PRELIMINARY TELEROBOTIC EXPERIMENTS OF AN UNDERWATER MOBILE MANIPULATOR VIA SONAR

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***Abstract*—Robotic inspection of underwater infrastructures and scenarios can be enhanced when a wireless communication link is available, as the umbilical can be avoided and the mobility of the robot improved. To this end, previous experiments on sonar [1], Visual Light Communication (VLC) and Radio Frequency (RF) have been performed, which show the necessity to have a multimodal underwater communication system, as well as providing the robot with autonomous behaviors and artificial intelligence capabilities.**

Underwater sonar communication is a mature technology, which works fine in open waters, providing low bit rates and fluctuating delays for long distances [2] [3]. It can also be used for calculating ranges and localizing/navigating robots [3] [4]. RF modems communicate at similar bit rates, reaching short distances, and constant delays, which make it an interesting alternative for industrial scenarios where sonar might present reflections and multipath effects. VLC is already offering interesting bit rates (e.g. 2Mbps) at short distances, being necessary to have a scenario with lack of light, and also needing a special care with the spatial orientation of the modem. In the context of underwater mobile robotics for inspection, some efforts have been made in order to transmit camera or sonar images to the surface via acoustic modems [5] [6]. Compression techniques have been designed specifically to this aim [7] [8].

A more challenging scenario is the use of underwater mobile manipulators for both, inspection and maintenance operations. When having a robot that physically interacts with a target having an expert in the loop, even in a supervised way, provides an extra level of safety for the intervention. As long as possible, the human presence is an extra value to the system, and sometimes really a necessity. Moreover, it requires a special care and study in order to get the most of the wireless communication system, needing the combination of compression, and telerobotic supervisory control techniques.

In order to face this challenge, a preliminary study is being done in order to remotely control, in a supervised way, a G500 underwater mobile robot, provided with a Reach Bravo 7 robotic arm. The system includes an underwater monocular color camera, and a pair of Evologics Wise [9] acoustic modems, one installed in the robot and a second in a buoy.

***Index Terms*—Underwater Communications, Robot Networks, Simulation, Remote Control, Hardware In the Loop**

I. Summary of Experiments and Roadmap

As can be seen in Figure 1, the mobile manipulator has a 6 DoF robotic arm installed in the front, in order to face maintenance underwater interventions. An Evologics Wise acoustic modem is available in the upper part of the robot.

