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Feed spreaders in sea cage aquaculture – Motion characterization and measurement of spatial pellet distribution using an unmanned aerial vehicle

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ABSTRACT

Pneumatic rotary feed spreaders represent essential equipment in the feeding system of present day industrial-scale sea cage aquaculture. This study presents experimentally obtained attitude measurements and corresponding surface distribution patterns of pellets in order to characterize the dynamic behavior and performance of such spreaders. Spreader attitude and direction were measured by employing an attitude and heading reference system along with a rotary encoder. In addition, an unmanned aerial vehicle (UAV) was used to record pellet surface impacts from the air, and the position and direction of the spreader was obtained by applying computer vision methods to the recorded video. The proposed UAV method was fast to deploy, requires minimal equipment installation and presents a viable alternative to the approach of collecting pellets manually using Styrofoam boxes as reported in earlier studies. The findings from this study may be used as a base for further development and refinement with respect to using an UAV to observe the performance and spatial pellet distribution from various feed spreaders used in aquaculture. Such a tool may be valuable for farmers and equipment producers which may easily evaluate the performance of various spreader designs. In addition, the results serve as valuable input for parametrization and validation of mathematical feed spreader models.

1. Introduction

Atlantic salmon (*Salmo salar*) farming has over the last few decades grown to become a major source of food and the business has become a significant employer and contributor to the national income of several countries (Oppedal et al., 2011). Annual global production has been able to increase to over 2,087,000 tonnes (FAO, 2015) due to continuous knowledge-based improvements and optimizations of the farming process. After an initial hatching and growth period which takes place in indoor tanks, the salmon smolts are transferred to floating sea cages where the main part of the grow-out phase takes place. These cages are typically cylindrical with a diameter of 29–50 m and depth down to 48 m (Oppedal et al., 2011). However, 76 m diameter cages are currently in use in Tasmania, and efforts are being directed towards development of even larger structures for deployment in more exposed coastal and offshore locations. According to Norwegian legislation, one cage may hold a maximum of 200,000 individuals and the stocking density is limited to 25 kg/m^3 (Norwegian Ministry of Fisheries and Coastal Affairs, 2008). Given a slaughter weight of 5 kg/fish and a daily feed ration of 1% (Oehme et al., 2012), 10 tonnes of feed per day may be distributed in a single cage with each farming site typically consisting of 4–16 cages. Feed constitutes close to 50% of all farming costs (Norwegian Directorate of Fisheries, 2015) and about 1.7 million tonnes of feed were used at Norwegian salmon and Trout farms in 2014, worth close to €2000 million (Norwegian Directorate of Fisheries, 2014). Substantial economic incentives thus exist with respect to optimization of feed utilization.

Feed pellets are cylindrical, 3–12 mm in diameter with a specific density that is slightly higher than salt water allowing the pellets to sink at 6–20 cm/s. For the majority of the growth phase, a centrally located pneumatic rotary spreader (Fig. 1) handles the feed distribution across the water surface. Feed is transported to the site by ship and offloaded into silos on a local barge which

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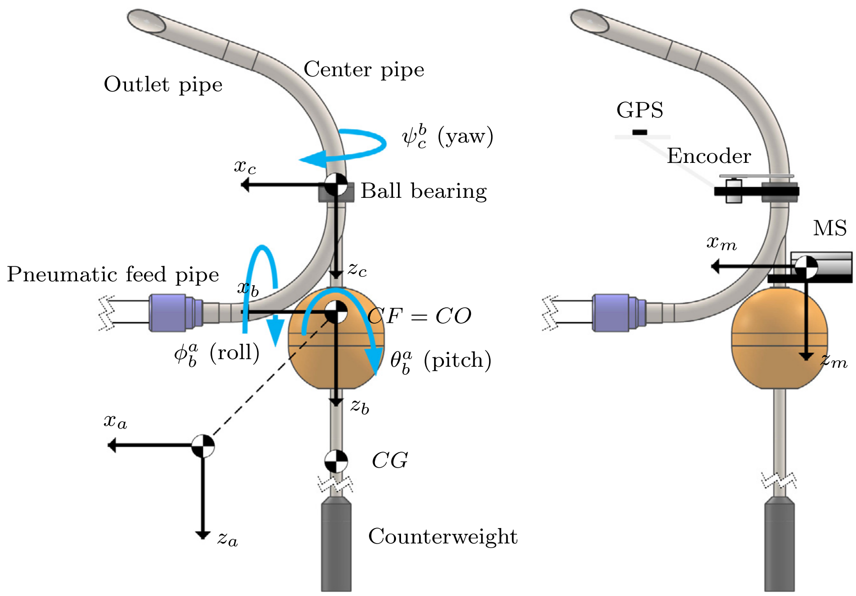

