Prospects of the future squid fishing based on the big data

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***Abstract*—In this paper, we propose a new approach to squid fishing that makes use of shared information. A typical squid fishing vessel is outfitted with 10 or more automatic squid jiggers lined along both sides of the vessel and controlled from the wheelhouse via a single control panel. All of the jiggers are centrally controlled from this panel, which typically has a monitor that provides the operator with real-time data on the operating mode and motor load of each jigger. In addition to determining the cumulative tonnage of a catch, such information can be overlapped upon vertical water temperature profiles to graphically depict a fishing ground and support highly detailed inferences of its location and extent. A squid jigger is comprised of a drum, around which is wrapped a wire that strings together a series of lures and sinkers. The drum is swiveled to move the lures up and down. Based on the idea that this commonly used device should be utilizable for the automatic measurement of water temperature profiles, we aimed to develop a ubiquitous sensor that can meet this criterion while also being easily used by fishermen at sea. Through 32 field trials, we confirmed that our device can repeatedly measure the water temperature distribution down to a depth of 300 m. Also, through direct comparison with oceanographic instruments mounted on actual research vessels, we were able to verify that the measurements produced by our device at thermoclines varied by no more than 1.3 °C from the values produced by such instruments. We are currently working to improve the response rate of our ubiquitous sensor with an eye toward real-world application.**

Keywords—squid fishing; big data; water temperature; sensor

I. INTRODUCTION

Water temperature can have a strong effect on the behavior of fish and other aquatic species. Thus, to efficiently harvest coastal fishery resources, fisherman must keep close track of water temperatures and associated shifts in fishing grounds and seasons, a task complicated by the trends of global warming. In this paper, we examine the application of big data methodologies to squid fishing, which not only occupies a particularly active corner of the fishing industry within such East Asian nations as Japan, South Korea, and China, but is also among the most automated areas within that industry.

In Japan, the squid fishing fleet is comprised of 3,632 vessels, 3,554 of which have a displacement of less than 30 tons and typically operate in coastal waters. In terms of domestic consumption, squid (Japanese flying squid *Todarodes pacificus*, also known by its Japanese name *surume-ika*) ranks second among the various types of seafood and caught approximately 70,000 tons (2013). Note, however, that over the 21 years from 1993 through 2013, the domestic squid catch (tonnage) has declined by approximately two-thirds, while crude oil prices have quadrupled. To maintain a sustainable, economically viable squid fishing industry, fishermen are asked to cut costs, particularly fuel costs. There are two general approaches to the maximization of fuel efficiency. One is to quickly and dependably locate productive fishing grounds. The other is to use energy-efficient LED lamps as squid attractor lights instead of metal halide lamps. In this paper, we focus on the application of big data methodologies to the first problem, more specifically, to inferencing of the location of productive fishing grounds.

Squid fishermen have long based their craft on experience and intuition. Veterans would keep a close eye on the progression of the seasons, including, for instance, the timing with which a given flower would bloom, and then use this information to infer when and where to look for promising fishing grounds. In recent years, though, such experience/intuition-based rules have lost their dependability amid global warming and associated changes in the marine environment.

Japanese flying squid are acclimated to water temperatures of 12 °C to 23 °C [1]. However, the thermal structure off the Japan coastline is notable for its complex intermingling of warm and cold currents, such that an area having a surface water temperature of more than 20°C might have a bottom water temperature of less than 10°C. Conversely, there are even areas where the bottom water is warmer than the surface water. Such complexity makes it difficult to infer the location of promising fishing grounds with only the surface water temperatures.

Squid fishing off the northern Japanese island of Hokkaido is conducted from June to the following January by vessels from both Hokkaido and elsewhere (Figure 1). According to statistics from the Ministry of Agriculture, Forestry and Fisheries, the 2013 squid catch off Hokkaido was approximately 29,600, corresponding to 37% of the nationwide total. Yet, while squid fishing remains an important economic pursuit in Hokkaido, annual catches have been declining yearly. For example, squid fishermen operating out of Hakodate (a major Hokkaido port) reported an aggregate catch of only 22,833 tons in 2013, compared to the aggregate catch of 50,617

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tons reported for 2003. One possible factor behind this decline is the increase in water temperature caused by global warming. As water temperatures rise, fishing grounds shift, such that past experience no longer serves as a reliable guide for locating productive fishing grounds. Professor Sei-ichi Saitoh of the Hokkaido University Faculty of Fisheries Science, has been monitoring surface water temperatures by remote sensing and providing fishermen with his data [2]. Yet, because the strong influx of the *Oyashio* Current along the Hokkaido coastline produces highly stratified temperature profiles (the temperature of water near the surface is often very different from that near the bottom), the only way to dependably infer the location of a promising fishing ground is to directly measure temperature profiles in the vicinity.