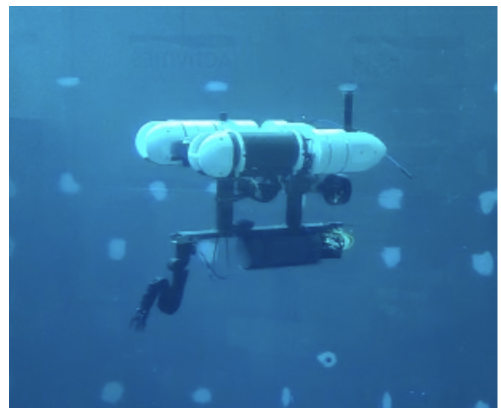


Fig. 1: Underwater Mobile Manipulator for the experiment

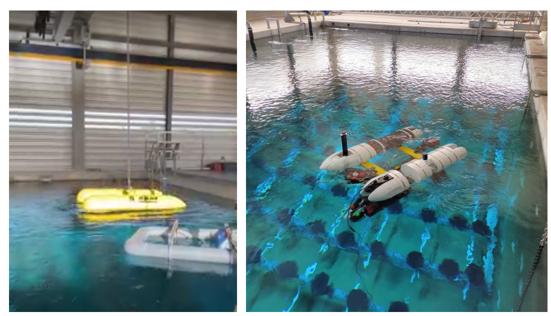


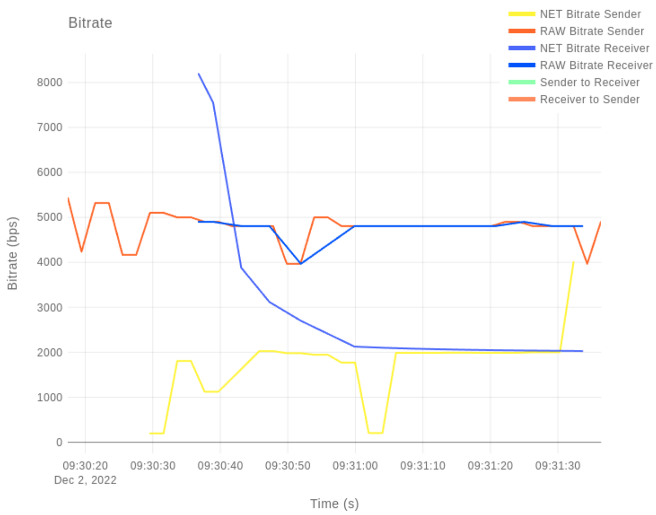
Fig. 2: Scenario 1 (CIRTESU Lab)

Moreover, as can be seen in Figure 2, a second acoustic modem has been installed in a buoy, connected to a surface Wi-Fi network to enable the operator to get the camera feedback and send the high-level control commands. At a first stage, the experiment is being done in a controlled lab scenario (i.e. Research Center for Robotics and Underwater Technology - CIRTESU), and a second test will be carried out in Castellón Port Sud (see Figure 3).

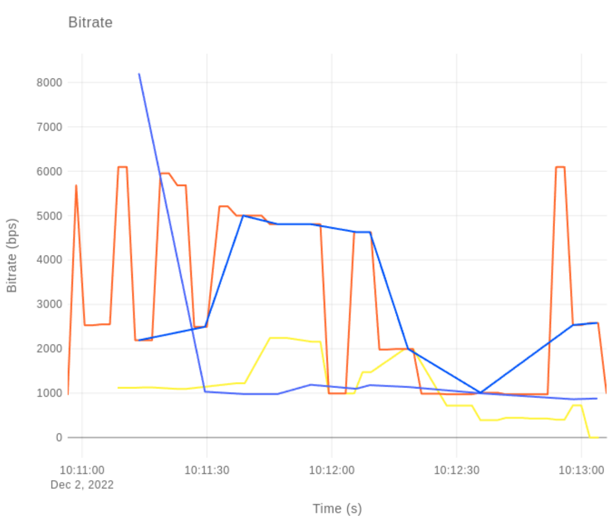
In the lab the acoustic modem is providing an unstable 5Kbps bit rate link, as can be seen in Figure 4, which represents a first step in order to test the proof of concept, software architecture, and to understand better the possibilities of the system.

As can be seen in Figure 5, the experimental roadmap

Fig. 3: Scenario 2 (Castellón Port)



(a)



(b)

Fig. 4: Modem performance in lab conditions

covers an incremental set of steps in order to accomplish the objective.

II. Experiments

First of all, we are performing the characterization of the sonar in order to identify the network properties and simulate communication without the necessity of using the robot physically. To do this, we use the acoustic sonar S2C R 18/34 WiSE Hydroacoustic [9], which has a theoretical range of 3 km in optimal conditions and a bandwidth of 13.9 kbits/s. However, as we will detail later, we did not achieve this theoretical bandwidth.

The modem can be used in two modes, immediate mode and burst mode. To do this, we developed the necessary source code to interact with the modem interface using AT commands and TCP sockets.

1) *Immediate Mode:* This mode operates through the D-MAC protocol, and each message allows a payload of 64 bytes. However, this type of communication is slower than the burst mode since it requires a confirmation response, which implies significant delays in an aquatic medium where propagation is slow. Therefore, we only use this mode for robot telecontrol, where it is necessary to receive confirmation of receipt. The figure 6 shows a comparison of both modes.
2) *Burst Mode:* The burst mode sends everything that is in the modem buffer without waiting for any confirmation, making it more suitable for sending images and telemetry. However, since there is no acknowledgment of receipt, some packets may get lost and therefore the integrity of the message is not ensured.

