Summary Report: Novel EM Sensor for Grading Fish

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Introduction

In commercial fish farming, fish must be graded and sorted throughout the process of production. Grading refers to both counting and estimating biomass whereas sorting refers to the physical categorisation of fish in to separate locations (i.e., tanks). These processes are often carried out in unison where grading can be thought of as the 'brains' and sorting as the 'brawn'. Size variability is common among many species of same-age farmed fish. As this variability in growth can be a major shortcoming in the long-term viability of a commercial aquaculture facility, producers often grade and sort fish regularly.

Accurate grading is important as it has serious implications for product yield, quality and cost of production. It provides vital feedback to farmers so that they can determine appropriate feed amounts based on the tank biomass, which when coupled with sorting, prevents larger, dominant fish inhibiting smaller fish from feeding and, ultimately, ensures that the harvested fish are of a consistent size. This practice optimises production by reducing cannibalism, decreasing size variability among harvested fish, and increasing feed conversion efficiency by using the appropriate size food grains. There are several methods that are used to grade fish, however, these are typically invasive, require holding and are typically performed *ex aqua*, which often leads to increased stress, injuries such as fin damage, scaring and scale loss, and mortalities. In addition, the process of grading itself is time consuming, can require significant labour and often with equipment that can be difficult to operate and/or maintain. As such, grading can sometimes do more harm than good. For example, certain species of fish, such as crappie, shad, and many ornamental fish, are very sensitive to handling/physical contact. When these fish are heavily crowded they experience severe stress and often do not survive [1].

Fish grading systems will usually rely on a physical intervention to perform grading and separation. In many cases, the fish are out of the water for some time or only partially submerged and are subjected to impacts that induce stress and physical harm. Our primary focus in this study has been to investigate the possibility of a new, *in aqua* and low cost technique for grading based on electromagnetic (EM) sensing. Two experimental approaches were designed and tested: (1) for *in situ* monitoring and (2) *in aqua* counting and biomass estimation.

Background

Near-field EM interactions are utilised in various applications such as magnetic induction (MI) communications [2], MI tomography [3, 4], and wireless power transfer [5]. They are being increasingly employed in sensing applications such as environmental monitoring (in soil [6] and underwater [7]), landslide inspection [8] and underground pipeline surveillance [9]. We hypothesised that near-field MI interactions can be used to estimate the biomass of fish for the purpose of grading.

Fish flesh consists of various types of tissue each with passive electrical properties (conductivity, permittivity, permeability). Magnetic induction is a non-contact/non-invasive method which can be used to investigate such properties. The method is based on the interaction of a primary magnetic field that will produce eddy currents in the fish, these currents will then produce a secondary magnetic field that can be detected in the surrounding region (Fig. 1).

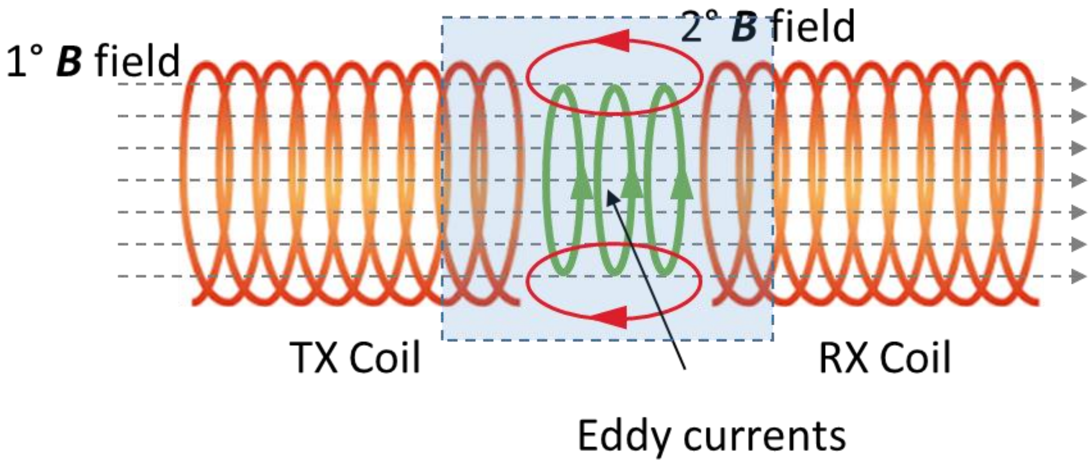

Figure 1: Transmitter coil generates alternating magnetic field. Eddy currents in the medium generate a secondary magnetic field.

