days of two researches. This is because 1) all devices and their setting have been done previously in the university, and 2) the network of this experiment is configured with a single star topology, hence it is easy to install in the field.

4. Experimental Results and Some New Ecological Knowledge

4.1 Leaving and Returning Pattern Derived from Infrared Sensors

Although the research project has just started, there’s a useful data observed by the sensor network. Figure 8 shows output (ON/OFF) of an infrared sensor placed in the front of a nest for 24 hours profile. In Fig. 8, ON indicates that an infrared sensor detects seabirds, and OFF means nothing detected. So, vertical lines indicate that a shearwater is going in and out of the nest. Data was taken on the middle of July, when shearwaters were breeding their chick. From Fig. 8, it is observed that 1) shearwaters are leaving for looking for food around 2-4 am, 2) they are returning to a nest around 8-11 pm, and 3) they are not in the nest for the rest of hours.

Eight infrared sensors are installed in an ecological area, so we’ll be able to extract some commonality among them. After those analyses and evaluation, we finally reach
indeed data by chicks who are practicing to fly at the front of nests and gone to the south this time, so these scattered data are not the ones by the parent shearwaters. These dots are indicated by a circle, in both Figs. 9 (a) and (b). The parent shearwaters had left a nest and are leaving before sunrises, and their leaving time is shifted along with sunrises. The same phenomenon can be observed in Fig. 9 (b). As clearly indicated in Fig. 9 (a), shearwaters are leaving before sunrises, and their leaving time is shifted along with sunrises. The same phenomenon can be observed in Fig. 9 (b) as to returning and sunsets.

We further pick up a new fact and knowledge from Fig. 9. There are scattered data, indicated by a circle, in both Figs. 9 (a) and (b). The parent shearwaters had left a nest and gone to the south this time, so these scattered data are not the ones by the parent shearwaters. These dots are indeed data by chicks who are practicing to fly at the front of a nest. After a sufficient amount of practice, a chicks loses weight, gets thin and will be ready to fly to the south.

Observation by human beings can not obtain the precise and continuous data of leaving and returning, hence the fact and knowledge above, i.e., leaving and returning is affected by sunrises and sunsets, is the first discovered by observation with the sensor network. Furthermore, chicks are so cowardice and do not come to the front of nests when human beings are there. So, chick’s practices indicated in Figs. 9 (a) and (b) are also quite a new and evident knowledge for ecological study of shearwaters.

Although an infrared sensor provides so useful and new data as mentioned above, it can not distinguish between male and female shearwater. It is under study to introduce RFID to monitor shearwaters as the next step.

4.2 A Group Leaving and Returning and Their Relationship with Winds

Figure 10 (a) shows output of the sound sensor which indicates a group of Streaked Shearwaters’ returning. Note that the date of Fig. 10 is different from that of Fig. 8, hence leaving/returning time is slightly different between two figures. The result of sound sensor shown in Fig. 10 (a) suggests that the amount of data is related to the amount of shearwaters. We have processed the sound sensor data by utilizing LPF (Low Pass Filter) to suppress noise, i.e., mainly sea waves.
Table 1  Sampling intervals and amount of data.

| Sensor | Sampling Interval | Data | Data per Sensor/Day |
|--------|-------------------|------|---------------------|
| Infrared | 800 [msec] ON/OFF | 1.1 [MB] | |
| Thermometer | 500 [msec] | 1.6 [MB] | |
| Sound | 200 [msec] | 9.5 [MB] | |

Table 2  Observation periods and total amount of data.

| Sensor | The Number of Sensors | Period | Total Amount of Data |
|--------|------------------------|--------|----------------------|
| Infrared | 8 | 7/20–11/23 | 975 [MB] |
| Thermometer | 6 | 8/27–11/23 | 737 [MB] |
| Sound | 1 | 7/13–11/23 | 1.22 [GB] |

4.3  A Chick’s Activity within a Nest

Ecological assumption shows that a chick keeps its metabolism as low as possible while waiting parents. In order to observe this assumption, 6 thermometers were installed in the field, i.e., 5 within nests and one to monitor an outdoor temperature. Figure 12 shows the experimental result of these 6 thermometers.