Fig. 1. Squid fishing vessel.

Here, by improving the accuracy of such information and, by extension, the dependability of the inferences derived from it, we seek to contribute to the energy conservation efforts of squid fisherman by reducing the amount of fuel they must expend to find these promising fishing grounds. Professor Saitoh estimates that a typical squid fishing vessel consumes approximately 900 liters of fuel per night, with about 10–20% of that spent in search of productive grounds.

The waters off Hokkaido are periodically monitored by three research vessels operating out of nearby Fisheries Research Institute. These vessels patrol the waters with CTD (conductivity/temperature/depth) profilers, the data from which are used to create water temperature profiles. Note, however, that measurements are only taken six times a year at 179 points, and thus the resulting profiles do not have the temporal and spatial density necessary for the effective/efficient inferencing of fishing grounds. There are, however, 394 squid fishing vessels in Hokkaido and if these vessels could also be used to measure water temperature profiles, the accuracy of the data and associated inferences would rise markedly.

There are two obstacles to such a plan. First, CTDs are expensive, running anywhere from 800,000 to 1 million yen. There is therefore the need for a low-cost alternative within the means of a typical squid fisherman. Second, CTDs are complex scientific instruments, designed to be operated by highly technically skilled researchers. Here, we need an easy-to-use alternative readily operable by a fisherman at sea. We therefore aimed to develop a ubiquitous sensor that combines low-cost with operational simplicity.

Figure 2 presents a conceptual image of a system for collecting data from ubiquitous sensors to use in inferring the location of promising fishing grounds. This fishing ground inferencing system is comprised of ubiquitous sensors to gather data, a tablet PC and related applications to handle and display data, a cloud server and associated database to collect and store data, and a cloud server–associated website to distribute data. The big data aspect indicates the manner in which all this information is brought together to create water temperature profiles.

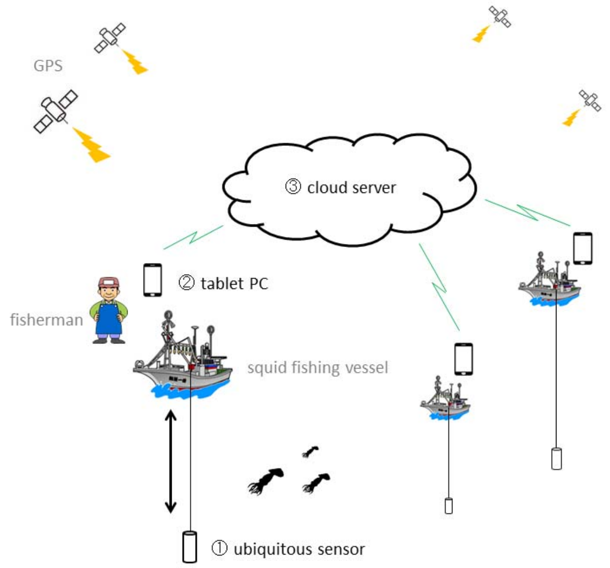

Fig. 2. Conceptual image of the fishing ground inferencing system.

II. Development of a Ubiquitous Sensor

We began by determining specifications for a ubiquitous sensor from the core assumption that it is to eventually be applied as standard equipment on a typical squid fishing vessel. As stated in *Fishing Encyclopedia of Hokkaido*, squid fishing is normally conducted in fishing grounds at depths of 70–200 m, and so we set the maximum operating depth to 300 m. These and other specifications are shown in Table 1. To minimize cost, we set our measurement range at -5 to 40 °C. As the Tidbit (Onset) water temperature data logger utilized by Fisheries Research Institute to compile long-term water temperature data records in 0.2 °C increments, we chose this same +/-0.2 °C precision for our system.

A. Selection of a wireless module

To facilitate on-site operation by fishermen, we selected a tablet PC as our device for controlling the ubiquitous sensors and displaying measurement data. We next had to choose a wireless module to transmit measurement data from the sensors to tablet PCs.

