Design Structure of SYMBIOSIS: An Opto-Acoustic System for Monitoring Pelagic Fish

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Abstract—In this paper, we present the mechanical structure of SYMBIOSIS: an opto-acoustic system that provides a mature, cost effective autonomous capability for the characterization, classification, and biomass evaluation of six target pelagic fish that are important to the fishery industry and that reflect on the health of the environment. SYMBIOSIS is devised as a blend of acoustic and optical components. The acoustic unit relies on an active underwater acoustic array that transmit wideband signals and analyze reflections to find moving targets. Once found, the optical system takes command and identifies the fish’s species. The system is completely autonomous and made to withstand a few months of deployment between recharging. We describe the basic components of SYMBIOSIS, as well as operational procedures for the system.

Index Terms—Detection of pelagic fish, Underwater acoustic signal detection, Underwater acoustic communication; Fish classification

I. INTRODUCTION

One of the key aspects in marine monitoring is the assessment of the marine life diversity, which is an indicator of the health of the ecosystem. The marine fauna directly affects coastal recreation, tourism, fisheries, aquaculture, and coastal industries, to name only a few areas of concern. The assessment of marine life must involve efficient and preferably autonomous surveys, to form large labelled databases using both mobile and fixed platforms [1]. To better understand the marine ecosystem, the data needs to be correlated across time and space [2]. To that end, SYMBIOSIS was founded. Symbiosis is an EU H2020 funded project aimed to automatically detect and estimate the biomass of pelagic fish, which are important to the marine ecosystem and for marine agriculture. SYMBIOSIS is aimed to bridge the knowledge gap of the abundance of these fish — data that is currently is obtained only via sporadic census surveys which are invasive by nature. Specifically, SYMBIOSIS is designed to directly identify and count different species of pelagic fish, thereby alerting legislation authorities about the true number of fish in a specific place but over large periods of time.

The current approaches for evaluating the marine biota can only give limited solutions. In particular, acoustic imaging techniques produce a very narrow beam to detect objects located directly below a surveying vessel, and does not fit the task of monitoring the marine environment. Moreover, there are no reliable commercial methods for the classification and biomass evaluation of fish, and the capabilities of the existing methods for fish detection are highly limited to simple seabed environments. In fact, the current detection capabilities involve many false alarms in non-homogeneous seabed environments that include highlights, shadows, sand ripples, sea grass, or boulders, and the current research is often performed manually [3]. As a result, current surveys are limited in space and require a long analysis process [4]. In this context, the goal of SYMBIOSIS is to reliably and autonomously detect, classify, and enumerate marine species. This may not only improve the efficiency of environmental monitoring tasks, but will also open the way for long-term and long-range surveys. Hence, one of the important goals of the system is to be energy and cost efficient such that the environment can be monitored from multiple offshore platforms over long periods of time.

As part of SYMBIOSIS, six species of pelagic fish has been identified. These species reside in both costal and deep sea as well as in the oceanic environment. Referring to Fig. 1, SYMBIOSIS implements an opto-acoustic detection mechanism that can operate both in the far field up to 500m and in the near field of 2-3 optical attenuation lengths. The system operates a chain of detection. Our detection chain starts with the transmission of low-spectral density acoustic signals, and the analysis of the received reflections from a vertical acoustic array for the detection and biomass evaluation of the fish (step 1). Once a fish is detected, an acoustic procedure (described below) will be carried out to evaluate the type of fish detected based on the target strength and its distinctive resonance frequency (step 2). By analysing the acoustic reflections, we will also estimate the range and bearing to the detected fish (step 1) such that only if the fish is detected close enough, the corresponding optical camera will be triggered and capture several optical images at a fast rate of 40 frames/s. Based on our advanced image processing and segmentation techniques, the captured optical images will be processed to enhance clarity in low light conditions (step 3). The segmented optical image with the detected fish will be further processed via machine-learning tools to classify the detected fish types and to evaluate their size and number, e.g., the fish biomass (step 3). Using wired transmission from deep to surface, backed up by underwater acoustic communication to reduce maintenance needs by a supporting vessel, and radio (THEMO deployment sites) / fiber-optic (PLOCAN deployment site) communication from surface to shore, the biomass evaluation results as well as the processed
acoustic reflections and optical images will be transferred to a shore station for further analysis and for sharing with the research community and legislation authorities (step 4). We now proceed by presenting the structure of our system in more detail. In this paper, we focus on the mechanical structure of SYMBIOSIS.

II. Structure of SYMBIOSIS

The SYMBIOSIS system is aimed for long-term off shore deployment. The system is attached with a cable to a surface buoy, and is anchored to the ground by a mooring cable. SYMBIOSIS is devised as a blend of acoustic and optical components. The cameras are set to cover 360 degrees at two depths, and are accompanied by strobes to increase visibility. The acoustic units are software defined ultra short baseline (USBL) systems including five hydrophones and one transceiver to allow directionality. The processing of each camera is handled by a designated powerful Jetson board, and a separate Jetson board is used to process the acoustic data. The systems run from a designated battery of 2300 Ah that can also be charged from a surface ship.