The measured signal is a function of the conductivity and mass of the fish as well as its shape and the excitation/geometrical parameters of the transmitter and receiver coils. With a primary alternating magnetic field incident upon a fish, the electromagnetic signal will penetrate to a certain depth (also being partly reflected), as well as transmitting in to the surrounding medium (i.e., water). For a sample of fish material between an excitation coil and a receiver, assuming the skin depth of the EM field in the fish is larger than the dimension of the fish itself, then from [3]:

$$\frac{\Delta B_S}{B_P} \propto \omega(\omega\varepsilon_0\varepsilon_r - j\sigma)$$

where B_S is the secondary magnetic field, B_P is the primary field, ω is the angular excitation frequency, σ is conductivity, ε_r is the relative permittivity, ε_0 is the permittivity of free space and j is a complex number representation, equal to $\sqrt{-1}$.

Experimental Method

Two test setups were designed, built and tested. The first embodiment sought to demonstrate the possibility of *in situ* biomass estimation. To test this case, a custom tank was constructed that allowed a transmitter coil to operate centrally within the tank in a waterproof enclosure. The receiver was mounted to the exterior of the tank. The second setup was designed to enable single file counting and biomass estimation of fish as they traverse from one tank to another. Initial tests were performed using standard electrical laboratory equipment to allow flexibility of excitation waveform generation and signal capture during optimisation (Fig. 2).

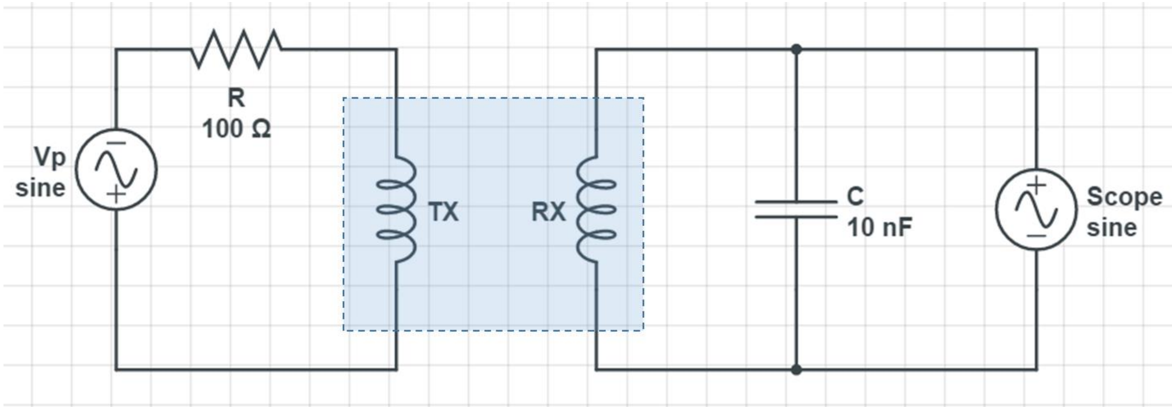

Figure 2: Schematic of general coil setup.

Results

Both setups were tested with a variety of fish under controlled conditions. Initial testing was conducted in the laboratory with whole fish (purchased from a fishmonger). For *in situ* testing, fish of pre-determined weight were added and removed from the tank over the testing period and the corresponding voltage change monitored (Fig. 3). The voltage change was found to be proportional to the total fish biomass with a linear response, $R^2 > 0.99$ (Fig. 4).