Tablet PCs are generally equipped with Wi-Fi and Bluetooth communications capabilities by default. However, we elected not to use Wi-Fi because of its comparatively high power consumption, instead focusing on the three types of Bluetooth modules shown in Table 2. All three modules can connect to the CPU within the sensor via UART (Universal Asynchronous Receiver Transmitter), but since only the RN-42 can support SPP (serial port profile), it was selected as the wireless module (the cB-OLS425 module can support SPP in a virtual mode, but mounting a virtual SPP mode would have forced us to reconsider the CPU specifications).

TABLE I. UBIQUITOUS SENSOR SPECIFICATIONS

Parameter	Value
Waterproof	300 m
Memory	200 points
Measurement range	-5 to 40 °C
Accuracy	+/-0.2 °C
Dimensions	73 (D)×234 (L) mm
Weight	1.5 kg
CPU	PIC16F1825 (Microchip)
Thermistor	B57504K (EPCOS)
Pressure transducer	PX2AN1XX500PSACX (Honeywell)
Wireless module	RN-42 (Microchip)

TABLE II. COMPARISON OF BLUETOOTH MODULES

Model	BLE113	cB-OLS425	RN-42
Bluetooth version	Bluetooth v4.0	Bluetooth v4.0	Bluetooth v2.0
Sensitivity	-93 dBm	-91 dBm	-80 dBm
Transmit power	1 dBm	3 dBm	4 dBm
Profiles	GATT, GAP L2CAP, SMP	GATT, GAP	GAP, L2CAP SDP, SPP
Dimensions	15.7×9.1 mm	21.5×15.1 mm	25.8×13.4 mm
Supply voltage	2.0 to 3.6 V	2.0 to 3.6 V	3.0 to 3.6 V

B. Ubiquitous sensor operating modes

Our ubiquitous sensor has three operating modes—a measurement mode, a transmission mode, and a wait mode. In the wait mode, which is intended to minimize power consumption, the sensor awaits a control command from the tablet PC. Here, the sensor repeatedly "sleeps" for 16 seconds and then "awakens" for four seconds to check for any incoming control commands. If it receives a command, the sensor switches over to either the measurement mode or transmission mode as directed. In the measurement mode, the sensor records measurement data; and, in the transmission mode, it transmits that data to the tablet PC. Both modes are provided with a timeout function, which automatically returns the sensor to the wait mode after 10 minutes of inactivity.

Temperature and pressure sensor data are initially collected as analog signals. In the measurement mode, these signals are converted to digital data using a 10-bit analog to digital (A/D) converter contained within the CPU. The digitized temperature and pressure sensor data is then temporarily stored within internal memory. Because the number of data points is limited to 200, the data within the memory must be sent on to the tablet PC after each measurement.

C. Control commands

Table 3 shows some of the major control commands for the ubiquitous sensor. The “@” mark indicates the start of a command, and the three letters that follow define the command. For example, @SET is the command to “set” the sensor; in other words, to shift to the measurement mode and, accordingly to clear all pre-existing measurement data from internal memory. Similarly, @GET is the command to shift to transmission mode. @UTC and @POS are commands to set sensor time (in coordinated universal time (UTC)) and position, respectively, as explained more fully below. @BAT retrieves the battery voltage and @NUM retrieves the number of measurements taken since the battery was last replaced.

Date/time is expressed in the format YYYYMMDD, hhmmss. Likewise, position is expressed as latitude/longitude in the format +/-dd.ddddd, +/-dd.ddddd, with “+” indicating either north latitude or east longitude and “-“ indicating either south latitude or west longitude. So, to set sensor date/time to, for example, 2015 March 15 09:00:00 and sensor position to 41.12345N / 141.12345E, one would send the following control commands to the sensor:

@UTC,20150315,090000<CR><LF>

@POS,+41.12345,+141.12345<CR><LF>

TABLE III. MAJOR UBIQUITOUS SENSOR CONTROL COMMANDS

Command	Function
@UTC	This command sets the time data
@POS	This command sets the position data
@SET	This command causes to enter measurement mode
@GET	This command causes to enter transmission mode
@BAT	This command returns the battery voltage
@NUM	This command returns the number of measurements

D. Case design

The main printed circuit board of our ubiquitous sensor is shown in Figure 3; and the temperature and pressure sensors are shown in Figure 4. The battery is enclosed within a waterproof case capable of withstanding pressure down to 300 m. The temperature and pressure sensors are mounted on a stainless steel (SUS 304) base that also serves as a cover for the case. The case itself is made of polyoxymethylene (POM) and is held in place with six stainless steel guide bars. A drawing of the case is presented in Figure 5.

