

Digital Scanning Sonar for Fish Feeding Monitoring in Aquaculture

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Summary

Feed waste results in increased production costs to the cage fish farming industry and produces negative environmental impacts. A computerized system, consisting of digital scanning sonar and current meter, was developed for monitoring, assessment, and optimization of the fish feeding process. The system can detect and monitor quantity and direction of wasted food pellets and also predict the trajectory of pellets through the water column. Pellets detected and tracked by digital sonar provide feedback information to the feeding operator and provide guidance on how to redirect or modify the feeding process in order to minimize feed waste.

Digital scanning sonar is user friendly and cost effective. It can be integrated as a major component of automated or semi-automated feeding systems on aquaculture farms. The system performed well and successfully enumerated individual pellets under the aquaculture cages. Presence of high concentrations of non-farmed fish outside of the cages resulted in the degradation of the ability to successfully detect and count waste pellets. Refinement of techniques and detection and filtering algorithms is necessary consistently detect waste pellets in the presence of unwanted fish echoes.

1. Introduction

Acoustic systems are commonly used for monitoring fish and other objects in marine and freshwater environments. Attempts to apply acoustic technology to the fish farming industry for fish biomass estimates and feed monitoring have been made with various degree of success [2].

In a typical salmon aquaculture farm, fish feed represents approximately 50 to 60% of the total direct production expenses. Wasted feed can range from 10 to 40%. Hand feeding methods can be more efficient but are labor intensive, while some automated or semi-automated systems tend to cause more waste feed. Feed waste also has some negative environmental impacts. Feed waste accumulated underneath fish pens can be toxic and may require periodic removal or re-siting of the net pens, which translates into additional labor costs and environment degradation. [3,5]

The operational concept of acoustic pellet detection and monitoring system lies in interrogation of a horizontal plane beneath fish cage, using scanning digital sonar capable of detection and quantification of all lost pellets. The current meter measures velocity of water, which allows prediction of the trajectory of sinking pellets. Sonar data on pellet loss through the net pen allows the system to recommend appropriate feed placement so the feed travels the longest possible distance and receives maximum exposure to the animals in the cage. It can also provide an alarm signal to stop feeding if pellet loss exceeds a predefined threshold.

BioSonics conducted an R&D program using a digital sonar system for fish feed pellet detection and monitoring from 1997 to 2001. Two prototypes of Fish Feeding Monitor (FFM) were built and deployed, one in Chile and one in USA.