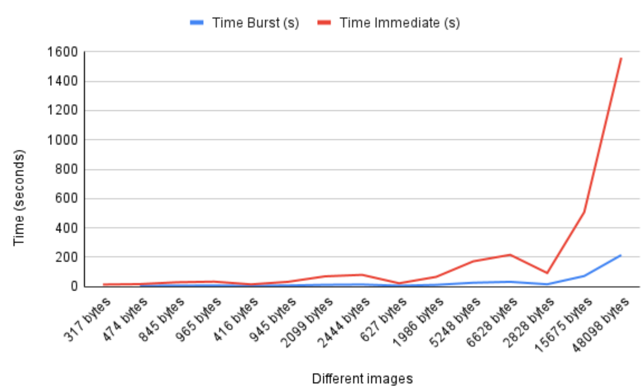


Fig. 6: Comparison burst mode and immediate mode

Initially, we conducted experiments outside of the water with two adjacent modems, in which we tried to send images with different resolutions (90%, 60%, 20%, 5%) and sizes (x0.9, x0.5, x0.2). However, these experiments did not provide useful information to characterize the network, so the results obtained are not presented.

We did a preliminary experiment in the CIRTESU LAB 2 with the modems separated by a distance of 2 meters, in

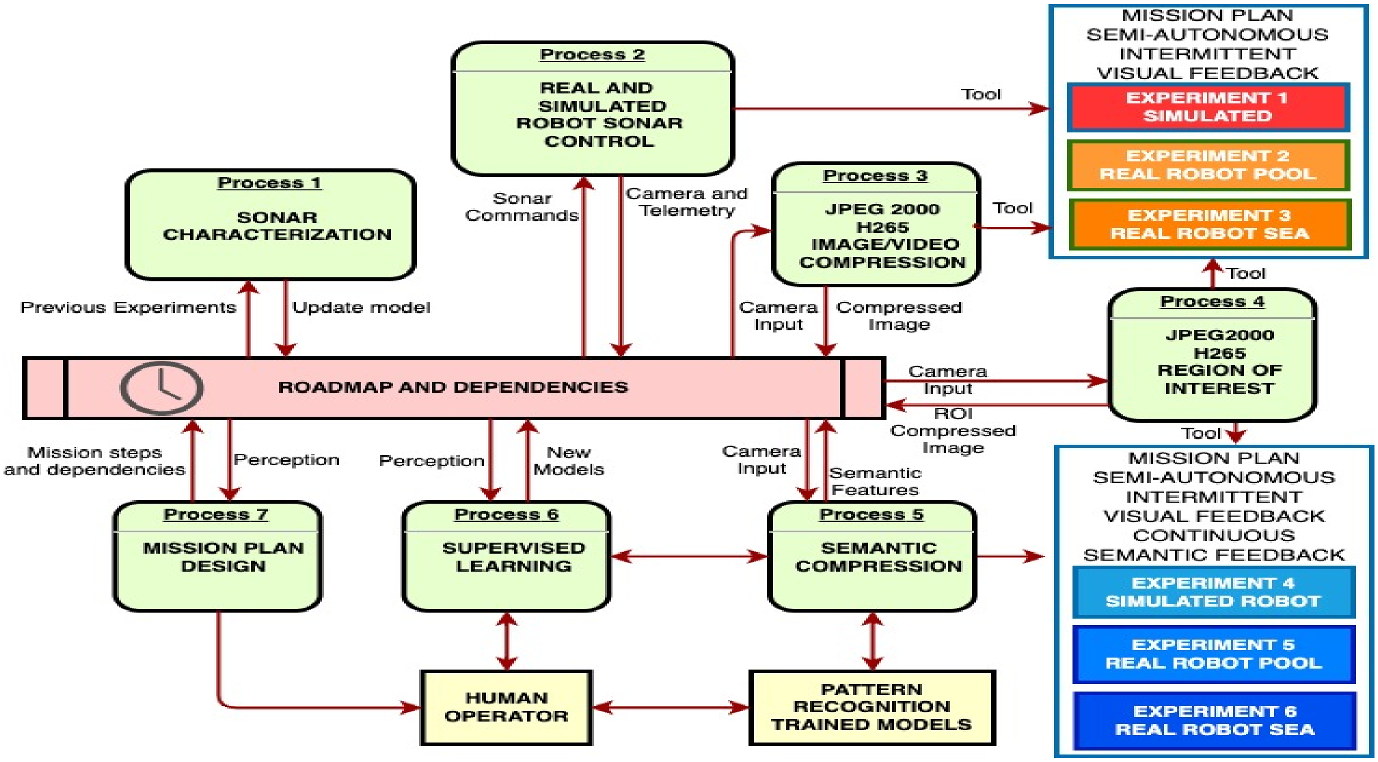


Fig. 5: Experiments Roadmap and Dependencies: *Sonar Characterization:* Communication sonar experiments in order to obtain the bit rate and delays. *Real and simulated Robot Sonar control:* Software implementation of sonar robot control. *JPEG2000/H265 Image/Compression:* Compressed images and videos for intermittent supervision. *JPEG2000/H265 Region of Interest:* Software implementation to reduce the image/video size by specifying regions of interest (ROI). *Semantic Compression:* Software implementation of a vision-based feature extraction tool in order to allow scene semantic description. *Supervised Learning:* Having the operator in the loop can help to update and learn new models of the semantic compression module. *Mission Plan Design:* The operator creates a mission plan with autonomous steps. They can confirm each step with high quality images and receive intermittent feedback during experiments.

which we sent images of different sizes. The results obtained are shown in figure 7

