Developing a Water Temperature Observation Network based on a Ubiquitous Buoy System to Support Aquacultures

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Abstract—**The authors have been working on the support of the fishery industry using the information and communication technology. A water temperature observation network is proposed for supporting aquacultures, and a ubiquitous buoy system developed for this purpose is described. The ubiquitous buoy system was created by leveraging ubiquitous sensing technology with water temperature observation buoys that can be executed for $1,000, a figure designed to meet the demands of scallop cultivation fishermen. Since there are no base stations and gateways in marine environments, we selected mobile phones for the Internet connection to send the water temperature data by email. The ubiquitous buoys developed are light weight and of a compact design, and can be easily installed in marine fishery environments. Furthermore, the economic cost allows the buoys to be used in multiple point observation systems. Consequently, not only does the system allow water temperature observations in real time, but it can also be used in future applications to build water temperature observation networks using multiple ubiquitous buoys that share water temperature data and allow analysis of multipoint, multi-layer water temperature data, and thus facilitate efforts to visualize the makeup of water temperature distributions below the surface. Forty ubiquitous buoys have been placed in scallop cultivation regions along the coast of Hokkaido, and the water temperature data is starting to be used.**

Index Terms— **Sensor Network System, Buoy, Aquaculture, Low-Power Sensor Node, Mobile Phone**

I. Introduction

In typical aquacultures carried on coastal regions such as scallop cultivation, Japanese *konbu* (kelp) aquaculture or Japanese *nori* (seaweed) aquaculture, fishermen will determine the timing of various fishing tasks primarily according to the water temperature. However, there are currently no systems available for providing water temperature information to fishermen in real time, and currently such fishermen must based their decisions using water surface temperature observations from boat-mounted or portable thermometers, or rely on predictions based on one-month old temperature data supplied by the Fisheries Experiment Stations.

For example, cold water masses that drift in every year during summer are responsible for large-scale death and damage in the scallop cultivation region in Usuya, on the west-coast of Hokkaido, Japan. However, such cold water masses move at deeper depths making them extremely difficult to predict based on surface water temperature readings, and currently there are no real solutions to detect it immediately. Furthermore, damage caused by *hydrozoa* parasites during the latter half of shipping season every year is a problem afflicting *konbu* aquaculture on Hokkaido's Rishiri Island. It is known that *hydrozoa* parasites occur more frequently when the water temperature exceeds 17°C, so real-time observations of water temperature are expected to reduce parasitic damage to the kelp crop. Additionally, planting cycles for *nori* aquaculture in Miyagi Prefecture's Matsushima Bay are conducted when the surface water temperature reaches around 23°C, and the surface water temperature is currently measured by sending a vessel to the aquaculture regions every day using a portable thermometer.

As this demonstrates, not only is information about water temperature extremely crucial to fisheries, but there is currently no system available for providing water temperature data of aquaculture region in real time to fishermen. Thus, this research seeks to develop a wide-area water temperature observation network for the purpose of supporting the aquacultures using existing ubiquitous sensing technology, which has traditionally only been researched in land-based applications. This research extended existing ubiquitous sensing technology for marine environments, and developed ubiquitous buoys capable of providing fishermen with real-time temperature data of aquaculture region.

Marine observation buoys can be used to acquire water temperature data in real time. However, conventional marine observation buoys [1] are not used in aquaculture region since they are typically large (weighing hundreds of kilograms) and expensive (costing tens of thousands of dollars each). Furthermore, even if such buoys were installed to detect the presence of cold water masses, single-point observation would be failed to observe flow speed, direction or volume and multipoint observations using several buoys must be required.

Recent years have witnessed greater use of water temperature data due to the development of midsized marine observation buoys (weighing less than 100 kg and costing several tens of thousands of dollars) for commercial fishing industry such as the RAS buoy [2] [3] and Marine Eye [4]. Nonetheless, visualizing the composition of water temperature distributions below the water surface requires using multiple observation points, which calls for making significant developments in reducing buoy size and cost. Based on these observations, this research developed a compact and low-cost ubiquitous buoy that can be installed by each fisherman for taking multipoint, multilayer measurements of water temperature in aquaculture region.

The MOTES [5] used in the Smart Dust project are a well-known example of a test bed for ubiquitous sensing technology. In the Smart Dust project, wearable sensor nodes called DOTs and indoor sensor nodes called MICA were developed. MOTES are currently the most commonly used sensor node, and are used in research concerning the sensing room temperature for managing air conditioning systems [6], for structural monitoring of buildings [7], and for analyzing walking patterns in the health care industry [8]. The U^3 (U-cube) [9] is a typical indoor sensor node.

