Underwater Current Measurements for Fish Feeding Control in Marine Aquaculture

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***Abstract*—One of the key issues in improving marine aquaculture is achieving efficient control of feeding, which accounts for large percentages of the production costs in aquaculture operations. To quantify the feeding behavior in seas where the environment conditions are variable, we propose to measure underwater currents generated by fish movement in a feeding activity. We developed a sensor suite consisting of custom-made current sensors and underwater cameras. We deployed this prototype in two sea fish cages and measured the changes of currents during a feeding activity. Results suggest that changes in current may be related to the feeding behavior of the fishes, but more data needs to be collected and analyzed to understand this relationship. To improve on the experiences from the initial experiment, we designed a modular sensor system that will measure currents at more than one side of the fish cage during a feeding activity.**

***Index Terms*—current, sensors, feeding, marine, aquaculture**

I. Introduction

Since early 1990s, the aquaculture industry has been expanding consistently to meet the rising demand worldwide, while production in capture fisheries has remained stable throughout the years [1]. However, this increasing production is still met with challenges in product quality, profitability, and environmental sustainability [2]. These are also present in Japan, where marine aquaculture accounts for 97.1% of the country's aquaculture production as of 2018 [6]. However, production has remained stagnant throughout the years, without any consistent increases.

One such challenge is the efficiency in feeding. Feeds account for up to 86% of aquaculture production costs and 8% of the given feed goes uneaten and settles at the bottom of the sea [7] [8]. As these feeds do not contribute to the fishes' growth, they are considered loss in production. In addition, they decompose and contribute to pollution. Efficient feeding therefore not only improves production yield and fish quality but also minimizes wastes in feeding, which in turn lessens income losses and pollution in the fish environment. Since it involves proper timing and quantity, efficient feeding control can be accomplished through a sound decision on the feeding activity of the fishes.

Conventional practice of this decision-making is through the judgement of the feeding behavior by an experienced fish farmer. Such decision making remains to be an "art," where prediction is still intuitive, subject to the expert's experience, and unquantifiable by a unified standard [2] [3]. While researchers have developed various ways to quantify such behavior, most works on intelligent feeding control focus on imaging measurements, with most performed in more controlled environments [4] [5]. Applying them in sea fish cages will prove difficult if not impossible.

Our research group has proposed a novel approach to this problem by measuring underwater currents. When given feed, fishes in sea cages swim towards the surface and swim around fast when hungry. Their behavior is the opposite when full, swimming below more slowly [9]. It has been observed that circular movements of a fish flock around a cage push the water outward [10]. We therefore hypothesize that changes in currents at different depths may indicate the changes in the behavior of fishes in different stages of a feeding activity. In this paper, we discuss the development of a sensor suite for measuring currents at different depths and the initial experiment in open-sea fish cages in which this device was tested. In addition, we discuss design of a modular sensor system, improving on the developed prototype, and to be deployed in the next experiments.

II. Current Sensor Suite

A. Current Logger Design

The sensor suite for the initial experiment consists of two custom-built propeller-type current loggers that use low-cost Hall-effect flow sensors, originally used for measuring flow along water pipes. These sensors generate pulses with frequencies corresponding to the propellers' rotation, which correspond to the speed of water flowing through them. Although

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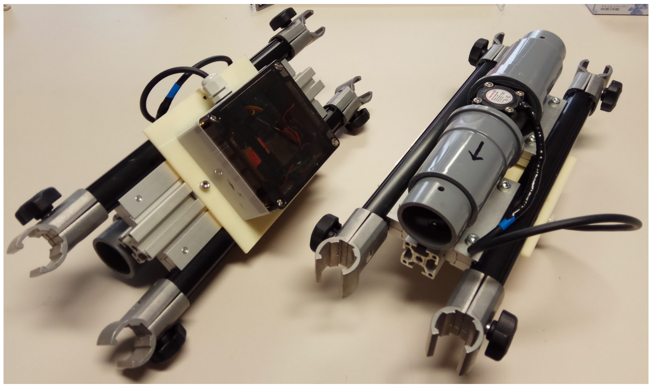

Fig. 1. Constructed current loggers for the initial experiment, together with frame attachments and sensor electronics.

