Automation in Marine Larviculture ASABE Paper 2100522

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Aquaculture is the fastest growing protein sector in the world. Automation in aquaculture is growing concomitantly with this field. Pond and tank systems routinely monitor dissolved oxygen (DO), operate alarm systems (often linked to a cell phone) to alert farmers of impending issues. Marine aquaculture is growing and larviculture is a critical life stage. During the larval stage, carnivorous fish often feed on zooplankton. When this occurs in natural ponds or lagoons, predation and mortality are often high. With larval fish in recirculating aquaculture systems (RAS), live feed such as rotifers and artemia are typically raised and then dosed into the RAS systems, allowing a much higher survival rate. However, this can be both time consuming and round-the-clock work as larval fish often need feeding every few hours. Automated systems to feed live feeds (e.g. artemia) can reduce human labor and possible human error, improve dosing and customize feeding for particular species or life stages. A discussion of recent and ongoing advances in automated live feed systems will be provided, sharing automated dosing, rates, feedback to optimize feedings and other critical aspects of these systems, including graphical user interfaces (GUI) and other communication structures.

Ease of use is important for these systems to gain commercial success and contribute to this growing field. These systems can also enhance sustainability, reduce human error and improve safety outcomes. Further development in these fields is continuing, and lessons learned can also be useful when applied to adjacent fields including environmental, biomedical and agricultural engineering.

Introduction

With a long term growth rate of 6-8% per year, aquaculture is the fastest growing protein sector in the world (FAO, 2018). As the field grows, culture systems are becoming more sophisticated. Automation in aquaculture is growing concomitantly with this field. At the same time, culturing animals for the entire life cycle from egg to reproduction, continues to be a challenge for this new field. For example, feeding tiny larval finfish can be a challenge. Larval finfish often require live foods. One of the most popular larval foods is *Artemia*, often wild harvested from the Great Salt Lake or other areas. However, there are limits to the wild harvest, so alternatives that can reduce dependency on *Artemia* could have positive ecological but also economic implications. Part of the challenge is the methods by which feeding is done at specific culture stages, requiring customized hand feeding at substantial labor and expertise. It is likely that, in the interests of keeping larval finfish alive, excess feeding occurs. This is often, then, an inefficient and expensive endeavor that merits improvement.

Automation in aquaculture has a significant history. Over the years, there have been substantial improvements in equipment and monitoring, especially of water quality, but also of feeding, fish health, utility management and other areas. Some commercially available systems can feed pellets (e.g. AKVA akvasmart; Fish Farm; Pentair and other suppliers); or even pump solutions into fish tanks. However, automated feeding of live *Artemia* is still at a primitive state. Leger et al. (1983) studied refrigeration of Artemia nauplii and noted viability. They also developed a simple pump system. What is needed, however is a liquid based, controlled flow system that allows high levels of survival and quality (e.g. high lipid content) as well as efficient movement of the *Artemia* to the feeding fish. This proposal would significantly improve automated *Artemia* feeding with a focus on precision dosing at intervals required to meet the needs of the fish being cultured. This type of system can then be used to enhance the weaning process to inert feeds, thus reducing the amount of total *Artemia* used in larval culture and simultaneously removing significant labor costs and possible human error. Our team has personal motivation to reduce "all night" feeding of larval fish, thus enhancing human health and thought, and ultimately enhancing fish health and development.

Hall et al. (2001), Price et al. (2005, 2007), Leger et al. (1983) and others showed that automated aquatic systems can be used in aquaculture. Modeling (Lamoureux, 2005) can help predict and potentially control aquaculture systems. Hall et al. (2002) controlled flow in aquaculture systems to affect water temperature, and Saidu et al. (2012, 2018) worked with the physical components to control and assess temperature control on aquaculture systems. Smith et al. (2014) assessed but did not control with an autonomous system in an aquatic environment.

Other automated dosing systems (e.g. Hargreaves et al., 2007) have been developed in research settings and then moved to the commercial world. For example, Aquaneering Inc. sells a dosing system called AquaDose used for pH and salinity control in aquaculture systems. Jebao sells a programmable auto dosing pump. Pentair AES sells systems to control water quality. None of these are truly designed to dose out live feed, nor do they have the flexibility required to provide the feeding automation that is needed. Recent work using automation directly applied to aquaculture (e.g. Hall et al., 2019) shows that further automation in the aquaculture industry is possible, and the present proposal focuses on one unique application: the delivery of live feed to larval finfish systems to minimize waste and optimize growth, thus reducing excess use of live feeds and enhancing overall culture techniques.

Biology of larval finfish should drive the design of automated feeding and culture systems. During early development, critical biological developments occur. For example, swim bladder inflation occurs in larval striped bass, typically between 8-10 days post-hatch (dph). During this period, the larval fish must ingest a microbubble of air to allow for inflation and subsequent development of the swim bladder. If this organ does not properly inflate, fish will not be able to properly manage their movement in the water and generally become deformed or die. Thus, studies on the development of this and other critical aspects of growth run parallel and must be considered with feeding. One practical consequence is that an automated feeding system feeding, for example, brine shrimp Artemia sp., should not create excess oily sheen preventing larval fish development. At the same time, sufficient feeding is required to enable growth and development. Hence, critical control and ideally feedback of both the physical feeding and biological health of the animals is needed.