Many types of sensor nodes have been developed for field sensing applications. For example, a wireless sensor module powered by solar cells featuring a special low-power wireless transmission unit was used in the Expo AMEDAS [10] environmental observation unit featured in the 2005 World's Exposition in Aichi Japan. For marine sensing, there is the Microcube [11] [12] [13] featuring a stackable structure that was developed by the authors. However, usage of these types of sensor nodes was limited to system evaluations or short-term testing, and there are many cases of special sensor nodes being developed for actual usage in the field. Consequently, a factor affecting the development of such sensor nodes for field sensing is that the purpose of the nodes is clear, which forgoes the versatility gained by developing a general-purpose sensor node platform. So, there is a need to develop sensor nodes that are compact, energy efficient, feature long-distance transmission capabilities appropriate for the intended environment, and with a casing that accounts for field conditions, that is, being water proof, drip-proof, cold resistant and shock proof. By way of example, Field Servers [14] are sensor nodes outfitted with wireless LAN technology specially developed for field sensing.

This research considers ubiquitous buoys as a type of specialized sensor node for marine sensing applications. Since base stations, gateways and relay nodes cannot be installed in marine environments, and wireless transmissions cannot be used underwater, current sensor node technology cannot be used for marine sensing applications due to limitations imposed by the usage environment. As a result, this requires developing purpose-built sensor nodes for such applications. Building a ubiquitous buoy required developing a compact, energy-efficient control board equipped with a mobile phone data transmission card, and inexpensive water temperature thermometer capable of multilayer temperature observations.

II. System Requirements

A. Ubiquitous Buoy Environmental Requirements

Aquaculture of *konbu* and *nori* occurs within 2 kilometers away from the coastline, and cultivation of scallops typically occurs within 10 kilometers of west-coast of Hokkaido near the area of Onishika, despite one area extending beyond 10 kilometers. As a result, the environmental requirements for the ubiquitous buoy system are determined by the aquaculture region located within 10 kilometers from the coast. The maximum depth of the aquaculture region is 50 meters.

B. Water Thermometer Precision Requirements

In observations performed by the Fisheries Experiment Stations using data recording water thermometers, a water temperature data logger called a TidbiT [15] is used. The temperature measurement precision of TidbiT is $\pm$ 0.2˚C, and according to an interview held with fishermen from the Usuya Branch Youth Group of the Shinsei Marine Fisheries Cooperative, a local Hokkaido organization engaged in scallop cultivation, water thermometers designed for aquaculture purposes need to have the same precision as the TidbiT and be capable of recording from 0 to 25˚C. Furthermore, it was also confirmed that a minimum of 10 water depth layers would need to be measured in order to properly observe the water temperature at different depths in detail. The real-time observation is also required in the scallop cultivation since scallop is especially vulnerable in the rapid change of water temperature.

C. Buoy Shape and Cost Requirements

Due to their large size, typical ocean observation buoys require large cranes to be in installed and extensive mooring set ups, which can run installation costs up into the tens of thousands of dollars. As a result, the ubiquitous buoys needed to be sized so they could be manually installed using a small fishing vessel (less than 10 kg), and they needed to have a design that allowed anchoring the buoys using existing aquaculture facilities. Additionally, during the interview a target cost of $1,000 was set for a buoy that could be installed individually. Since the water thermometers used in conventional marine observation buoys already cost in the range of $1,000, it was essential to develop a water thermometer capable of multiple depth temperature readings that uses a compact, energy efficient control board in order to create a ubiquitous buoy that is both compact and economical.

III. System Structure

A. Ubiquitous Buoy Composition

The ubiquitous buoys were developed for the purpose of observing water temperatures in coastal aquacultures. Mobile phones were selected as the method for data transmission. Currently, mobile phone technology can be used in almost every coastal region domestically in Japan. Using mobile phone technology allowed an observation system to be constructed easily since using mobile phones not only allows temperature measurements to be initiated at any time and any location, but the phones can also directly connect with the Internet. The RAS and Marine Eye buoy systems mentioned previously also employ mobile phone technology as the means of data transmission. Also, the US QREB [16] ocean observation buoys along coastlines use mobile phones.

B. System Composition

The composition of the system is indicated in Figure 1. The ubiquitous buoys are mounted with a mobile phone data transmission card, and the buoys send recorded water temperature data as an email after connecting to the Internet using a dial up connection. A Web database server with a fixed address is also set up on the Internet to handle data storage and delivery. The Web database server connects with a mail server every 5 minutes, and receives email when an email is present, and the water temperature data is then stored into the database. Each mail address that sends water temperature data is unique, allowing specific buoys to be recognized from the subject line of each email.