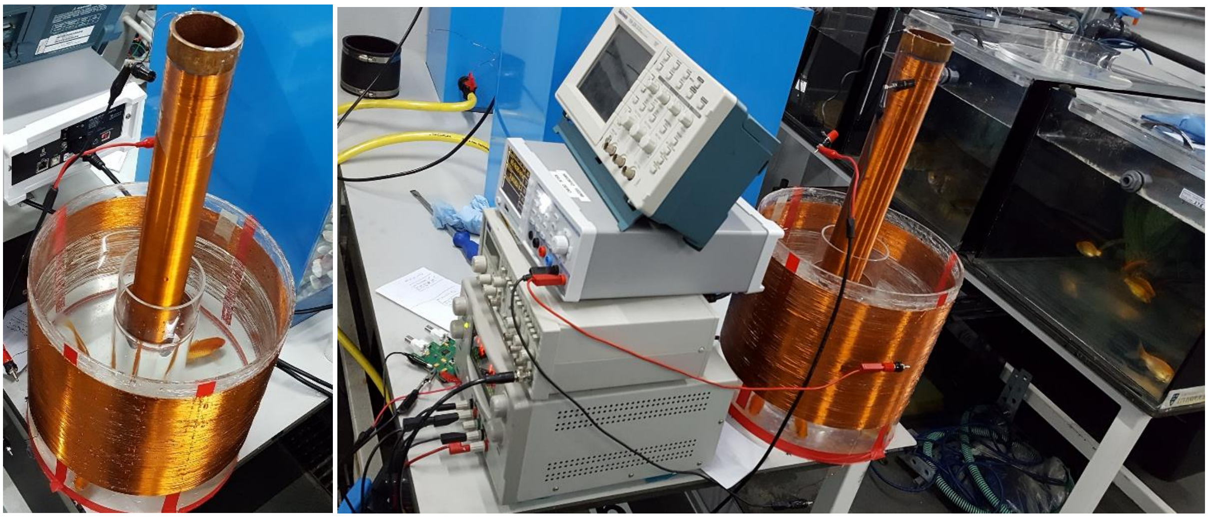

Figure 3: Experimental in situ tank setup during testing

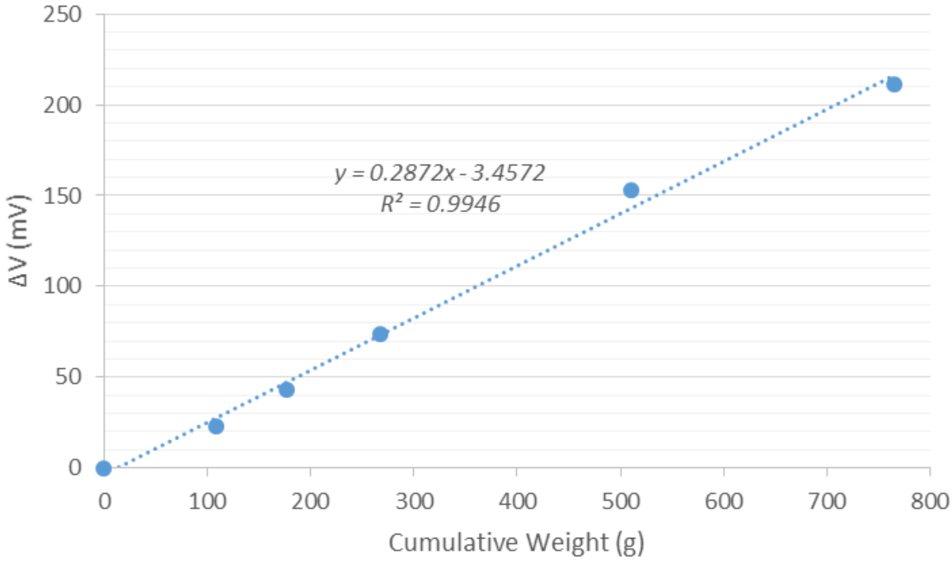

Figure 4: Background subtracted secondary rms voltage versus cumulative increase in total fish mass.

The second arrangement centres on a pair of co-axially mounted transmitter and receiver coils over a pipe connection between two fish tanks (Fig. 5). As a fish traverses between the tanks a signal is measured on the receiver coil.