As shown in Fig. 12, temperatures within nests are kept almost constant even when an outdoor temperature is changing. Ecological study indicates that the optimum temperature for a chick is 15–28 degrees C, whose range is indicated in Fig. 12. From Fig. 12, we could conclude that this optimum temperature is maintained from the end of August, i.e., chick’s birth to the beginning of November, i.e., chick’s leaving to the south.

Due to a constraint in the field, a nest with infrared sensor is not the same as a nest with thermometer. When we can compare and analyze data of both infrared sensor and thermometer, some new knowledge may be obtained. This is for the next step of the project.

4.4 Results of Camera Observation

A study of ecologists also suggests that Streaked Sheawaters do not fly to/from nests during daytime. This has not been proven yet and been difficult to observe since seabirds do not show them if human beings (ecologists) are around the nests. We have recorded a video remotely from a network camera for several days, checked the recorded video carefully, and finally found that Streaked Sheawaters never fly to/from nests during daytime. In the next step, we’ll try an infrared camera to capture Streaked Sheawaters during night.

4.5 Amount of Data and Bitrate of Sensor Network

As mentioned in Sect. 3, we have installed 8 infrared sensors, 6 thermometers and 1 sound sensor, with 3 Atlas nodes. Table 1 shows sampling intervals and data per sensor and day. Table 2 indicates the total amount of data for the observation period. The total amount of data for the observation period resulted in 2.93 GB, which seems to be small and could be stored in an Atlas server.

The bitrate at the ingress of the Atlas server was about 16.1 kb/s, which also is small and sufficient for wired Ethernet connections. It is, however, necessary to reduce the amount of data and bitrate considering the future expansion of the sensor network, e.g., broader area for observation, use of wireless connection such as ZigBee. An approach for that
may include a dynamic sampling in which infrared data will be transmitted only when it detects shearwaters. These are left for the future improvement of this sensor network.

4.6 Troubles and Evaluations of Sensor Network Itself

Although the filed is the area of a heavy rain, wind and humidity, Atlas sensor network has worked so well and no Atlas node has been broken. There’re some troubles of installation for three months experiment as follows;

- AC power and Ethernet Cable near the power supply station were cut by mowing of residents, which was immediately monitored and recovered. We should display more clear sign on the experiment field next time.
- One infrared sensor was broken due to a plastic case broken and flooded. Since this outage was also monitored remotely, a broken sensor was replaced within a few days. There’s a possibility that seabirds prong the plastic case. So, we’ll paint the case with more invisible color next time.
- There’re two disconnections of simple twisted pair cables between Atlas node and sensors, caused by steps of human beings (researchers of ecologists). We’ll try to make cable installed underground next time.

The cost of this sensor network includes about JPY 5,000 for one infrared sensor and about JPY 2,000 for one thermometer. Although an Atlas node is under development and its cost is for further consideration, the cost of sensors for this experiment is considered reasonable and has no problem for expanding it to larger network. Note that we need only one sound sensor which is composed of a microphone and a developed filtering circuit, whose components cost less than JPY 3,000.

5. Conclusions

A sensor network can be effectively used for monitoring and observing a wild life to understand its ecological behavior and interactions with geoenvironmental assessment. In this paper, we have reported on how a sensor networking has been developed and used for observation of Streaked Shearwaters in Awashima island, Japan. We have used Atlas sensor platform with infrared sensors, thermometers and so on. All these sensors themselves are less expensive and are not special ones, i.e., available on the market. So, we expect that this experiment may also be applicable or considered as useful examples for other wildlife observations.

The first outcome of observation has also been reported in this paper. Particularly emphasized is that an infrared sensor has detected a leaving and returning of Streaked Shearwaters of the nest, and has identified that a leaving and returning is affected by sunrises and sunsets. An infrared sensed data has also shown a chick’s practice before flying to the south. These facts and knowledge have not been clearly obtained by observation of human beings, so have demonstrated the usefulness of sensor networking for ecology observations. A sound sensor has indicated that the more a north-west wind is strong, the more likely the number of returning Streaked Shearwaters.

The project has just started jointly by a wildlife ecologist and Internet researchers, and needs to be improved to further clarify ecological behavior of Streaked Shearwaters. Use of RFID to distinguish between male and female is an example for the next step. It is anticipated that a sensor network be used more widely for a wildlife and environmental observations.

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