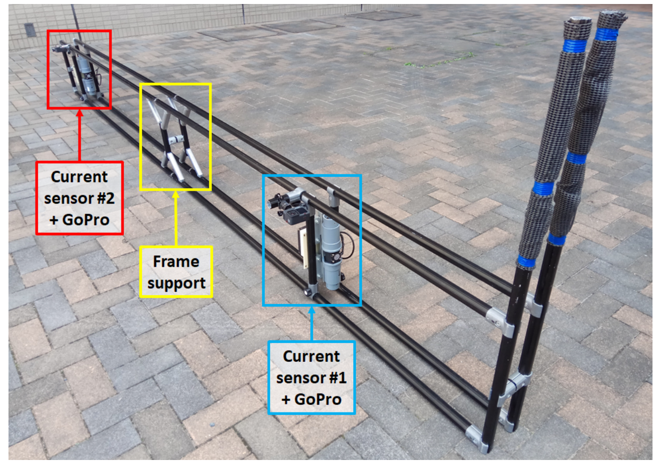

Fig. 2. Sensor suite consisting of current sensors and underwater cameras mounted on a 4-meter metal frame with support.

these sensors can only measure at a single direction, and have less accuracy compared to electromagnetic induction or acoustic current meters, they have an advantage of scalability due to their lower cost. By reinforcing them with waterproofing, they be easily reproduced for future measurement campaigns, with multiple sensors measuring at different depths at different sides of the cage. Attachments were added to them so they can be mounted in position, as shown in Fig. 1.

Each logger's microcontroller board would measure the frequency of the pulses detected from the sensor for a chosen interval. At the end of the interval, the average current speed would be calculated using previously collected calibration data. Using a real-time clock, timestamps were then appended to each measurement and the data would be stored in an SD card for later retrieval. It featured Bluetooth communication through the microcontroller, enabling it to be remotely triggered by another computer to control the logging operation before it was submerged. This lessened the need to open and close the waterproof enclosure housing to switch the power of the sensor electronics for every measurement. Subsequently, this lessened the chances of human error which would have led to seawater damaging the components.

Each logger was powered by 9-volt power supply (six AA batteries in series) also housed together with the other electronic components. Its endurance was tested by operating it with all its components active, until the sensor stopped functioning properly, measuring its voltage around every 30 minutes. It was observed that the sensor was able to record continuously for around 22 hours.

A modular metal frame was constructed on which the two loggers were mounted on, along which their positions could be adjusted easily. It could be extended from four to twelve meters, allowing the sensor suite to be setup according to the preferred maximum depths of current measurement. To reinforce the frame's structure and prevent it from any bending caused by the current, supports were attached at parts where bending could occur, especially at its joints.

For the initial experiment, the frame was extended to four meters, as shown in Fig. 2. One sensor was fixed at 0.7 meters from the top of the frame for measuring the currents close to the surface where the fishes gather during feeding. The other sensor was fixed at 3 meters from the first sensor for observing the currents at a deeper part of the cage where the fishes are when not eating.

B. Current Sensor Calibration

The standard unit for measuring current speed is cm/s. To determine the measured speed from its output pulses, the developed flow sensor was cross-calibrated with a digital clamp-on type flow sensor (Keyence FD-Q32C), as shown in Fig. 3. Both sensors were connected to a tall container, which constantly accumulates water from a source. A valve partially controlled the flow at the outlet, as velocity and flow rate were dependent on the height of the water in the container, and subsequently on its volume.