System users can access the Web database server via a PC or mobile phone browser, and can view water temperature data in graph or text formats. Also the Web database server has an automatic warning mail delivery option that sends the user a warning email when a rapid change in water temperature is detected that crosses some preset threshold value. Emails from the ubiquitous buoys also contain information about that buoys battery voltage, with warning emails automatically sent out when battery voltage becomes low, suggesting a battery replacement.

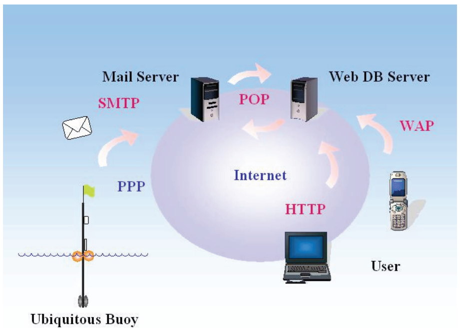

Figure 1. Schematic diagram of ubiquitous buoy system.

IV. Water Thermometer Development

A. Composition and Installation of the Water Thermometer

Water thermometers available on the open market typically cost several thousands of dollars, and since such technology is not capable of multistage connectivity, such thermometers would not work with this project since the same number of communication cables and control board interfaces would need to be developed for each thermometer used in the project. Consequently, a water thermometer was developed for this project that uses an RS-485 multidrop interface. Given that the maximum water depth was 50 meters, the water thermometers in this system were battery powered since the conductor resistance using an external power supply from the control board would be around 40 ohms per kilometer. Figure 2 shows the water thermometer used in this project. A low power PIC12F683 (Microchip) was selected for the micro-controller. The water temperature sensor uses a thermistor, and calculates the water temperature by converting the resistance in the thermistor from an analog to digital signal. Table 1 indicates the specifications of the water thermometer.

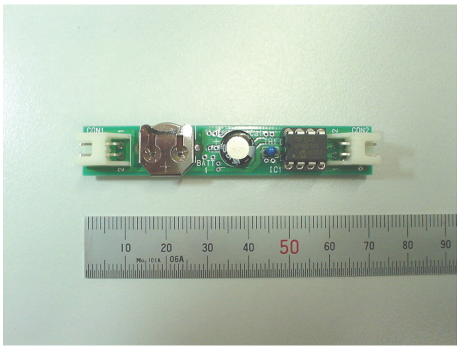

Figure 2. Circuit board of developed thermometer.

Table 1. Specifications of Circuit Board of Thermometer.

Controller	PIC12F683 (Microchip)
Interface	RS-485 half-duplex
Sensor	103AP-2 (SEMITEC) thermistor
Standby current	1uA, typical
Operating current	390uA, typical
Measurement range	-10˚C to +25˚C
Size	70mm×12mm
Weight	5g
Battery	CR1220 lithium battery

Double-core cabtyre cables connect the control board and water thermometer, allowing a maximum of 16 water thermometers to be connected to a single cabtyre cable. The water thermometers are normally in sleep mode, but are activated in unison when a polling signal is received from the control board, and return to sleep mode once again after recording the water temperature and sending a response. When recording the water temperature, the analog signal is converted to digital three times, and the median value used for the water temperature. Furthermore, each water thermometer was assigned with an ID from 0 to 15, so that data conflict was avoided by controlling the timing of data transmissions using time slots determined for each thermometer ID.

The length of the transmission data including the thermometer ID and water temperature data was 7 bytes, and the transmission speed was 1,200 bps, which required a total transmission time of 64 milliseconds since 11 bits are required to send 1 byte of information. The transmission time slot was set at 200 milliseconds to provide ample waiting time in order to prevent endless loops from occurring due to noise in the system. The nominal capacity of the batteries was 40 mAh, which allows one measurement per hour for a total span of two years.

B. Calibration Test

The water thermometers were placed inside water-proof casings constructed using silicon molds (one component epoxy RTV rubber) since the casings had to maintain water-proof under water pressures found at 50 meters of water depth. Also, since the analogue to digital signal conversion used to calculate water temperature was based on a conversion table created using a datasheet, it was necessary to confirm the time responsiveness of the measuring precision and water temperature conversion. Then, a high precision XR420-CTD Conductivity Temperature Depth Profiler (CTD) used for marine environmental observations was used as a reference to calibrate the water thermometers.

The calibration was performed by filling a plastic container (49.5 x 27.5 x 29. cm depth) with 20 liters of tap water and submerging the CTD and water thermometer while the two units are fastened with a band, then recording the water temperature for 24 hours at 3-second intervals after inserting two 1.7 kg pieces of block ice. The water temperature data retrieved from the CTD and water thermometer are indicated in Figure 3. This calibration test was performed in standing water.