Other considerations including the fact that Artemia will continue development and become unsuitable feed if held for more than a few hours at room temperature. Thus, refrigeration of artemia and flushing of live animals from feed lines are important additional considerations in proper development and design of automated feeding systems of live feeds like Artemia and rotifers.

Thus, design objectives included high value-to-cost ratio; user friendly operation; and biologically relevant operation. Specific design objective included the ability to feed at a known interval; to alter the amount of feed as larvae grow; feedback to assess success in feeding; and delivery of known quantities of feed, with a design goal being accuracy within 10% of desired feeding volume.

Methodology

Understanding these unique challenges, and with the biology guiding design, the team, including aquacultural engineering; bio and ag engineering; fish biology; computer science and electrical engineering, started the process.

After considering a number of design alternatives, and running preliminary tests with various hardware and software options, a preliminary configuration was designed and built. This involved a microcontroller driven, peristaltic pump delivery system, with artemia cones in a refrigerator and customized software and graphical user interface (GUI).

As appropriate, peristaltic pumps were tested for biological, mechanical and electrical effectiveness. After pumping live artemia through peristaltic pumps not once but 10 times, approximately 95% survival was observed, suggesting this was a biologically acceptable option. After this, testing of peristaltic pumps showed a lift of about 1 meter (even when the tube was dry) is workable; and the accuracy of volume delivered, once calibration was completed, was +-5%, indicating very good volumetic delivery. This still assumes a known and consistent density of artemia per ml, and improvements to confirm this via feedback loop is ongoing as of this writing. Peristaltic pumps in one of the units (capable of delivering artemia to 4 fish tanks; as well as inlet and saline flushing water shown).

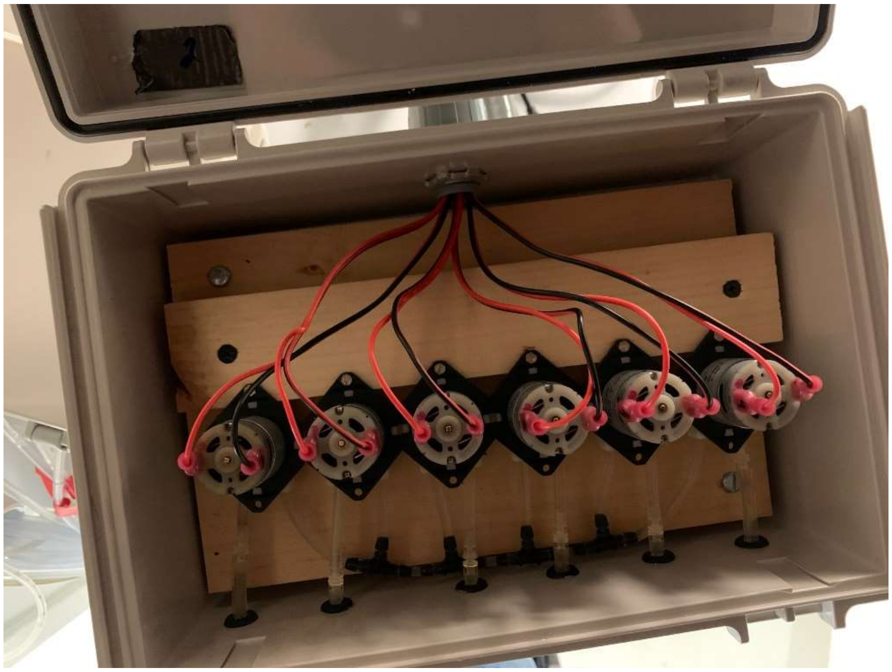

Figure 1: Peristaltic pumps were used to pump artemia from a refrigerated source via 1 input pump; four separate pumps to deliver to 4 treatment tanks; and one pump to flush lines with clean water.

Once the peristaltic pumps were confirmed as functional, waterproofing of electronic components and pump elements was done via waterproof cases. In addition, as a general principle, electronics were located vertically above water components whenever possible to reduce the possibility of water in electronics for functionality and safety reasons. An example of five of the boxes is shown in Figure 2. Inside of each is six peristaltic pumps and appropriate connections as shown in Figure 1.

Figure 2. Plumbing from multiple treatment 'boxes', each with multiple peristaltic pumps, is shown, mounted on top of the refrigerator where artemia are kept. Flexible tubing then carries artemia into an adjacent 'wet room' with fish tanks on racks where fish are cultured.

Electronic components to drive the peristaltic pumps were chosen. Although a number of microcontrollers were considered, the Beaglebone was chosen as it had the ability to drive this number of units and was relatively straight forward to interface with. The beaglebone was programmed to drive the pumps in series (e.g. pump 1 first; then pump 2, etc.) due to limitations in power to drive all of them simultaneously. This allowed basic functionality.