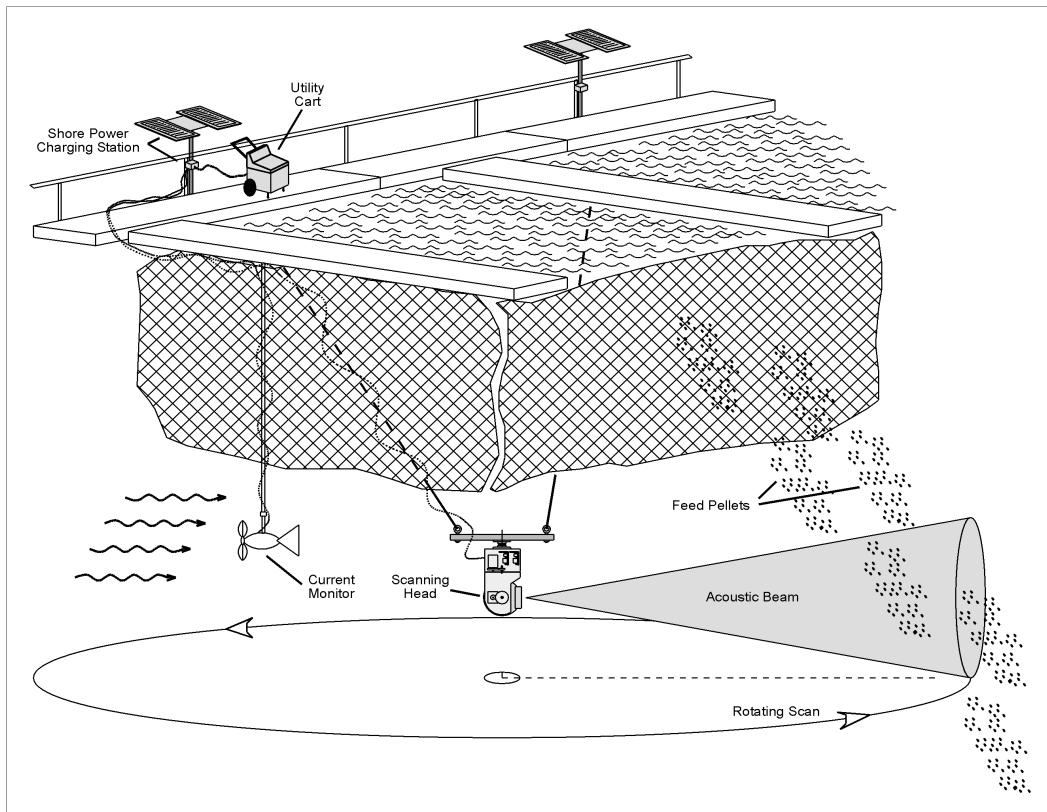


Figure 1. Representative concept for deployment of the Fish Feeding Monitor underneath a fish farm cage

Figure 1 shows the conceptual diagram of a net pen, FFM deployment, and waste feed. Fish are fed with pellets ranging in size from 3 to 12 mm, depending of fish size. Pellets are delivered to fish in the cage manually or mechanically. Some of the pellets are eaten by fish the balance pass through the cage. The trajectory of sinking pellets depends on pellet size, surface delivery point and velocity of the water current (speed and direction).

2. Material and Method

2.1. Pellet Sinking Model

From 1997 to 1999 BioSonics conducted a series of experiments on fish farms, in Lake Union and in the University of Washington Hydraulic Laboratory on acoustic measurements, tracking, and monitoring of sinking fish feed pellets.

Pellets were measured and tracked with BioSonics 201 kHz and 420 kHz split beam digital echosounders and an active tracking sonar system [4]. Acoustic measurements from various pellet sizes are presented in Table I. Sink rate (speed and direction) of individual pellets was measured under

different current velocities for different pellet sizes. Selected results are presented in Table II.

Table I. Selected results from measurements of Target Strength of pellets using 200 kHz, 6° split beam digital tracking sonar. Pulse duration 0.4 ms, 10 pings/second, pellet orientation vertical.

Pellet Size [mm]	Average σ [dB]	Average TS [dB]	Standard Deviation
3.5	-59.4	-62.1	3.4
8.5	-53.7	-55.0	4.7
11	-47.6	-48.9	3.8

Table II. Mean Sinking Rates (MSR) and Standard Deviations (SD) of three feed pellet sizes (3.5 mm, 8.5 mm and 11 mm) calculated from data acquired with a split-beam tracking sonar 201 kHz, using pulse duration $\tau = 0.1$ ms and $\tau = 0.4$ ms.

$\tau = 0.1$ [ms]	3.5 mm	8.5 mm	11.0 mm
MSR [m/s]	0.134	0.166	0.201
SD.	0.009	0.006	0.022
$\tau = 0.4$ [ms]	3.5 mm	8.5 mm	11.0 mm
MSR [m/s]	0.121	0.166	0.208
SD	0.004	0.006	0.027

2.2. Pellets Detection and Quantification Algorithm

Numerical echo-integration algorithms were developed and tested to count lost pellets. The method used to determine pellet loss with a sonar sweep or conical scan uses the concept of flux through a control area, as shown on Figure 2.

The calculation of the flux method of the pellet detection assumes a known sinking rate of pellets, which can be determined *in situ* using target tracking, from a model, or from *in vitro* experiments. Calculation of total pellet loss requires an estimate of the area through which feed is lost. As a first approximation, it will be the area above the conical scan, which is a planar slice where the sonar beam axis intersects a sphere. This area corresponds directly to the volume that is echo integrated for density estimates:

$$A = \left(\frac{\psi}{2\pi} \right) (r_2^2 - r_1^2) \pi \quad (1)$$

where: A is a planar area of flow [m²],

ψ is the angle swept [radians],

r_1 is the start range of a ping [m] and

r_2 is the end range of a ping [m].