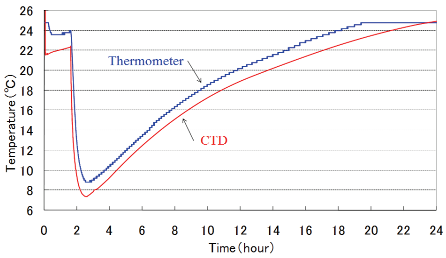

Figure 3. Calibration result of thermometer.

Since the water thermometers were molded out of silicon, the response to water temperature change was delayed, with approximately a 10-minute delay observed when compared with the results of CTD. Moreover, due to a discrepancy in water temperature observed, the following calibration equation (1) was derived based on linear approximation using 20,400 data points acquired from the time the lowest water temperature was observed at 2.5 hours past the start of the test until 19.5 hours had elapsed when the water temperature had became saturated.

$$Tc = 0.9842T - 1.1373 . \qquad (1)$$

In this equation, T represents observed water temperature, and T_C is the water after calibration. Figure 4 indicates the distribution of measurement error after calibration. Using the calibration equation allows a measurement precision in this test that is ± 0.2°C.

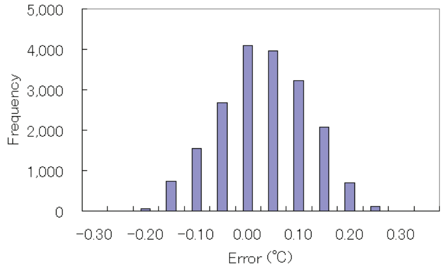

Figure 4. Distribution of error after calibration.

V. CONTROL BOARD DEVELOPMENT

A. Preliminary Investigation using a Prototype Buoy

From 2004 to 2006, a preliminary investigation was performed in the ocean in a scallop cultivation region near Usuya district on the west-coast of Hokkaido, Japan using a prototype buoy [17][18]. The control board of the prototype buoy used a Microcube. Figure 5 shows the conditions of the preliminary investigation using the prototype buoys. The preliminary investigation yielded the following results.

- Mobile phone technology can be used within 10 kilometers away from the coastline.
- Stable data transmission requires an antenna that is at least 1 meter above the water surface.
- Battery life during winter significantly dropped when compared with summer.
- The water thermometer developed for this study could be used continuously at a depth of 50 meters.
- Compared with the water surface, significant water temperatures differences were observed along with the vertical direction.

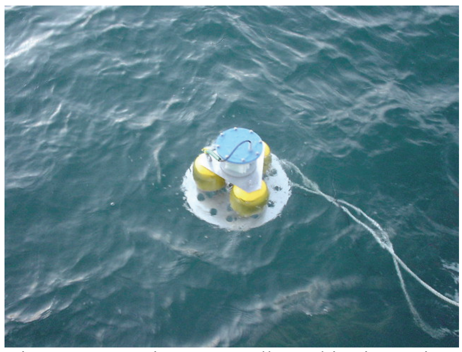

Figure 5. Experiment on scallop cultivation region.

Since the prototype buoy could not continually operate in winter for more than one week when using four UM-1 type alkaline dry batteries, the Usuya Branch Youth Group of the Shinsei Marine Fisheries Cooperative performed the test run determined that batteries would have to maintain in winter for at least three months in order to be practical. As a result, a marine alkaline dry cell (a battery pack using four UM-1 type alkaline dry cells) that is used for general marine sign light systems was selected given the need to have a power source that is easily workable and available for replacing batteries at sea.

B. Control Board Development

In order to properly develop the ubiquitous buoy system, the buoy control board needed to be as compact and energy efficient as possible. Consequently, a control board specifically developed for this project was designed by completely removing redundancies like the PC interface and extended bus interface from the control board used in the prototype buoy. Specifications of the developed control board are indicated in Table 2, and an image of it is shown in Figure 6. The main feature of this control board is that the unit uses a double CPU made from the main-CPU and sub-CPU. Each CPU has its own individual power supply, with the main-CPU handling water temperature data transmission, making the dial-up Internet connection, and sending email, and an energy efficient sub-CPU controlling the power supply of the main-CPU, giving the entire board an energy efficient design. HD64F3029F (Renesas) was selected for the main-CPU, which was equipped with a specifically built protocol stack [19] for making the PPP connection. An energy efficient micro-controller similar to the one used in the water thermometer was selected for the sub-CPU. The sub-CPU starts the main-CPU once every hour, and stops the main-CPU when either the main-CPU interrupts or times out after 60 seconds.

