SOUND: A swarm of low-cost floaters for sustainable fishing

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Abstract—The SOUND project focuses on developing a swarm of low-cost Lagrangian floaters capable of providing non-invasive aquaculture and fishing support, especially in remote areas and developing countries. The floaters drift with the current and use their buoyancy control mechanism to achieve profiling and depth-keeping behaviours, performing active acoustic fish detection and biomass assessment. This paper details the mechanical and algorithmic design of the SOUND floater prototype, as well as results achieved in laboratory experiments and during sea trials.

Index Terms—Lagrangian floater, marine monitoring, depth control, vehicle design

I. Introduction

IT is widely acknowledged that fish are an important group both ecologically and commercially. Yet, our knowledge of fish presence, composition, abundance, and behaviour is frequently limited to anecdotal sightings and reports, often by invasive techniques such as net catches [1]. In that context, in-situ ocean monitoring that enables remote access monitoring of fish can advance our understanding of the presence and behaviour of important fish populations. That includes enhancing our knowledge regarding the movement and abundance of fish, and understanding behaviours such as schooling, cohesiveness, and vessel avoidance. Monitoring of fish populations will also enable efficient management of key coastal commercial activities; most significantly reducing fishing bycatch and pushing for data-driven marine decision making [2]. To that end, we are designing an autonomous system that is able to perform on-the-fly monitoring of fish schools.

Project SOUND designs a swarm of low-cost Lagrangian floaters that drift with the water current, while performing active acoustic fish detection and fish biomass assessment (Fig. 1). This spatial detection from multiple floaters is shared through underwater acoustic communication and translates into fish spatial distribution; data that is currently available only from models. The target autonomy of the floaters is 5 days of operation at depths up to 50m. The floaters provide omnidirectional acoustic monitoring at a detection range of 100m and report their detection results using satellite communication.
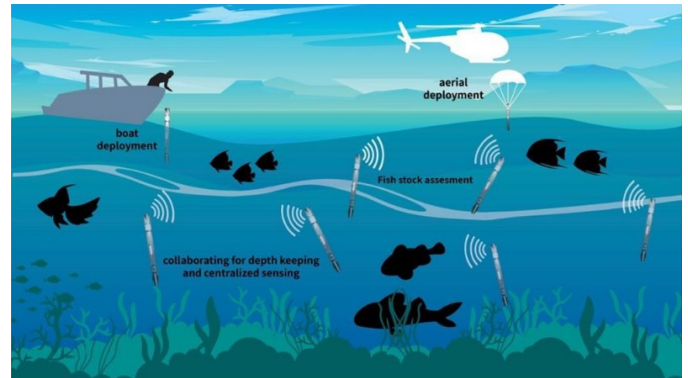
Fig. 1: Illustration of the SOUND project concept.

II. Floater design

In this paper, we discuss the mechanical and depth control aspects of a floater within the realm of the SOUND project. Flotation devices for ocean monitoring are currently in use throughout the world. The most well-known devices are the Argo floats [3], which are profiling floaters that continually probe the water column while collecting temperature and salinity measurements. Their depth profiling involves a hydraulic pump inflating or deflating an external bladder. The depth-changing mechanism of the EM-APEX floaters provides buoyancy control by a combination of an air pump inflating or deflating an air bladder, while a piston simultaneously pushes or pulls oil into a reservoir, thereby achieving shifts in average density [4][5]. The mechanism used by the RAFOS floats [6] manages their depth by adaptively adjusting a ballast weight to attain buoyancy towards a certain desired depth. Quasi-Lagrangian floats that control their buoyancy by changing their volume via moving two concentric cylinders over each other are described in [7]. However, the high-intensity noise radiated by the motor during depth-keeping impacts the continuous acoustic monitoring. Similar limitations are present when using a pump that pushes oil through a bladder for buoyancy change [8], or a thruster to actively control depth [9].