To calibrate the flow sensor, the pulse frequency collected was correlated to the speed of water through the propeller sensor, which was calculated from the water speed through the digital flow sensor. Since the two sensors have different cross-section areas, and since the digital sensor only measures the flow rate, the relationship between the flow rate and speed of a fluid through a pipe and the continuity equation were used to calculate the flow speed at the propeller sensor, which is given in the equation

$$v_F = \frac{v_{DF} A_{DF}}{A_F} = \frac{q_{DF}}{A_F}, \tag{1}$$

where $\mathrm{v_F}$ and $\mathrm{v_{DF}}$ are the speeds of water through the propeller and the calibration flow sensors, respectively; $\mathrm{A_F}$ and $\mathrm{A_{DF}}$ are the cross-section areas of the propeller and the digital sensor pipes, respectively; and $\mathrm{q_{DF}}$ is the flow rate.

Part of calibration was selecting the interval for averaging the measured speeds. There were three candidate averaging periods were used for calibration – 1, 5, and 10 seconds. One-second readings were found to be discrete as the microcontroller count discrete number of pulses per second. The range of readings from the digital sensor were classified into the corresponding discrete readings from the propeller

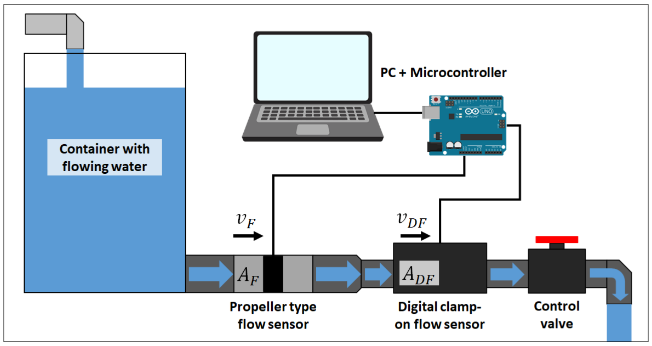

Fig. 3. Setup for the cross-calibration of the propeller flow sensors using a digital electromagnetic flow sensors, with the readings recorded in a computer.

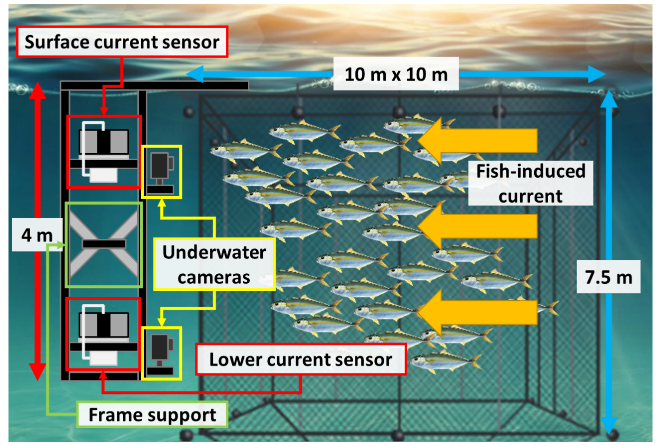

Fig. 4. Initial experiment setup using the constructed current sensor suite attached to one side of the fish cage, making measurements during a feeding operation.

sensor. Readings using the 10-second configuration were more continuous. However, chances of averaging high and low sample values were higher. Using 5 seconds or 1 second may not properly represent the actual measurements. Using the 5-second period seemed to be a favorable configuration as readings with large differences would less likely be averaged together, while remaining continuous. This was therefore the selected configuration for the upcoming experiments.

C. Underwater Camera

In addition, two underwater cameras were added close to the propeller sensors for visual record of the fish activity at the depths of interest. Two GoPro cameras were used for the initial experiment. A storage of 512 GB was used for each camera. Based on experience from the initial experiment, starting at around 80% battery capacity, each camera was able to record up to 87 minutes of HD videos until its battery was exhausted. Total storage consumption throughout the operation was 27 GB. Attachments were added to the camera to enable its mounting on the sensor frame.