After the main-CPU starts, 1) the data transmission card configures, 2) the water thermometer polling signal is sent, and 3) the water temperature data from each water thermometer is collected. Next, 4) the Internet connection is made using a dial-up connection, 5) water temperature data is sent by email, and 6) an interrupt signal is sent to the sub-CPU. Approximately 30 seconds of operation time are required to complete steps 1 through 6.

TABLE 2. SPECIFICATIONS OF CONTROL BOARD.

Main-CPU	HD64F3029F (Renesas)
Main clock	16MHz
Protocol stack	Smalight PPP (Renesas)
Sub-CPU	PIC12F683 (Microchip)
Sub clock	31kHz
Standby current	170uA
Size	80mm×50mm
Weight	22g

A compact flash card slot was installed on the control board, and control board operation was confirmed using three types of mobile phone data transmission cards. The types and current consumption for each data transmission card are indicated in Table 3. DoPa is a TDMA type data transmission card, and FOMA is a W-CDMA type data transmission card. System users can ultimately select the transmission type that is serviced in the target marine region.

Using the marine type alkaline batteries allows continuous operation in excess of eight months even during winter when the temperature falls below freezing, since the standby current is controlled up to 0.2 mA.

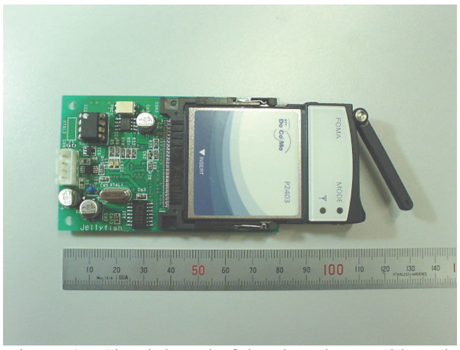

Figure 6. Circuit board of developed control board.

TABLE 3. OPERATION CURRENT OF DATA COMMUNICATION CARDS.

Data communication card	DoPa MAX 2896F	FOMA P2402	FOMA P2403
Operation voltage	3.3V	3.3V/5.0V	3.3/5.0V
Standby current	0.2mA	0.2mA	0.2/0.2mA
Operation current	269mA	326mA	272/188mA
Operation time	30sec	27sec	25/19sec

VI. INSTALLATION

A. Ubiquitous Buoy Composition

Figure 7 shows a sketch of the outer dimensions of the typical ubiquitous buoy. The compact design of the specifically developed control board allowed the use of readily available fishing gear floats, without the need to develop a special floating device.

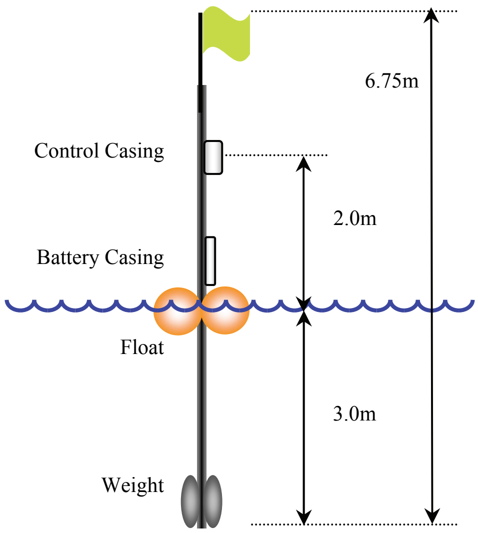

Figure 7. Sketch of ubiquitous buoy.

The ubiquitous buoys were constructed using a fishing pole since the data transmission needed to occur at least 1 meter above the water surface in order to establish the stable communication. Furthermore, the control board and battery pack were located separately so the buoy would float in a more stable position, and the batteries could be replaced more easily. This was done by placing the control board in a waterproof casing on the upper portion of the pole, and placing the heavier battery case in the middle of the pole closer to the surface of the water. Specifications for the control board and battery casings are indicated in Table 4. Both the control board and battery casings were made in a round design that allowed the casings to be easily installed on the pole using hose bands. For the casing material, 5 mm thick polyacetal was used in order to prevent damage should the buoy be struck by a small fishing vessel. Additionally, the water thermometers and transmission cables were attached to the buoy's mooring rope as indicated in Figure 8.

A main feature of this ubiquitous buoy system is that the buoys are made with readily available fishing gear, and can be manually installed relatively easily by a few operators at low cost as indicated in Figure 9.

TABLE 4. SPECIFICATIONS OF CONTROL BOARD AND BATTERY CASINGS.