The system is constructed out of three units.

1) **Upper Unit**: As illustrated in Fig. 2a, deployed at 5 m depth, the top unit includes six cameras and six corresponding strobes; three software defined USBL systems at 7kHz-17kHz range; an underwater acoustic modem, and a relay system.

2) **Middle Unit**: As illustrated in Fig. 2b, deployed at 11 m depth, the middle unit includes the battery pack as well as the main controller of the system.

3) **Lower Unit**: Similar to the illustration in Fig. 2a, deployed at 20 m depth, the lower unit includes six cameras and six corresponding strobes; two software defined USBL systems at 7kHz-17kHz range; two software denied acoustic modems at 18kHz-34kHz range aimed for better detection resolution, and a relay system.

To communicate between the three systems and to pass energy, we use combined Data/Power cables, which supply the devices with different voltage levels and provide 100Mbit/s Ethernet link. The cables are attached to a metal wire that screws into the units via designated connectors (see Fig. 2), thus avoiding twists and turns that may break the communication cables. On the other hand, since the surface buoy keeps rotating, we cannot place hard wires between the deployed unit and the buoy. Thus, the communication to the surface buoy to transfer health status as well as detection results is done via acoustic communications.

A. **USBL Devices**

The USBL consists of a modem transducer (at the geometric center of the USBL grid) and five hydrophone receivers on the periphery. The USBL grid represents a pentahedral pyramid, in which the hydrophones of the grid are situated in all pyramid corners. The distances between the hydrophones differ from the standard S2CR717 USBL serial model, amounting 62 mm from the center of the antenna (87.7 mm between adjacent hydrophones). The USBL is a combination of the Evologics serial product S2CR7/17 USBL, and the Evologics serial product S2CR7/17 SDM. The development of a five-channel USBL circuit operating on the software-defined scheme with the five USBL grid hydrophones, provides an access for an upper
layer protocol to all five raw sampled signals synchronously collected from the USBL grid hydrophones. The unit also has a pressure sensor integrated into the product.

The software-defined USBL can be controlled by a set of simple commands:

- per a binary command a user-defined reference signal with a duration of 1024 samples (two bytes each sample) with a sampling frequency of 62.5 kHz can be saved into the memory of the software-defined USBL;
- after setting the USBL to the listening mode (per another binary command), the central channel of the antenna (namely, the transducer, staying in the geometrical center of the USBL grid) starts performing a continuous real-time processing of the input stream of digitized acoustic activity registered by the central transducer. During the real-time processing, the device estimates the correlation function of the digitized stream immediately saved in the buffer (1024 samples in 2-byte format) with the user-defined reference signal, and compares the output of the correlator with a detection threshold. If the output of the correlator does not exceed the threshold, the buffer content is shifted by 1 sample and complemented with the next sample. The estimation of the correlation of the buffered stream with the reference signal is repeated again, is compared with the detection threshold, and so on, until the output of the correlator exceeds the detection threshold (i.e., until the input signal that matches the reference signal is detected at the antenna input);
- after detecting the matched signal in a central transducer channel, digitized signal stream starts to be sent to the corresponding TCP/IP socket beginning to flow into the corresponding buffer. The fact of digitized signal stream appearing in the buffer can be detected by corresponding system calls (binary requests). System calls, particularly for \texttt{Iread} waiting on the socket\texttt{I}, must be included in the upper layer (user-defined) program; e.g. using one of existing standard solutions implemented by the user in his program for polling the socket. Immediately after the appearance of the signal stream on the socket in the central transducer channel, the signal streams digitized with the five hydrophones of the USBL grid also
begin to synchronously flow into five buffers connected to the hydrophones (the synchronization of the streams collected into the buffers is about ten of nanoseconds). Each of the buffers can record up to 51200 samples. In each stream, the sample sequence is preceded by the detector response time stamp, and since the sampling rate is known, each sample is strictly time bound;

- to provide more flexibility for the user a binary command \( \text{\texttt{AIoff}} \) has been implemented to set by the user a controllable parameter introducing a delay, which the device must wait up before starting to record signal stream to the buffers from the USBL grid hydrophones. Also, the number of samples required to be recorded to the buffer is a controllable \( \text{\texttt{AIS}} \) user-defined parameter indicating the required length of the signal which must be written to the buffer, ranging from 0 to 51200 samples (with the step of a multiple of eight);

- after processing the signal stream by the user-defined program, by means of a corresponding binary command the device can be set back to the listening mode. After setting this mode again, the previously recorded signal streams in the buffers are deleted. The buffers are ready to receive new signal stream.