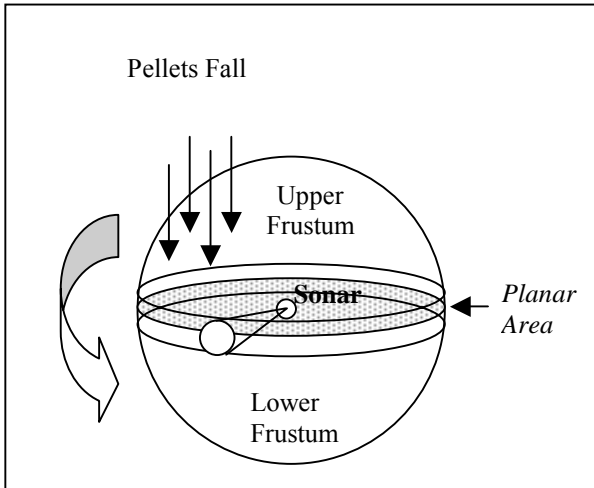


Figure 2. Diagram of the method used to determine the sample volume of the sonar sweep.

The number of lost pellets per unit of time is equal to the density times the flow of pellets through the area (m³/s). The density of pellets was estimated by echo integration in the feeding monitor program. The flow of pellets is equal to the sinking rate times the area. Therefore, the number of pellets lost per unit of time is:

$$\frac{P}{t} = A \rho \omega \quad (2)$$

where: P is number of lost pellets,

t is time [s],

ρ is density of pellets [number / m³],

ω is sinking rate of pellets [m/s].

Total number of pellets P_t lost can be calculated by multiplying the above loss rate, times the time interval of monitoring the feeding T.

$$P_t = \frac{P}{t} T \quad (3)$$

The combined loss equation is, letting monitoring time be T :

$$P_t = A \rho \omega T \quad (4)$$

BioSonics BioMonitor program reports densities at each individual ping (ρ_p), and cumulative sum of densities over all pings (n), i.e. ρ_p and $\sum_{p=1}^n \rho_p$.

Given constant ping rate and simplifying, the loss equation can be written:

$$P_t = A \omega \lambda \sum_{p=1}^n \rho_p \quad (5)$$

where: λ is ping rate [pings/s].

3. System Description

The Fish Feeding Monitor (FFM) consists of the following modules: digital sonar, current meter, and computer and software for instrument control, data storage, processing and display.

The hardware consists of a BioSonics digital echosounder, a 200 kHz, 6° single beam transducer installed on a rotator unit, a current meter, and two computers for instrument control, data acquisition, analysis, and data storage.

The transducer, rotator unit and current meter are deployed below the cage (Figure 1). This placement allows detection of waste feed pellets that pass out of the cage and monitoring of water current. Since individual pellets have a low target strength and they can best be detected in a small sampling volume. The cluttered environment under the cage (fish, cables, anchors, etc) and the close proximity of the transducer to the cage require a

transducer with very low side lobes and BioSonics transducers have side lobes of less than -30 dB.

The research prototype of FFM was built around the existing technology of the BioSonics DE Model 200 kHz, 6° digital sonar system [1]. Modifications to the digital sonar engine (both hardware and software for data acquisition) were necessary to accommodate the scanning rotator/transducer assembly. Data file for each ping are stored on the operating computer hard drive. Data files contain general information about sonar system parameters (e.g. frequency, beamwidth, transmitted power, receiver sensitivity, pulse length, threshold etc.), information for each individual ping in a form of echo envelope amplitude (digitized at a frequency of 41.33 kHz), digitized phase information of an echo signal (in split-beam mode), and rotator motor orientation.

The FFM also incorporates information from a current meter (Falmouth Model ACM-CBP-S, two component digital Doppler current meter) with compass.

Several modules of the FFM system were designed, developed and implemented specifically for this project. These are as follows:

- Scanning Rotator allowing changes to pan and tilt angle of transducer,
- Rotator Motor drivers and Power Supply,
- Software for scanning rotator motor control “BioScan”,
- Lost pellet detection software: “BioMonitor” with Plane Position Indicator (PPI) of detected pellets, and lost pellet counter.

3.1. Rotator and Scanning Software (BioScan)

The rotator assembly consists of two stepper motors (pan and tilt axis) and gearboxes, installed in an oil-filled, sealed housing. Two programmable motor controllers and power unit for the rotator are installed in a separate weatherproof case.

BioScan software was developed for control of the dual-axis rotator step-motors, and is integrated with the data acquisition and waste feed monitoring software (BioMonitor). BioScan allows for control of the speed, acceleration and deceleration characteristics of the rotator. The user can control the position of the motors in real-time, program the movement, or select pre-programmed scanning patterns.

3.2. BioMonitor, Waste Feed Monitoring Software.

The BioMonitor software was developed for pellet detection, quantification, and visual display. It receives TCP/IP streaming hydro acoustic data from the digital echosounder transducer and uses a high-resolution color echogram, in a Plane Position Indicator (PPI) format, to display the location and quantity of lost pellets.