III. Fish Farm Experiment

A. Experimental Procedure

The initial experiment was performed on March 18, 2021, in a fish farm located in Usuki City in Oita Prefecture, Japan, with the aim to make initial observations on the changes in underwater currents in a fish feeding activity using the sensor suite. Measurements were made each in two 10 m x 10 m x 7.5 m cages while the farmer dispenses food to the fishes in those cages. Each cage contained around 3500 Yellowtail amberjack fishes (*Seriola lalandi*), having been raised for a year with an average weight of three kilograms.

The sensor frame was attached to one side of the fish cage, particularly on the frame above the surface, as shown in Fig. 4. When attached to the cage, the frame top was 0.3 meters above the surface. This meant that the first current sensor measured the current at a depth of 0.4 meters, and the second sensor at 3.4 meters. Ropes were attached at the end of the frame to prevent it from swaying by the current. Measurements at both cages lasted for around 80 minutes, while moist feed was propelled from the fisherman's boat to the center of the fish cage.

At the start of each feeding operation, the fisherman would dispense feeds gradually in small amounts to lure the fishes to the surface while minimizing as much waste as possible. Once the fisherman assesses that most fishes are swimming near the surface, the feeding machine would be set to dispensing feed continuously, which would last for around one hour. Upon the fisherman's assessment that the fishes have swum back deep down the cage, feeding would be stopped.

B. Results and Discussion

For easier analysis of the pattern of the measurements, the plots of the collected measurements were smoothened out by calculating the 30-second moving averages of the readings, averaging data point with the previous readings from the last 30 seconds. Activities in the fish cages were noted down, recording the time of occurrence. These activities were pinpointed at the plots of the current measurements.

In the first measurement, as seen in Fig. 5, the current at 3.4 meters was lower than at 0.4 meters. Video recording showed presence of slow-moving fish, which coincided with the low readings. The same reason could be said about the measurements in the second cage, shown in Fig. 6, although no video was recorded to confirm this due to insufficient battery power.

Surface measurements in the first cage were more uniform than those in the second cage, although the latter had larger readings. It was noted by the fisherman that feeding activity of the fish in the first cage was low on that day. Visual recordings above surface indicate that the fishes in the second cage appeared to be swimming more actively during feeding.

Surface currents in both measurements were low in the first 8-10 minutes after feeding started. Within these times, feed was dispensed only in small amounts to lure the fishes to the surface. From then on, measured current at the surface significantly increased. This coincided with the fact that the

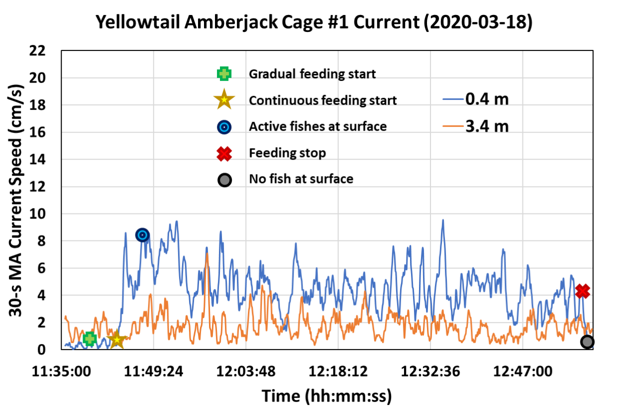

Fig. 5. 30-second moving averages of the current measurements from the first fish cage, with more uniformity among peak readings.

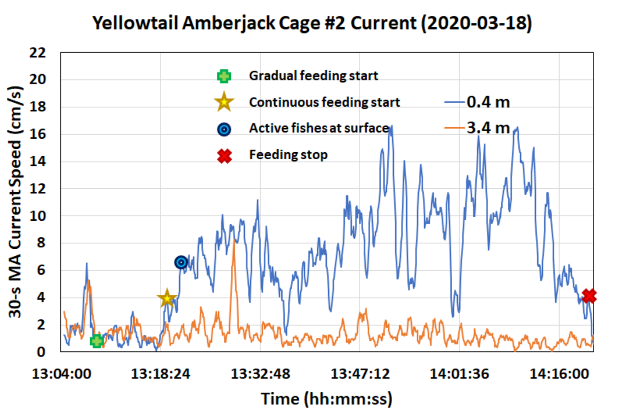

Fig. 6. 30-second moving averages of the current measurements from the second fish cage, showing higher peak measurements compared to the previous measurements.

fishes were observed to start swimming more vigorously at the surface, prompting the fisherman to start feeding them continuously. Toward the end of feeding in the second cage, results showed that current started to decrease gradually. This was validated by visual recordings of less frequent splashing.