- for digitization of the input signal from each of the USBL grid hydrophones the sample rate can be configured by the user command to one selected from the list: 1 MHz, 500 kHz, 250 kHz, 125 kHz, 62.5 kHz, 31.25 kHz. Depending on the sampling rate selected, the maximum signal lengths recorded in the buffers can be thus changed by the user;

- after detecting the matched signal in the USBL input, an automatic gain control (AGC) circuit can be set to active state for adjusting the gain level of the device preamplifiers. After detecting the matched signal, the AGC (if set active) does not change the gain level for entire signal length (i.e. for up to 52100 samples) during its recording into the buffers of the USBL grid hydrophones. The gain level is updated once per receive cycle (each time after the USBL is set to the listening mode \( \text{\texttt{AIS}} \) update of the gain level occurs at the time of the matched signal detection);

- as mentioned above, detection of the matched signal is implemented on the basis of estimation of the correlation between the received signal and the used-defined reference signal. Since user-defined waveforms recorded as reference signals can exhibit different properties at the output of the correlator, the response level of the correlation detector is implemented also as a parameter controlled by the user by means of a corresponding command;

- the transmission power control is a user-controlled parameter between 164 and 184 dB re 1\,\mu Pa @ 1\,m (four gain levels in the range of -20 ... 0 dB), as well as the sensitivity control at the reception is implemented as a user-controlled parameter (two attenuation steps: 0 and -20 dB).

The supply voltage of the SDM S2CR7/17 USBL can stay in relatively wide range, between 19 and 28 VDC, with a permissible instantaneous (in-rush) current of 10 A. The SDM S2CR7/17 USBL is marked on the antenna housing for orientation of the antenna\(\text{\texttt{A}}\)'s local coordinates when installed on a user platform. Connection of the USBL electronics to the computer can be established via the Ethernet interface. As an option also RS422 interface can be alternatively used.

### B. Cameras and Strobes

To acquire underwater images in different lighting conditions and ensure preserving details without saturation while taking photos of high reflecting objects in water column, imaging sensor with high sensitivity and wide dynamic range should be chosen for that application.

A SYMBIOSIS camera module consists from the following components:

1. Ximea MQ042CG-CM USB 3.0 camera with Kowa LM8HC lens,
2. Nvidia Jetson TX2 module at Auvidea J120 baseboard,
3. DC/DC converter to supply the board with stabilized 12 V.

Based on previous positive experience, CMOSIS CMV4000 was a preferred option for the SYMBIOSIS project. The sensor has following features: 4.2 Megapixel resolution with 2048 by 2048 effective pixels of 5.5\,\mu m x 5.5\,\mu m size, 60dB dynamic range, 44/45/46% quantum efficiency for blue (470nm), green (525nm) and red (640nm) channels correspondingly. The sensor has an 1:1 aspect ratio and the size of 1 optical inch (11.3 x 11.3 mm).

The camera module is assembled into the cylindrical housing with outer diameter of 109 mm and total length of 270 mm excluding connectors. It has a dome port with a protection cage around and two wet-mateable connectors at the other end. The dome port has internal curvature radius of 46 mm and made from acrylic glass. Combination of the dome port and 8mm wide-angle lens makes it possible to achieve 70\textdegree angle of view. The camera module is depth rated up to 200 m.

Internally all camera module components are assembled on an aluminum frame which is directly connected to an anodized aluminum lid. Heat produced by the components are transferred through the frame to the lid, which is directly exposed to the environment.

Combining the camera and the embedded computer into one module gives a possibility to use high bandwidth of USB 3.0 connection to acquire images and avoid using high-speed interfaces (e.g. SuperSpeed USB, Gigabit Ethernet) outside the pressure housing. Raw images should not be transferred outside the module, but segmented and classified using neural networks running on the Jetson module.

To ensure stable operation of the SYMBIOSIS system when there is not enough ambient light, each camera is additionally coupled with an LED flash. The LED flash consists of sixteen 6W LEDs with 180 lm/W efficacy, providing total luminous flux of about 17000 lm. To prevent overheating of the LEDs...
each flash has a massive nickel-plated brass housing and is fully molded with transparent polyurethane.

**C. System Power**

The anticipated power consumption of the SYMBIOSIS system is presented in Fig. 3. The calculation shows that using a 2300 Ah battery and assuming detection of fish once per hour, the system is expected to work without re-charging for almost a full month.

**III. SYSTEM DEPLOYMENT**

The structure of the three SYMBIOSIS units is shown in Fig. 4. While the middle unit is connected to the lower and upper units via hard cables, the upper unit is attached via a swivel to the surface unit. This is required in order to keep the system from rotating with the surface unit, which otherwise would draw tension on the unit’s connectors. To bridge the 5 m gap between the upper unit and the surface unit, we use high speed underwater acoustic modem. This allows obtaining classification results from the deployed unit, as well as telemetry about the status of the system.