E. Development of the tablet PC application

We also developed an application to, among other function, transmit control signals from tablet PCs to ubiquitous sensors. First, as for the tablet PC, we selected the Panasonic FZ-B2B502KBJ, which features a high degree of dust and moisture resistance. It runs on the Android 4.4 operating system. In addition to being able to send control commands to ubiquitous sensors, this application can display measurement data and also relay measurement data from the ubiquitous sensors onto a cloud server. Figure 6 shows positional data as mapped on a tablet PC screen by the application, and Figure 7 shows measurement data as graphed on that screen to produce a water temperature profile. Measurement data is sent from tablet PCs to the cloud server in the form of e-mail messages, with the subject line containing an ID to identify the ubiquitous sensor and the body containing measurement data from that sensor.

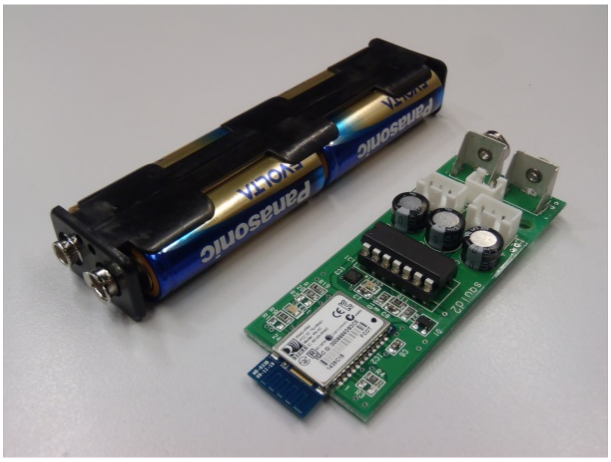

Fig. 3. Printed circuit board within ubiquitous sensor.

Fig. 4. Pressure sensor and temperature sensor.

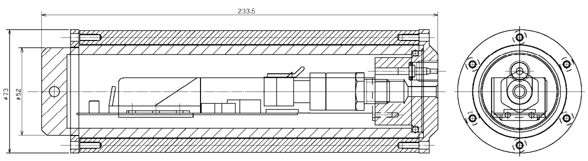

Fig. 5. Ubiquitous sensor case.

F. *Cloud server development*

We configured a cloud server running Debian as the operating system, PostgreSQL as the database engine, and Apache as the web service. We also developed a PHP program that receives e-mail messages sent by the tablet-based application and stores the measurement data they contain within a database. A server-associated website distributes data to the tablet PCs, enabling them to also display historical data.

Fig.6. Mapping of measurement data.

Fig.7. Graphing of measurement data.

III. UBIQUITOUS SENSOR EVALUATION

We conducted 32 test trials to evaluate the performance of our newly developed sensor. Of these, we conducted 25 trials with the *Hakusan-maru* research vessel of the Ishikawa Prefecture Fisheries Research Center, three trials with the *Hokuyo-maru* research vessel of the Wakkanai Fisheries Research Institute, and four trials with the *Hidemori-maru* a small fishing vessel affiliated with the Shikabe Fisheries Cooperative Association. These trials had three general objectives; to calibrate our sensor; to assess its ease of use on actual fishing vessels; and to evaluate its response characteristics.

A. *Sensor calibration*

Our ubiquitous sensor is comprised of a temperature sensor and a pressure sensor, both of which output an analog signal for conversion into a 10-bit digital signal by an A/D converter contained within the CPU. Taking the measurements from a Sea-Bird CTD mounted on the *Hakusan-maru* as the true value, we determined a conversion equation to compute the digitized data to water temperature/depth values. Figure 8 presents an onboard view of a calibration test. Sensor measurements entail some scatter; to derive calibration lines able to accommodate such scatter, we took four sets of measurements with three ubiquitous sensors and one CTD. Taking the A/D output value of the nth temperature sensor as T_n and the A/D output value of the nth pressure sensor as D_n, we arrived at the following linear equations to express water temperature as in (1) and water depth as in (2) as functions of those values.

$$Water\ temperature\ (n) = 0.1123T_n - 25.664 \quad (1)$$

$$Water\ depth\ (n) = 0.4841(D_n - D_0) \quad (2)$$

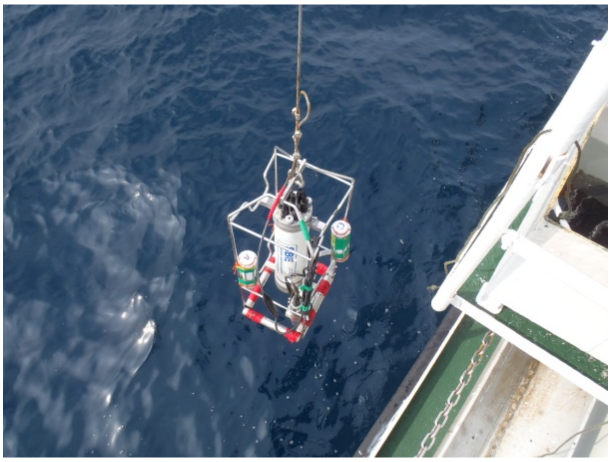

Fig. 8. Calibration testing on the *Hakusan-maru*.