Size of control board casing	ϕ 60mm×210mm, 593cm^3
Weight of control board casing	460g
Size of battery casing	ϕ 50mm×355mm, 697cm^3
Weight of battery casing	568g
Material	Polyacetal
Weight of battery	575g

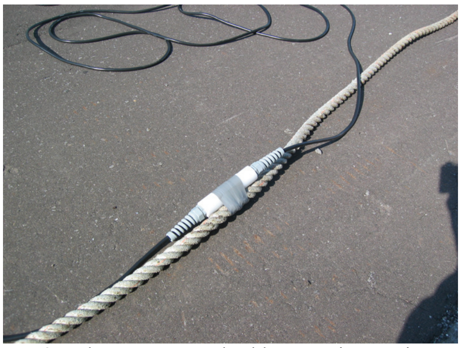

Figure 8. Thermometer and cable set up in mooring rope.

Figure 9. Handling of ubiquitous buoy.

B. Ubiquitous Buoy Installation

Currently, the ubiquitous buoys are supporting aquacultures in the Usuya region on the west-coast of Hokkaido, the Shikabe region on the south-coast of Hokkaido, and the Soya region on the north-coast of Hokkaido as shown in Figure 10. Installation methods and distance from the coast for each buoy vary at each location.

In the Usuya region, the buoys are primarily operated by the Youth Group of the Shinsei Marine Fisheries Cooperative for the purpose of taking water temperature recordings in scallop cultivation regions. However, in the Soya, the buoys are used to measure water temperature for both scallop cultivation and *konbu* aquaculture, and the buoys are operated primarily by a Fisheries Experiment Stations. Operation methods for the main service regions are indicated in Table 5. Now, a total number of 40 ubiquitous buoys have been put into service.

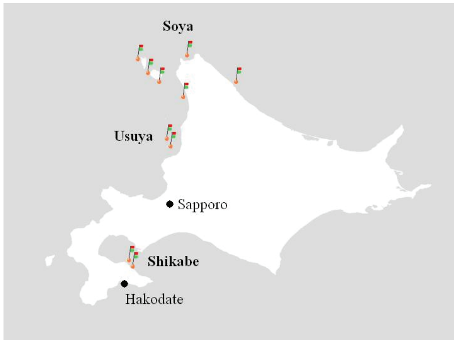

Figure 10. Supporting aquaculture regions of Hokkaido.

TABLE 5. SUMMARY OF OPERATIONS.

Region	Kind of aquaculture	Number of buoys	Beginning of operation
Usuya	Scallop	5	September, 2006
Shikabe	Scallop	2	March, 2007
Soya	*konbu*	3	May, 2007
Soya	Scallop	5	August, 2007

VII. EVALUATION AND OPERATION

A. Evaluation in the Usuya Region

The first evaluation of the ubiquitous buoy system was performed in the Usuya scallop cultivation region located nine kilometers out on the west-coast of Hokkaido. Two ubiquitous buoys were installed into scallop cultivation equipment in a region of the ocean 50 meters deep that recorded temperature data at five water depths (3, 10, 20, 30, and 40 meters). Figure 11 shows a buoy in operation. During the evaluation, the main rope was located at a depth of 20 meters, and anchored above the 20 meter water thermometer. The scallop cultivation equipment is indicated in Figure 12. The main rope is laid out parallel to the surface of the water, and scallops in cages suspended from the main rope. The depth of the main rope can be freely adjusted, allowing fishermen to prevent damage to the scallops by selecting the water depth with the most favorable temperature for scallop cultivation.

The evaluation period was from September 13 to October 24, 2006. Current and past water temperature data can be easily accessed on the Web database server and displayed in a graph, allowing fishermen to intuitively see changes in water temperature. Figure 13 shows a graph of daily temperature variation during

September 20, 2006. As a result of Typhoon Number 13 hitting the scallop cultivation region on this day, a 5˚C temperature difference was observed between the surface and lower depth of water at 6 AM, with the temperatures becoming even at noon due to the ocean getting stirred up by the typhoon. Figure 14 shows the temperature variation during a one week period starting October 4, 2006. Around the first hour of October 8, the water temperature at 40 meters starts to fall, followed by a sudden drop in water temperature at 30 meters about half a day later (around noon). Finally, the water surface temperature also drops a small amount. As this graph indicates, the multilayer observations of water temperature contain a vast amount of useful information, and allow subtle observations of water temperature change. For example, the graph in Figure 14 suggests that changes in water temperature at lower depths may be influencing the temperature at the water surface. Furthermore, despite the typhoon hitting the region during the evaluation period, only two transmission errors were received out of 958 transmissions, yielding a transmission success rate of 99.8%, which suggests this system is highly practical for actual usage.