The floater described in [10] is designed to be negatively buoyant, while thruster operation is scheduled to ascend or descend. To reduce battery usage and noise, the floater includes a parachute-like tarpaulin sheet that, much like an umbrella, opens when the floater sinks and closes when it ascends.
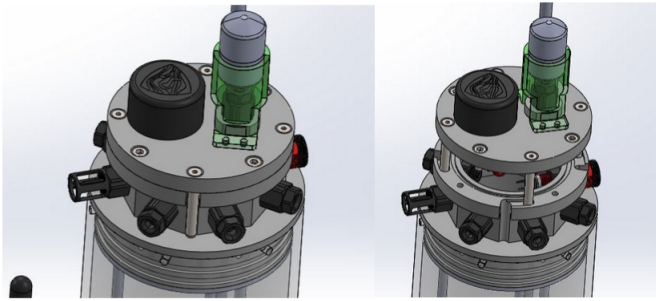
Fig. 2: SOUND floater prototype top cap design, sealed for deployment (left) and open for access (right).

Fig. 3: SOUND floater prototype antenna and hydrophone mount design (left). Full hull prototype with hydrophone mount (right).

Another design is that of the aMussel robots [11] whose buoyancy control mechanism comprises a piston and impenetrable membrane, which enables them to float to the water's surface or sink to the seabed. The SOUND floater builds on these designs by being capable of passively maintaining depth via achieving neutral buoyancy and thus an overall quieter and more efficient operation.

A. Hardware design

The main body of the SOUND floater consists of a plexiglass tube of a length of 95 cm terminated on one end by the buoyancy mechanism and on the other by a sealing cap containing all required penetrators, switches, probes, and active parts of acoustic devices. The cap is designed to separate into two parts that are relatively movable, as shown in Fig. 2. When the two parts are joined together the cap is closed and completely seals the upper part of the cylinder. When the upper part of the cap is opened via a pull-and-rotate motion, a user can get direct access to the floater electronics without a need for opening the entire system, which can be used for wired battery charging, direct serial communication, and general maintenance. Below the top section of the cap is a groove for cable glands, sensors, and probes that don't necessarily need to be placed on the top of the device. Four hydrophones are placed symmetrically on a mount radiating outwards from the main body of the floater, while the acoustic projector is mounted on the top of the cap. The hydrophone mount also doubles as an attachment point for the 1m long antenna for GPS and Iridium signal when the floater surfaces for data transfer (Fig. 3).

The depth control mechanism of the SOUND floaters is based on varying the buoyancy of their elongated and bottom-heavy body. Their design entails a single variable-volume chamber with a piston near the bottom of their main enclosure, making the unit buoyant as the volume changes. The floater has the most volume and highest buoyancy when the piston is completely out, and the least volume and lowest buoyancy when the piston is completely retracted. The actuator controlling this change is a single piston with a linear driving mechanism and a rolling diaphragm (Fig. 4). A lead screw is used for this linear mechanism, as it can produce a large force, thereby overcoming the high pressures at greater depths. A detailed view of the linear driving mechanism is shown in Fig. 5. Within it, a central spur gear is rotated by three other
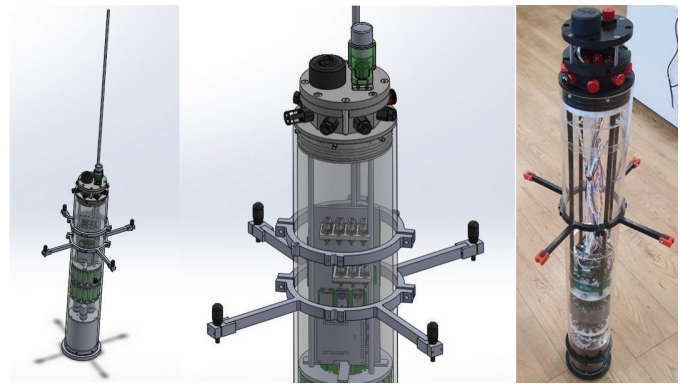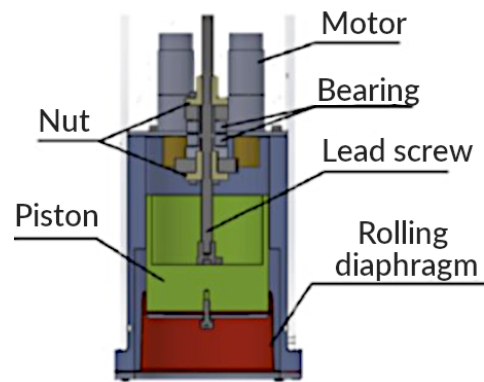

Fig. 4: SOUND floater buoyancy mechanism design cross-section.

spur gears that are connected to the motors. The nut connector couples the two outer nuts with the central spur gear. The lower nut and the central spur gear are directly fastened to the nut connector, whereas the upper nut is connected via the shaft collar.