An example of the BioMonitor graphical user interface is shown in Figure 3. The upper part of the display is the PPI, which shows the range and acoustic image of detected pellets.

The echo strength of detected pellets is color coded in decibels (dB) for graphic display on the PPI. Lower strength signals (‘cooler’ colors) indicate small amounts of detected pellets. In the case of detection of individual pellets, the target strength (dB) is directly related to pellet size. Higher strength (‘hotter’ colors) indicates high densities of pellets detected.

4. System Testing and Deployment

4.1. System Calibration and Testing.

Prior to integration of the system components for the FFM, the digital echosounder and motor control system were calibrated and tested as individual modules. A standard target test was also performed to verify the system performance measured during standard hydrophone calibration.

After completing tests of the individual modules, the system was integrated and tested under various operating conditions in the calibration tank. In particular, the system’s noise levels were examined during active scanning of the rotator motors to determine if there was any acoustic signal interference attributable to the rotators. Results indicate that the noise level of the system was satisfactory for detecting the smallest of individual pellets (Target Strength = -65 dB) at a range of 25 meters, which was the expected maximum operating range of the system at the fish farm.

Upon completion of the laboratory tests, the integrated system was tested at a nearby boat dock. The purpose of these intermediary tests was to allow further examination of the systems performance in an environment that more closely approximated that of the fish farm.

4.2. Deployment of FFM at a Local Fish Farm.

The prototype FFM was tested at the Northwest Sea Farms net pen facility, located on Bainbridge Island, Washington. Initial tests were conducted below an empty net pen, with the primary goal of confirming the ability of the FFM to detect pellets under the conditions presented at a typical fish farming facility.

For these tests, the rotator/transducer assembly was attached to a mounting pole, such that the pole could be adjusted to any depth in the water column up to 12 meters deep below the fish cage.

The rotator/transducer assembly was then deployed between two net pens containing fish, to test the sonar system's ability to detect and quantify pellet loss below a functional net pen. During these tests, fish were fed using the automatic airlift feeders (IAS "Aero Spreader" Systems Series 1001 SE) used at the fish farm. With these feeders, pellets were blown by air, and spread over the entire surface area of the net pen.

5. Results and Discussion

In general, the Fish Feeding Monitor performed well. The system was found to have a high Signal/Noise ratio, with no noise or interference from the rotator motors on the acoustic signal. We demonstrated that we were able to detect individual pellets, below the unoccupied net pen, at a range of 25 meters, which is the anticipated range for the commercial prototype. The Signal/Noise ratio was better than 6 dB for a -60 dB target.

The one major problem we encountered in the field-testing of the FFM was due to the presence of numerous small fish beneath the net pens during feeding operations. Although this result was not unexpected (preliminary testing showed evidence of small resident fish populations), the magnitude of fish density far exceeded our expectations.

Fish aggregations below fish farm cages were attracted to the wasted fish food and appeared in significant numbers during field trials. Although pellets can be readily detected and quantified by the digital sonar in absence of these fish, their abundance in the sample volume tends to obscure the bulk of the sinking pellets, making pellet

quantification was impossible with the existing technology. It is unknown, at this time, if this abundance of small fish is a seasonal issue or whether it will be a persistent problem.

Detection of sinking pellets in the presence of fish under the cage is possible, while quantifying them under these conditions will be more difficult. Figure 4 illustrates the situation encountered when the small fish are present. This problem will be addressed in a special research project. Considering different "behavior" between feed pellets and fish, and using various techniques of echo signal processing (such as neural networks and fuzzy logic classifiers) can potentially be used for separating pellet and fish signals.