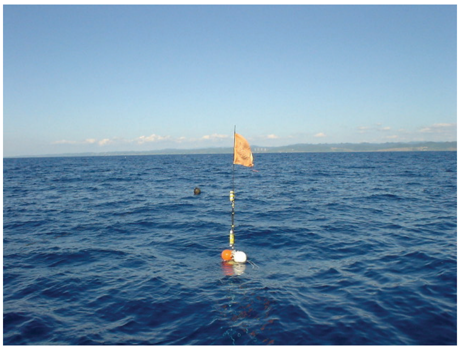

Figure 11. Evaluation in Usuya scallop cultivation region.

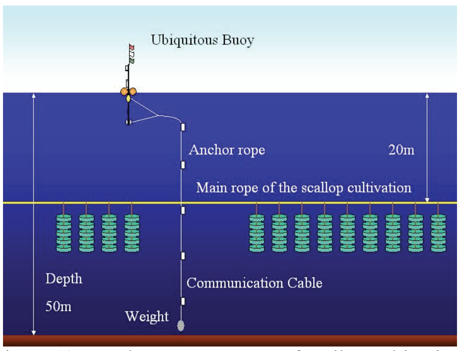

Figure 12. Underwater structure of scallop cultivation.

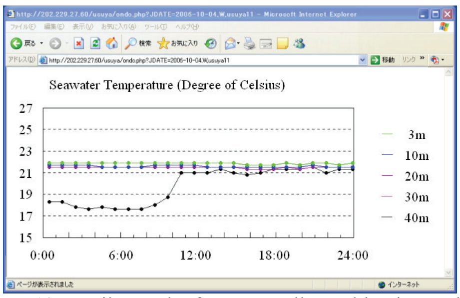

Figure 13. Daily graph of Usuya scallop cultivation region.

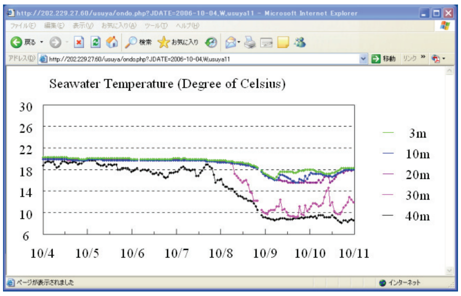

Figure 14. Weekly graph of Usuya scallop cultivation region.

B. Operation in the Usuya Region

Two ubiquitous buoys capable of recording water temperature at 10 different water depths were installed in a scallop cultivation region located 10 kilometers out from Usuya in August 2007. Since the evaluation revealed that significant water temperature changes were observed at 10-meter intervals, especially in the vertical direction from the lower water depth, it was decided to take temperature readings at 5-meter intervals, for a total of 10 water depths, from 5 to 50 meters. The two ubiquitous buoys were installed approximately parallel to the shoreline, and separated from north to south about five kilometers. Comparing water temperatures from the same water depths using 467 observations taken from August 8 to 27, 2007 shows that water temperature varies significantly according to water depth. The average temperature change at 5 meters depth was 0.2˚C with a maximum of 1.0˚C observed, and the average change at 50 meters depth was 0.6˚C, with a maximum of 3.4˚C. The transmission success rates for each buoy up until August 27 was 99.8% (one error out of 478 transmissions) and 100% (zero errors out of 517 transmissions).

An additional three ubiquitous buoys were installed in September 2007, for a total of five buoys, allowing water temperature data to be analyzed at 47 points. Currently this data is being used to visualize the makeup of underwater temperature distributions in the 5 km x 5 km Usuya scallop cultivation region.

C. Observation Using a Recording Water Thermometers

Given that water temperature was recorded in one-hour intervals in the Usuya region, it is possible that short-cycle water temperature variations were not observed. Consequently, the TidbiT mentioned previously was used in 2007 to investigate the suitability of the one-hour observation interval by taking closely packed temperature readings every 3 minutes from August to October, a period when water temperature variation is most pronounced. The TidbiT unit was installed in the same form as the ubiquitous buoys to a fishing indicator pole, and recorded water temperature at 10 depths, at 5-meter intervals up to 50 meters depth. Figure 15 shows the water temperature variation at 5, 25 and 50 meters, and Figure 16 shows the power spectrum at 50 meters. As a result, it was found that short-cycle temperature variations up to two hours that cannot be detected at one-hour observation intervals comprised 12% of the power at

5 meters, and 25% of the power at 50 meters, indicating that short-cycle variations increase at lower water depths.

However, experience with scallop cultivation has shown that scallop damaging cold water masses occur over a couple of days, and the scallops are capable of withstanding minute variations in water temperature. Furthermore, even if the observations were taken at 30-minute intervals, short-cycle variations undetectable up to one hour would comprise 10% of the information at 5 meters, and 22% at 50 meters, which when compared to the observations taken at one hour does not constitute a significant difference. Consequently, observations taken at one-hour intervals were deemed appropriate for supporting the needs aquacultures.