Figure 3. Adjacent 'tank room' where fish are cultured. Note flexible lines leading to each customized tank. A saline rinse pushes artemia through the lines after the artemia to flush the lines and make sure fish receive all the artemia.

Early in development, it still required editing the code to choose different timings and parameters (how often to pump, how long/what volume is required at each time), and there was little visibility other than checking tubes to see if flow was occurring. As a consequence, a graphical user interface (GUI) was developed to enhance ease of use and operation.

The GUI was developed and refined over a series of cycles with input from engineers and ultimately with the goal of allowing a biologist to be able to operate the devices easily. The resulting GUI is depicted in Figure 3. This has 'slider bars' to set concentration, feeding rate, timing and other factors. It also shows status e.g. when is the system operating and when is it flushing. In addition, a number of simple alarms were added including an estimate until the end of the available artemia in the refrigerator. This is important for operators to check and clean or add to the artemia reservoirs. Other possible alarms include noting when pumps are operating and, with feedback, the effective density and rate of delivery of artemia, as well as simple alarms if there are any noted failures such as loss of power. The GUI operates on a computer or a tablet (shown in Figure 3). Communication is wireless, again allowing electronics to be separate from 'wet' areas.

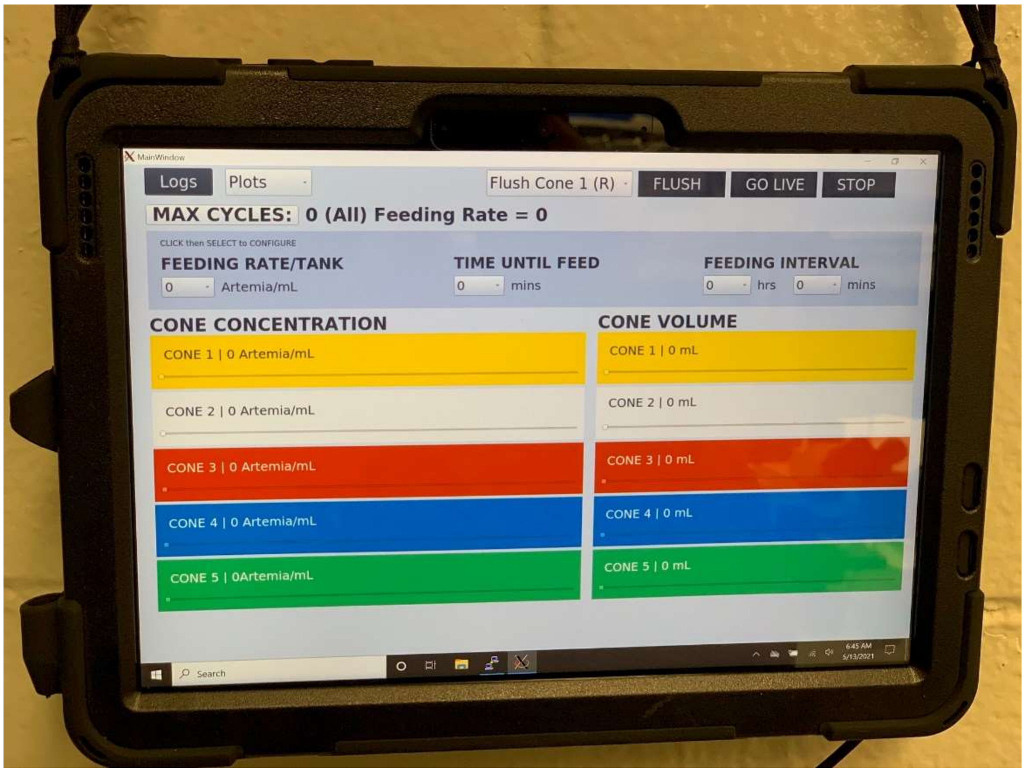

Figure 4. Graphical User Interface is visible, user friendly and provides interface with 'sliders' to set desired feeding rates, timing, concentrations and other relevant parameters.

Results

More than 95% of artemia arrived in the fish tanks alive and healthy. Pumping volumes have an accuracy of +-5-10%. Total pumped artemia may still be somewhat inconsistent due to changes in artemia density. A feedback system to assess and deliver a more accurate artemia count is under development. Overall, the system seems robust and effective, with two major benefits: operators can rest and work on other functions, enhancing their performance and safety;

and the fish receive a consistent and well measured dosage of artemia on a very regular schedule, enhancing fish growth and development.

Conclusions and Future Work

The aquaculture industry is very fast growing, but unlike terrestrial agriculture which has been selecting and managing animals for hundreds or thousands of generations, aquaculture is a very new endeavor. For example, striped bass are currently in generation 8 after about 30 years (it takes roughly 4 years per generation). As a result, development of breeding and early life stage management is ongoing. Engineering of systems to assist in all stages of aquaculture is one way of enhancing the industry. This work focused on feeding enhancements during the larval stage, and should be applicable, with minor alterations, to a number of related species. In addition, the lessons learned can enhance safety, efficiency, and overall culture of aquatic species, contributing to both the productivity and sustainability of the fast growing aquaculture industry.

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