Fig. 1. The spreader with reference system definitions and with the measurement system (MS) mounted. Figure based on Skøien et al. (2016). In this figure the center pipe points in the direction of the feed pipe, $\psi_c^b = 0$ or known as a "*U*" configuration due to the single U-bend the pellets experience through the spreader.

typically handles feed delivery and monitoring of an array of sea cages. A set of blowers supply compressed air which propels pellets along feed pipes to the individual sea cages. The outlet pipe of the spreader has a spiral shape and is cut at an angle which causes the airflow to create a torque about the vertical (z_c) axis, inducing the rotation of the center and outlet pipe. The airflow is the driving force for both the rotation as well as the feed throw and pellets are expected to leave the spreader at about 6.6–9.4 m/s (Kevin Frank, pers. comm.) depending on airspeed, spreader configuration and length of the feed pipe. As a result the spreader creates an annular feed distribution pattern across the surface (Oehme et al., 2012; Skøien et al., 2016).

The spatiotemporal feed distribution within the sea cages is an important factor as it links to fish welfare, aggression, growth rate and feed loss. In Atlantic salmon, suboptimal feed intake is related to inefficient and reduced growth (Einen et al., 1999). Confinement of spatial and temporal availability or the amount of feed should not occur so fish may forage unrestrictedly (Talbot et al., 1999) and these factors also affect growth variation and aggression (Olla et al., 1992). The feed availability is a central factor in achieving efficient production (Juell, 1995) and a highly localized delivery of feed may lead to monopolization by dominant individuals (Juell, 1995).

Summaries by Ruzzante (1994), Attia et al. (2012) and Talbot (1993) discusses relations between agonistic behavior and feeding in salmonids, and it is likely that large distribution of feed will reduce agonistic behavior and positively affect growth (Thorpe et al., 1990; Ryer and Olla, 1991; Olla et al., 1992; Thomassen and Lekang, 1993; Thorpe and Cho, 1995; Ryer and Olla, 1996; Kadri et al., 1996; Attia et al., 2012). However, one should keep in mind that salmonids do well at adapting to different feeding regimes (Talbot, 1993; Thorpe and Cho, 1995; Talbot et al., 1999; López-Olmeda et al., 2012). Feed loss from commercial farms have been estimated to 7% (Gjøsæter et al., 2008) which results in poor resource utilization (Thorpe and Cho, 1995; Alfredsen et al., 2007).

These studies warrant the belief that spatiotemporal feed distribution is an important topic that should be studied closely and optimized. To investigate the complicated joint effects of fish physiology, behavior, feed distribution and environmental factors, a range of sea cage and fish models have been created (Alver et al., 2004; Føre et al., 2009; Alver et al., 2016). The feed distribution from the spreader seeds the initial surface distribution used in these models and is thus of importance. Oehme et al. (2012) showed that the surface feed distribution from a rotary spreader only covered a limited percentage of the surface area and was skewed to one side. This result warranted a further inquiry into the behavior and performance of the spreader itself. Measurements of spreader attitude has been made in Skøien and Alfredsen (2014) and physical models of its behavior has been created in Skøien et al. (2015, 2016).

Experiments obtaining the spatial surface pellet distribution from a rotary feed spreader have been conducted earlier by Oehme et al. (2012) and Skøien et al. (2016). Both studies employed Styrofoam boxes floating on the water surface to capture pellets and subsequently deducing the surface spread pattern from a section of the surface area. Oehme et al. (2012) used two rows of boxes attached to each other on the long side on each side of the spreader, forming a single line. In Skøien et al. (2016) this arrangement was expanded to four rows, effectively capturing pellets in a cross formation. The experimental setup proved able to accurately quantify the pellet distribution in the area covered by each box, however, with limited spatial resolution. The majority of pellets land outside the boxes leaving a substantial area of the surface unmapped. This method is also expensive and laborious due to the time it takes to count or photograph the contents of each box and empty them for each replicate run of an experiment. The position of the boxes are difficult to maintain in high winds and requires personnel inside the sea cage at almost all times.

This study presents an alternative method of determining surface pellet distribution using an unmanned aerial vehicle (UAV) and also provides attitude data obtained from a representative rotary pneumatic spreader (*CF90 Double*, AKVA group, Bryne, Norway) across different operating conditions. The results are then compared and discussed in relation with previously obtained attitude measurements from Skøien and Alfredsen (2014). In addition, a novel method of obtaining the surface pellet distribution is presented, using an UAV to observe the surface of the sea cage. Both experiments were run simultaneously to obtain corresponding data for later use in simulations, model parametrisation and verification of spreader models. The spreader models may in turn be