Furthermore, observation intervals directly impact system operation time by affecting transmission costs and battery life, so need to be set at an appropriate level. Using a one-hour interval, the transmission costs for one month around $20, and allow for over eight months of continuous operation time even when the temperatures dip below freezing in winter.

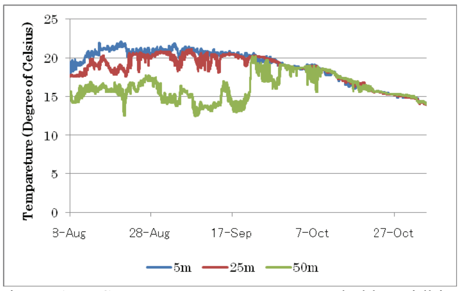

Figure 15. Seawater temperature recorded by TidbiT.

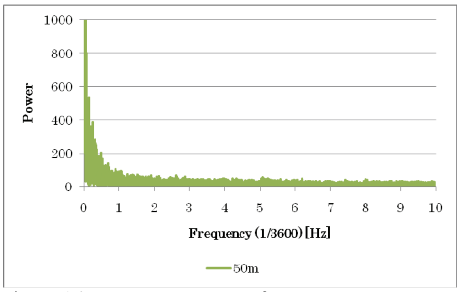

Figure 16. Power spectrum of seawater temperature.

D. Ubiquitous Buoy Applications for Coral Reef Preservation

Given the ubiquitous buoy system uses mobile phone technology as the data transmission method, there is no need to install base stations or gateways in each ocean region, and observations can be initiated at any time or location with ease. As a result, the project provides a wide-area sensing system appropriate for Japanese coastal areas. Looking at the advantages of this buoy system, a similar ubiquitous buoy system was installed in April 2008 in Okinawa, a southern island of Japan, that is a site of one of the world's remaining coral reefs. The system installed in Okinawa was modified to record temperatures from -10˚C to +40˚C since Okinawa is in a subtropical region.

Preserving and restoring Okinawa's coral reefs is currently an important research initiative in Japan, with many coastal engineering and ecology experts engaging in coral related research. Bleaching, a main problem afflicting coral reefs, is closely related to water temperature, and providing multipoint, multilayer information about water temperature over a wide area would provide a valuable data source for many researchers. For this reason, water temperature observations were conducted using the TidbiT unit described previously. However, not much data has been acquired from this unit yet because the data needs to be acquired after collecting the TidbiT data logger from the buoy, and the buoy was temporarily lost when it drifted away due to the many typhoons that hit Okinawa. For these reasons, building a temperature observation network using a ubiquitous buoy system was suggested to the Coral Preservation Committee of the Japanese Coral Reef Society. Not only would a ubiquitous buoy system allow water temperature measurements in real time, but the system has the advantage of storing the data on onshore servers, which prevents data loss in the event a buoy is lost in a typhoon. Currently, the committee is conducting a preliminary investigation for installing a ubiquitous buoy system in the *Sekisei* coral reef as indicated in Figure 17, the largest in Japan, with plans to start real-time water temperature observations from May, 2008. Multipoint, multilayer observations of water temperature in the *Sekisei* coral reef are expected to yield detailed algorithms describing the bleaching phenomenon happening to coral reefs. It is also expected this system will provide useful information for planning actual strategies for preserving coral reefs and selecting locates for coral reef transplantations.

Figure 17. The *Sekisei* coral reef.

VIII. CONCLUSION

This paper described a water temperature observation network for supporting aquacultures, and reported on the development of a ubiquitous buoy application. Hokkaido's scallop industry is worth an average of $160 million a year, with damage occurring to 10% of the harvest each year. The Usuya's cultivation exports $4.5 million worth of scallop shellfish every year, but has experienced 30% damage to the harvest caused by cold water masses. Consequently, the ubiquitous buoy system is expected to be a useful tool not only for fishermen, but also for the Fisheries Experiment Stations.

In the Usuya and Shikabe scallop cultivations, the ubiquitous buoy system is already providing real-time temperature data that will be used to prevent selecting scallops directly after a rapid change in seawater temperature, which can weaken the scallops and damage the harvest. The ubiquitous buoy system features a compact and lightweight design, allowing it to anchor to existing aquaculture equipments, plus it can be easily installed by small fishing vessels under one ton, allowing for rapid system scalability.

In the future, it is hoped that additional ubiquitous buoy systems are employed for water temperature observations over wide areas around the entire coastline of Japan, allowing all observation data to be made available on the Internet [20].

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