Using multiple, small electric motors coupled together makes it possible to drive the buoyancy system within a low-power and low-voltage floater, while still providing high torque and fast actuation. This mechanical system is combined with two limit switches that detect top and bottom extreme piston positions when touched and activated by the lead screw. A
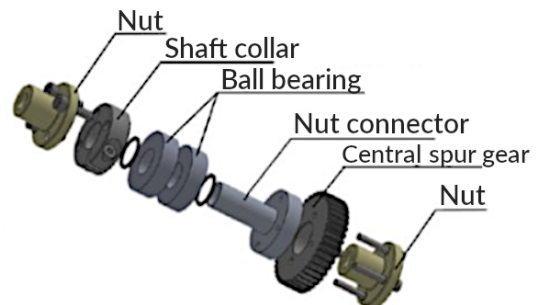

Fig. 5: Detailed view of the linear mechanism design.

Hall effect quadrature encoder and a pressure sensor enable control algorithms of low complexity to allow implementation on low-cost electronics. The functionality allows the floaters to maintain a certain depth, profile, or surface for data reporting or retrieval. Noise is suppressed on the motors themselves by a vibration-absorbing material (silicone) that is glued between the motor and the floater's body. This decouples the motor from the floater enclosure to avoid disturbances to the acoustic unit. Reducing motor usage during operation also serves to reduce noise and allows for better energy efficiency.

The main electronics of the floater are divided into two parts that have independent power supplies, ensuring the noise-sensitive acoustic sensing and processing part is isolated from the part dealing with motor and buoyancy control. The entire electronics and battery support skeleton is connected to the top cap. The acoustic sensing section consists of a Raspberry Pi 4 as its main board and includes the entire acoustic data acquisition and processing subsystem, while the general sensing, depth control, and communication section uses an Arduino Micro board to manage acoustic communication between individual floaters and floater-to-topside via an acoustic nanomodem. The Arduino-run part also acquires data from the pressure/temperature sensor on the top cap and the position encoder and limit switches on the buoyancy mechanism, closing the loop for depth control.

Fig. 6: The inner and outer depth control loop.

Fig. 7: SOUND floater performing depth-keeping in laboratory pool conditions.

B. Software and algorithmic design

The main behaviour loop of the floater is run on the Arduino Micro, while the Raspberry Pi 4 runs a sleep/wake cycle in order to conserve power, waking up when its advanced processing abilities are required. The floater has two basic behaviour states: profiling and depth keeping, where profiling includes searching for a point of interest in the water column, and depth keeping includes staying at the depth of a detected and reported point of interest.

Controlled sinking and surfacing for vertical profiling is done by shifting the piston from a neutrally buoyant position defined by an encoder offset. To reduce motor activity, we target the piston's shift to render minimum negative or minimum positive buoyancy, as the floater's movement speed is not a priority. During operation, the floater is initially trimmed so that neutral buoyancy is equivalent to a piston position of the piston bottom being flush with the floater hull bottom edge. As shown in the block diagram in Fig. 6, the final depth control loop is closed using the pressure sensor's temperature-compensated depth reading. This is designed to calculate the desired piston position setpoint for the inner control loop with regards to the offset from the desired floater depth.