SYMBIOSIS units are 1.5 m long each, and the whole array is spread over roughly 20 m. One of the key issues in the success of the operation, is how to deploy the system. For ease of deployment, SYMBIOSIS is mounted only after the surface unit is in place. This means that the cable connecting the surface unit to the anchor should be dis-attached and re-connected after the three units are in place. To that end, we use scuba divers. The process includes four steps:

- **Step 1:** The divers will tie a 20 m rope connecting one side to the swivel of the surface unit to the mooring cable from its other side. The divers will then disconnect the mooring and let the mooring cable drop 20 m in the water. At this point, the surface unit will be held by the mooring and the above rope.

- **Step 2:** The SYMBIOSIS system will be connected onboard the deploying vessel. It will then be deployed from the vessel and held on a single surface buoy.

- **Step 3:** The divers will connect the lower unit of the SYMBIOSIS system to the lower side of the rope (depth of roughly 25 m), followed by connecting the upper unit to the swivel at depth of roughly 5 m. At this point, the SYMBIOSIS will be stationed parallel to the connecting rope with some slack.

- **Step 4:** The divers will cut the rope, letting the SYMBIOSIS system drop by roughly 2 m. Our calculations showed that the hit on the system will be low. The divers will then clear the remaining of the rope at 2 m depth and at 22 m depth.

The deployment procedure relies on three design aspects:

1) The upper and lower units end with rigid poles attached to a 1.5 m iron cable. This will allow the divers to have some slack while connecting the system. We believe that an iron cable of 10 mm diameter will be sufficient.

2) A similar iron cable will hold the three units. With a 10 mm diameter of iron wire directly screwed to the units, the systems are not expected to twist by more than a few degrees. This allow us to connect the electric cables between the units by strapping the former to the connecting metal wire.

3) To smooth the transfer of force from the SYMBIOSIS system to the mooring, the lower unit will be connected to the mooring via a swivel.

**IV. CONCLUSIONS**

In this paper, we presented the key components of SYMBIOSIS: a system made to identify pelagic fish offshore. The system includes a novel design of a software defined USBL system, which allows bearing and range estimation of fast moving targets, as well as a structure to combine optical cameras with strobes. We shared the design details of the above systems, as well as the operation procedures of SYMBIOSIS. To demonstrate its capabilities, the system is planned to be deployed for a few months in different sea environments, and results will be freely shared with the scientific community.

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Fig. 3: Anticipated power consumption of the SYMBIOSIS system.

| Device | Power consumption | Approximation of working operation time (hrs) | Average power per day (W) | Peak current (A) per day | Number of device (frac) x operation | Total power (W) |
|--------|-------------------|---------------------------------------------|---------------------------|-------------------------|------------------------------------|----------------|
| Camera: ISW Standby | 0 | 2 | 0 | 0.0325066667 | 1.0 | 2 | 0.131006667 |
| Camera: ISW LT | 0 | 2 | 0 | 0.0325066667 | 1.0 | 1 | 0.032506667 |
| Camera: ISW TX | 0 | 50 | 15 | 0.2552010101 | 2.0 | 1 | 0.5048020202 |
| Camera: ISW TX | 0 | 50 | 15 | 0.2552010101 | 2.0 | 2 | 1.0048020202 |
| Light system | 0.01 | 24 | 0 | 0.023534938 | 2.0 | 2 | 0.047069876 |
| Computer Octave Carrier for W/Adv. system TX2 | 15 | 43 | 0 | 14.35 | 1 | 1 | 14.35 |
| Other system | 0 | 50 | 0 | 1.75 | 1 | 1 | 1.75 |
| Data Memory 1.14 | 0 | 4.4 | 0.00 | 0.193333333 | 1.0 | 2 | 0.386666667 |
| Total | | | | | | | 0.540769231 |

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|--------|-------------------|---------------------------------------------|---------------------------|-------------------------|------------------------------------|----------------|
| Camera: ISW Standby | 0 | 2 | 0 | 0.0325066667 | 1.0 | 2 | 0.131006667 |
| Camera: ISW LT | 0 | 2 | 0 | 0.0325066667 | 1.0 | 1 | 0.032506667 |
| Camera: ISW TX | 0 | 50 | 15 | 0.2552010101 | 2.0 | 1 | 0.5048020202 |
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|--------|-------------------|---------------------------------------------|---------------------------|-------------------------|------------------------------------|----------------|
| Battery package (W/Amp) | 2300 | | | | | 2300 |
| time of operation (day) | 44.71687 | | | | | 44.71687 |

Fig. 4: Illustration of the full SYMBIOSIS system.