B. Ease of use

To assess the ease of usage of the sensor in operation at sea, we conducted two trials on the *Hidemori-maru*, one in summer (August) and the other in winter (December). Figure 9 is a scene from the summer trial. The sea is generally calm in the summer and rough in the winter. Through these trials, we verified that a single unaided operator can quickly and easily take a temperature profile under both of these sea conditions using the tablet PC. The operator was also able to graphically display the profile (see Figure 7).

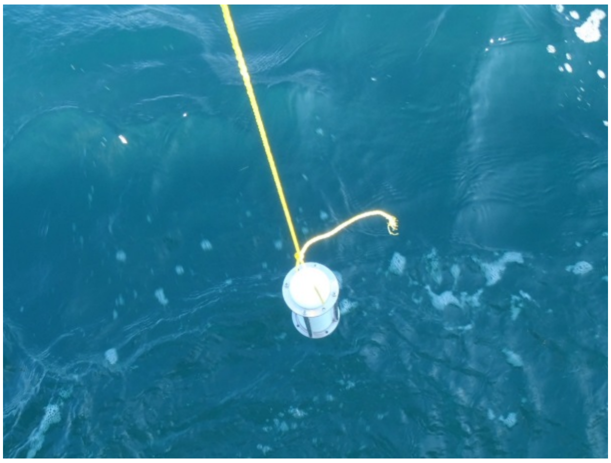

Fig. 9. Trial on the *Hidemori-maru*.

C. Responsiveness

Figure 10 compares a temperature profile obtained with our ubiquitous sensor against a profile obtained by a CTD. The research vessel here was the *Hakusan-maru*. It is generally recommended that oceanographic instruments be lowered into the water at a rate of no more than 1 m/s; and thus we here lowered the sensor and CTD at an average rate of rate of 0.78 m/s down to a depth of 310 m. We based our assessment of temperature sensor performance on the assumption that the pressure sensor is reliable in terms of both responsiveness and accuracy. We thereby confirmed that from depths of 180 m and beyond, our ubiquitous sensor maintains the target accuracy (i.e., CTD value +/-0.2 °C). However, within a thermocline around 40 m, the sensor value was found to deviate from the CTD value by as much as 1.3 °C. The slope (rate of change of water temperature) at this area was approximately 3.2 °C/m (3.3°C/s). This is a sharp change, and here the inability of our sensor to adequately track it alerted us to a need to redesign the sensor (case).

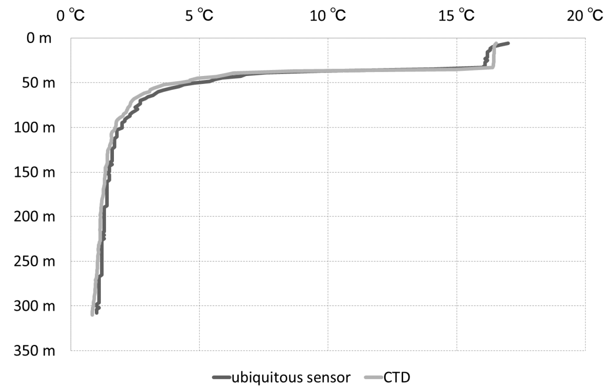

Fig. 10. Assessment of ubiquitous sensor response characteristics.

IV. CONCLUSION

To improve the temperature-response characteristics of our ubiquitous sensor, we redesigned the case while referring the structure of a typical CTD. Figure 11 shows the result. We are now working to install the redesigned version of our sensor on several squid fishing vessels toward the ultimate goal of creating and practically applying a fishing ground inferencing system that combines these sensors with components such as our tablet PC application and cloud server–based database/website. We are also evaluating the response characteristics of the sensor on the *Hakusan-maru*.