The controller implemented in the outer loop of the system is a three point controller that enables switching between sinking and surfacing, while maintaining a dead zone of depth tolerance in which the floater piston moves back into its neutrally buoyant position. The control law for setting the desired piston position $d_{setpoint}$ is thus:
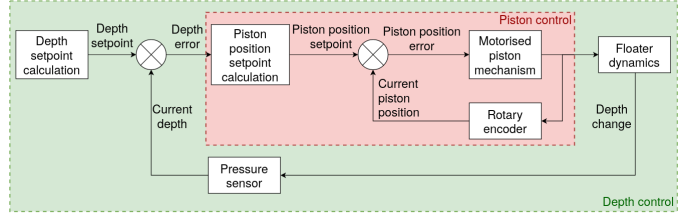
$$d_{setpoint} = \begin{cases} d_{sink}, & z - z_{setpoint} < z_{tolerance} \\ d_{surface}, & z - z_{setpoint} > z_{tolerance} \\ d_{neutral}, & \text{otherwise} \end{cases} \quad (1)$$

where z is the current floater depth, $z_{setpoint}$ is the desired floater depth, and $z_{tolerance}$ is the depth tolerance, and d_{sink}, $d_{surface}$, and $d_{neutral}$ are constant encoder offsets determined empirically that define piston positions for achieving positive, negative, and neutral floater buoyancy.

The inner loop controller is a bang-bang controller [12] applying maximum negative or maximum positive voltage to all three of the motors actuating the piston, depending on the reading from the encoder, with the goal of moving the piston to the desired position as quickly as possible.

III. DEPTH CONTROL EXPERIMENTS

A. Laboratory conditions

The operation of the floater was validated in laboratory conditions in the LABUST laboratory pool in Zagreb, Croatia. The floater was trimmed to be approximately neutrally buoyant in the pool, tied to a rope and deployed, then acoustically commanded to perform sinking, depth-keeping, and surfacing within the 3m depth available (Fig. 7). The depth tolerance for these experiments was set to 20cm.

Floater behaviour data along with motor activation indications are shown in Fig. 8 for an experiment performed in the pool. We observe slow oscillations around the target depth and sharp drops in the floater's battery voltage as the motors activate and work to push against external water pressure, extending the piston.
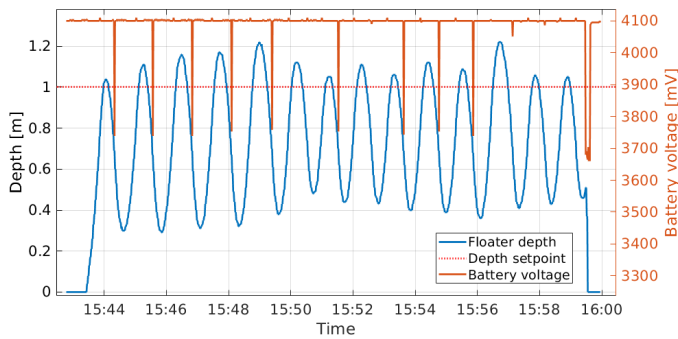
Fig. 8: Floater depth, setpoint, and battery voltage recorded during a 15-minute experiment in laboratory pool conditions.
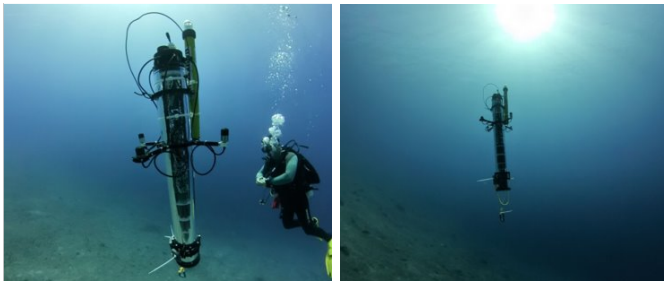

Fig. 9: A photo of the SOUND floater prototype at 20m depth deployed in Eilat, Israel, July 2023. Picture taken by Mr. Liav Nagar.

B. Field trials

Sea trials were performed in July of 2023 in order to check the simultaneous operation of the floater's depth keeping and acoustic subsystems in realistic conditions. After integration in laboratory facilities in Haifa, Israel and a pressure chamber test for the required maximum depth of 50m, field experiments were done in Eilat, Israel where the bathymetry is steep, granting easy access to a variety of depths (Fig. 9).

The floater was manually scheduled for depth-keeping around 17m, and was observed by a pair of scuba divers. Throughout operation, acoustic sensing was performed in a reef environment with multiple reflections. The depth tolerance for these experiments was set to 50cm.