Results of this experiment indicate that suggest that the behavior of fish during feeding have a significant effect on the underwater currents, meaning that it may serve as a significant measurement for quantifying feeding behavior. However, this needs to be analyzed further and be backed by more data: underwater videos; more measurements before and after feeding; simultaneous calibration sensor measurements.

IV. Modular Sensor System Design

Based on the experiences of the initial experiment, there are various improvements needed in performing current measurements during feeding. By measuring from more than one side of the fish cage, we can determine the global current flowing through it, and subsequently, isolate the currents generated by the fishes' movements. Synchronization of all sensor readings are needed to minimize error in analysis so that events can be

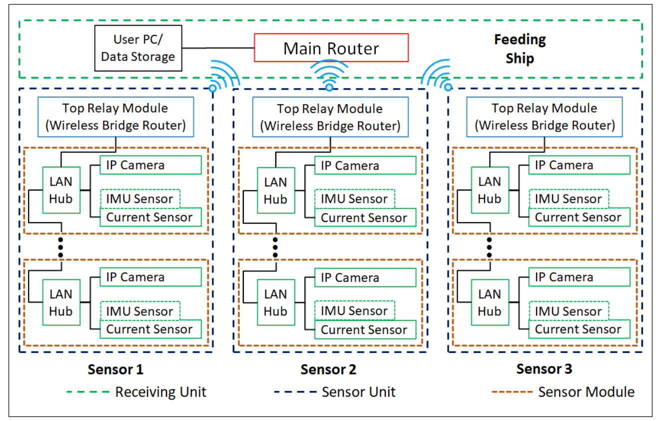

Fig. 7. Modular sensor system design with multiple sensor units consisting of multiple sensor modules, transmitting data to a user computer at the feeding ship.

pinpointed on the results more accurately. Making the sensors modular allows more flexibility in the experiment setup, being able to measure at more than two depths per side.

These are some of the concerns currently being addressed in developing a modular sensor system for the next experiments. In our new design, as shown in Fig. 7, multiple physically separated sensor units would transmit sensor data via Wi-Fi to a user computer onboard the feeding ship, which would store the received data. Each sensor unit would have two or more sensor modules daisy-chained to the top relay module through underwater cables (power and Ethernet).

The top relay module would be composed of the bridge router and the power supply of the sensor unit. Each sensor module would consist of the propeller current sensor and an IP camera. An optional inertial measurement unit (IMU) could be added for measurement of the sensor's movement as influenced by the currents, whose data would be piggybacked on the current sensor's control unit. A LAN hub (network switch) would connect the sensors (through an Ethernet module) and the camera to the top module and subsequently, to the main router and user computer in the feeding ship. With this setup, the sensors, especially the cameras, would have more steady sources of power, and data from all sensors would be properly synchronized.

V. Conclusion

In this paper, we proposed the use of sensors measuring underwater currents for quantifying fish feeding behavior to assist in optimizing feeding decision. We developed a sensor suite consisting of two prototype underwater current loggers using modified flow sensors, and underwater cameras. This sensor suite was deployed to measure currents during feeding activities in two fish cages. Experiment results showed changes in currents corresponding to certain parts of the feeding activities, as well as to observations from the surface. While these suggest that these may be used to measure feeding behavior, more data needs to be collected and analyzed. This is currently being addressed in the design and development of a modular sensor system measuring currents at more than one side of a fish cage.

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