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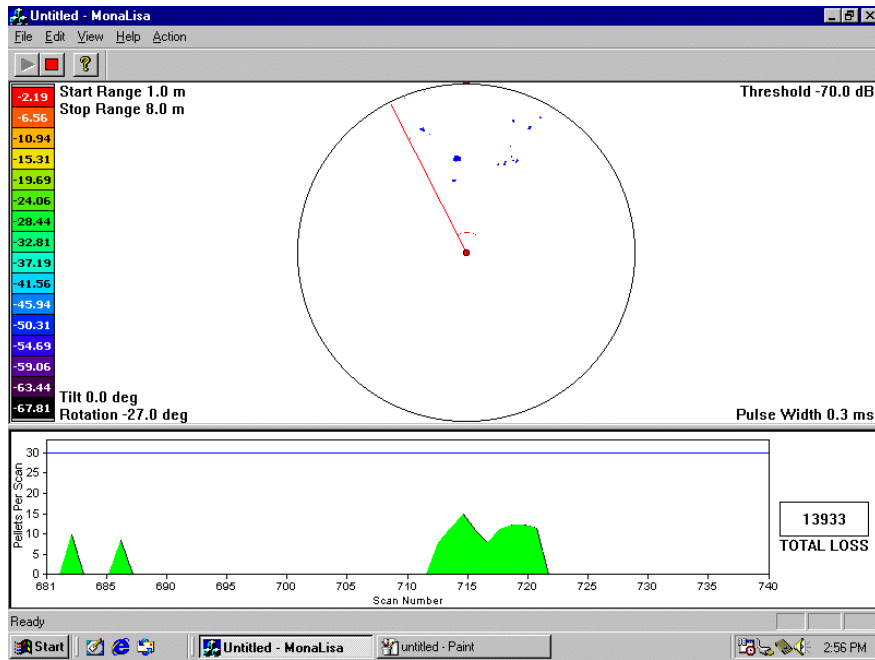


Figure 3. Screen capture from BioSonics PPI and pellet detection monitor. Individual feed pellet traces are indicated, in blue, detected at a range of 4 to 8 meters from the FFM. The graph in the lower part of figure indicates the number of pellets in each detection and also cumulative value as TOTAL LOSS.

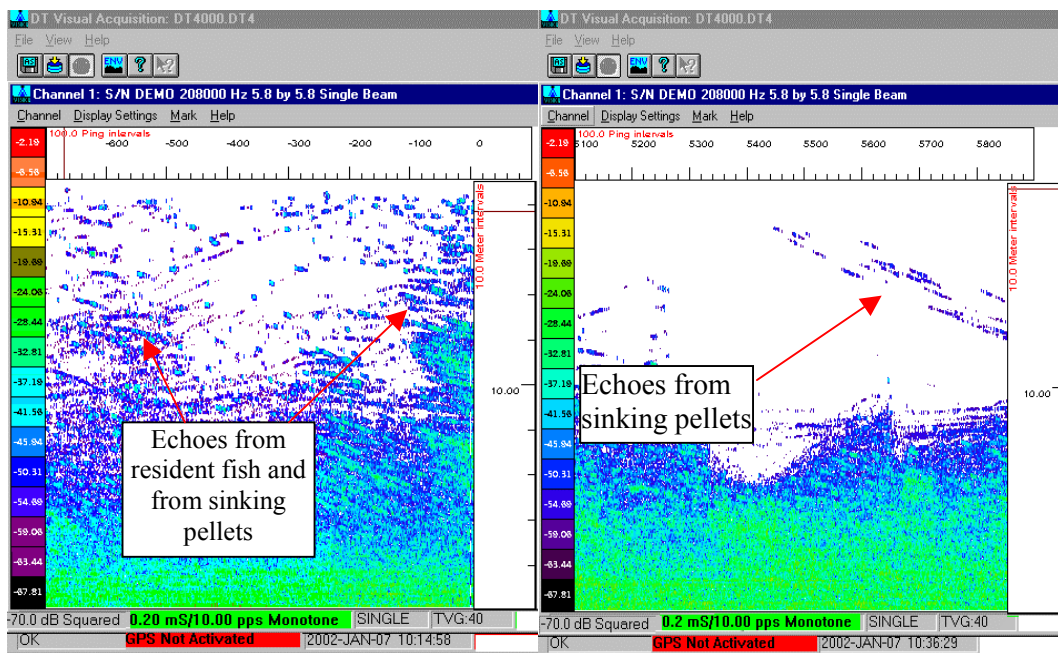


Figure 4. Screen captures for BioSonics data acquisition software. The sonar transducer was deployed below fish cages at the aquaculture facility. Depth range of both echograms 1 to 20 meters. Echo signal level is color-coded; red color indicates largest signal level, and "cooler" colors indicate signal of lower value. The echogram on left displays a mixture of echo traces from resident fish and from feed pellets with fish moving in a random fashion. It was difficult to distinguish between fish and pellets echoes during data collection. The right echogram shows only pellet echoes, in the absence of fish. The shape of echo trace from sinking pellet is straight line with a slope towards right low corner of echogram, indicative of the pellet trajectory (behavior).