From discussions with professional fishermen, we have confirmed a strong interest in ubiquitous sensors for application to not only squid fishing, but also shrimp trawling and offshore bottom trawling. We have therefore disclosed our system specifications and other such information to encourage the unconstrained third-party development of applications for the use of ubiquitous sensors in these and other similar areas.

Figure 12 shows an automatic squid jigger in action and Figure 13 shows a typical jigger load display on the control panel. Jiggers are driven by an AC motor under sensorless vector control. Load current can be calculated as a function of motor load, with the resulting value corresponding to the number of squid currently on the jigger line. In the example of Figure 13, the squid fishing vessel has four jiggers mounted on each side for a total of eight. Icons indicate the current operating mode for each. Next to each icon, we see two parallel bar graphs. The thinner bar on top indicates lure depth; the thicker bar on the bottom indicates the number of squid currently caught on that line as calculated from motor load (for example, here we see that the starboard No. 1 jigger is currently pulling up eight squid). Note that we can take the integral of the motor load as an indicator of catch tonnage per unit time.

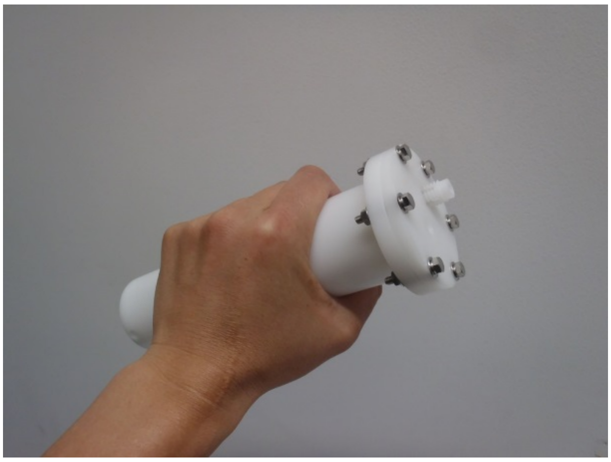

Fig. 11. Redesigned ubiquitous sensor case.

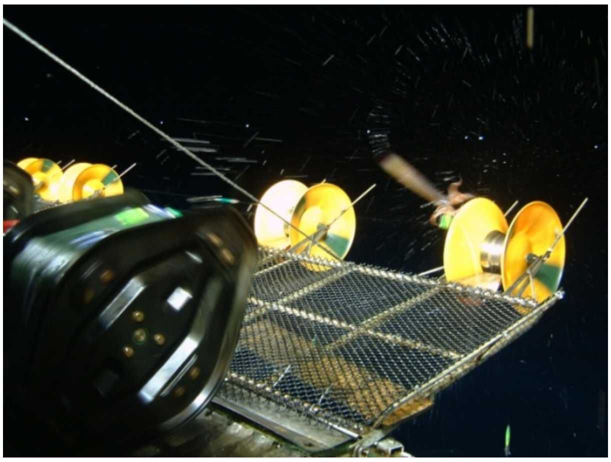

Fig. 12. Automatic squid jigger in action.

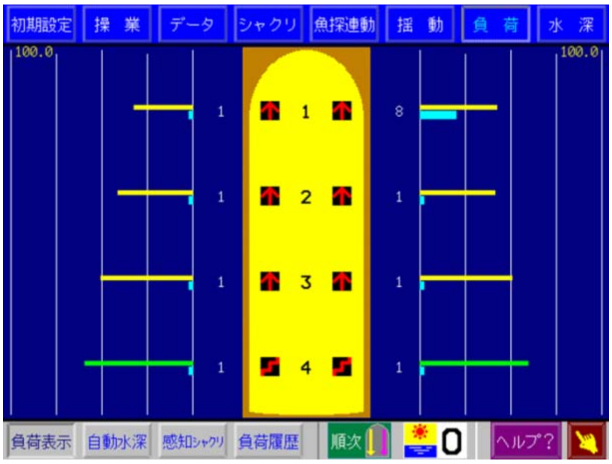

Fig. 13. Control panel load display.

The current version of our ubiquitous sensor is tubular, with a diameter of 50 mm, a length of 175 mm, and a volume of 344 cm^3. A typical squid fishing sinker (1.1 kg) has a volume of 160 cm^3. Here, we would like to miniaturize our ubiquitous sensor down to the approximate size of a sinker and then automate the measurement of water temperature profiles by using the sensors in place of sinkers. This would facilitate the big data processing of water temperature profiles and catch tonnages, enabling us to more accurately infer the location of promising fishing grounds and thereby contribute to the efficiency and effectiveness of squid fishing operations.

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