A diagram of the floater's depth profile is shown in Fig. 10. The data shows that the floater oscillated up to 2.5m around the desired depth, and that ascend rate and descend rates are roughly similar at 0.12 m/s. A diagram of the depth error and battery usage is shown in Fig. 11. The results show sharp changes in voltage whenever the motor is operated, consistent with but more pronounced than the ones noted in the pool experiments. A slight decrease in the average voltage is visible as well. It is clear that the operation of the motor was very frequent and caused increased battery usage, indicating a need for a different and less simplistic controller approach. Another issue that became apparent as a result of these experiments is the long-term inaccuracy of the piston position estimation via the rotary encoder, leading to a need for frequent re-calibration using limit switches.

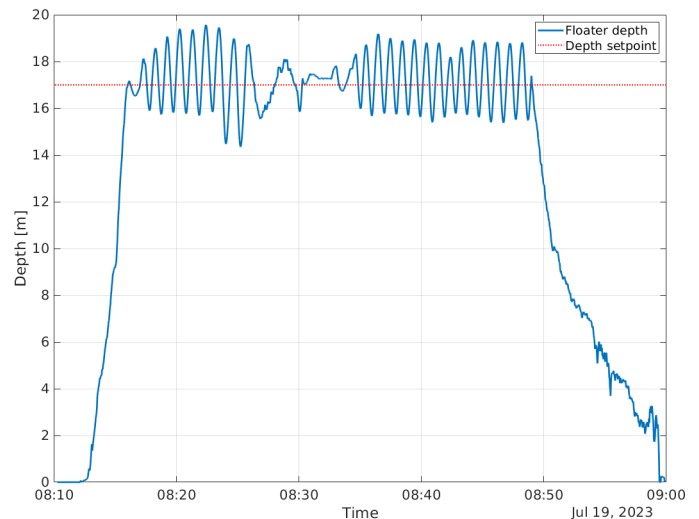In addition to depth-keeping, experiments done in the field

Fig. 10: Floater depth and setpoint data recorded during a depth-keeping experiment in Eilat, Israel.
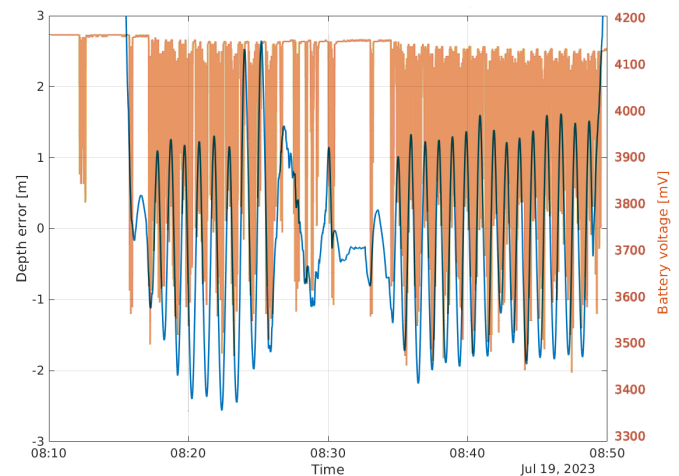

Fig. 11: Floater depth error and battery voltage data recorded during a depth-keeping experiment in Eilat, Israel.

included autonomous operation of a predefined mission. The floater was scheduled to maintain a certain depth for 30min and then to surface for retrieval. A pair of scuba divers followed the operation of the floater, and an operator on a pier remained in contact with the floater via acoustic communication. The mission cycle (depth keeping followed by surfacing) was completed successfully. This mode of operation, including on-the-fly mission selection, will serve as the foundation for SOUND floater swarm behaviours.

IV. CONCLUSIONS AND FUTURE WORK

A working prototype of a low-cost Lagrangian floater with depth control capabilities was developed, built, and tested in both laboratory and field conditions. The piston-based buoyancy control system showed satisfactory performance in the required depth ranges and did not interfere with the operation of the active acoustic sensing of the floater. A redesign of the buoyancy mechanism is in progress, focusing on increasing robustness and replacing DC motors with steppers for more

precise position control. A PID controller will be implemented in the depth control loop, with the goal of eliminating oscillations and steady-state errors and ultimately minimising motor usage. Finally, a long-term stress test of the floater will be performed in order to ensure it is capable of fulfilling the 5-day operation requirement.

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