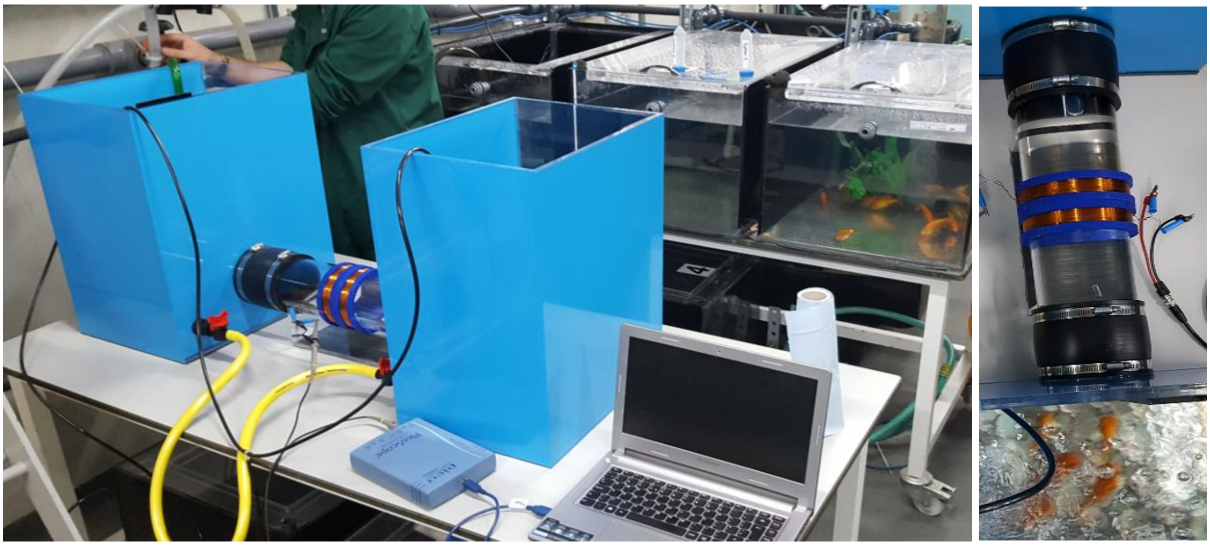

Figure 5: Experimental setup to allow fish to pass between two tanks.

Three whole sea bass of approximately equal weight (511g, 482g, 497g) and length were drawn through the sensor region manually at approximately the same rate (Fig. 6).

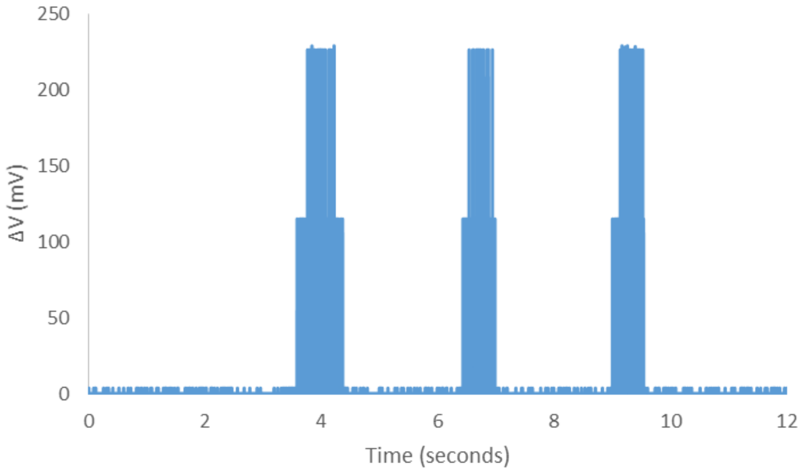

Figure 6: Background subtracted peak voltage change versus time for three fish of roughly equal weight passing through the sensor region between the tanks.

The width of the signal is proportional to the time over which the event occurs (i.e., rate at which it passes through the region) and the length of the fish. The number of peaks correlates to the number of fish that passed through the sensor region, between the tanks.

Conclusion and Future Work

This report has given a brief overview of the research conducted as a result of the award received from the Douglas Bomford trust. This has enabled initial experiments to be designed, built and tested in order to examine the use of magnetic induction for fish grading. In particular, results demonstrate the possibility for *in situ* and online monitoring of fish biomass. Further work is needed to evaluate the validity of this approach for practical use, such as with high stock densities and the influence of changing water quality parameters (e.g., salinity, temperature, etc.) on performance. We gratefully acknowledge the funding received from the Douglas Bomford trust towards this research and express our sincere gratitude to the funder.

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