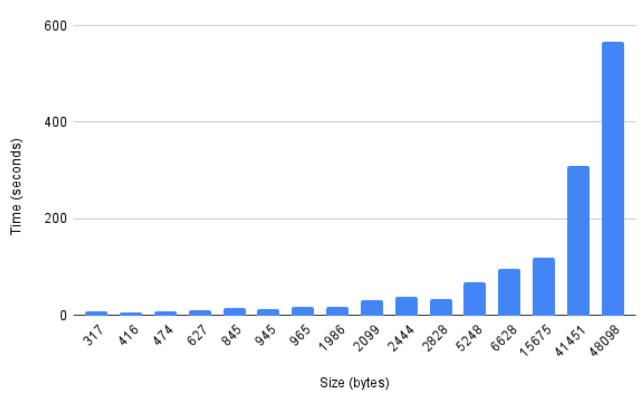


Fig. 7: Results obtained sending different images in CIRTESU tank

When we moved the modems more than two meters apart, we experienced communication issues. At first, we thought that it could be due to low gain. After increasing gain, we encountered problems with reflections because there are too many walls in the scenario 2, which do not allow proper communication.

We tried to prevent reflections by using insulating foam as shown in figure 8, but we were unsuccessful. We plan to repeat the experiment in a real scenario 3 soon.

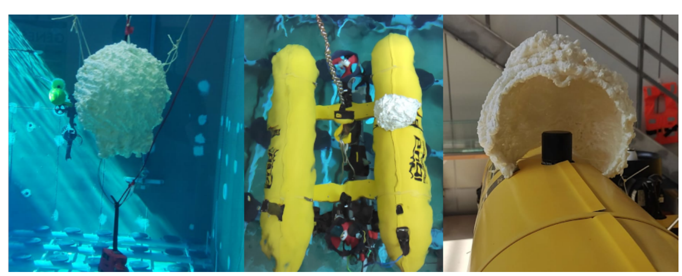


Fig. 8: Mounted with insulating foam to prevent reflections

III. Sonar Characterization

We did communication sonar experiments in order to obtain the bit rate and delays in specific robot/buoy situations for both, lab and sea conditions.

To achieve this, we measured the transmission times of images of different sizes. Each image was sent multiple times to obtain different samples and increase the variety. Subsequently, we developed a ROS [10] node, shown in Figure 9, that simulates the transmission via the acoustic modem and calculates the approximate waiting time for a given image size.

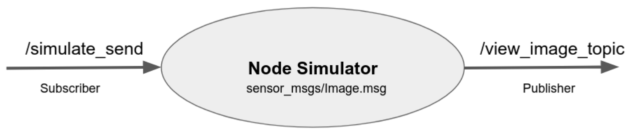


Fig. 9: ROS Node for simulation

The node subscribes to the "/simulate_send" topic and waits to receive the image that the user wants to send. Once received, it calculates the approximate transmission time using the formula 1. This formula considers the image sizes immediately above and below, and takes the average of the X and Y attempts for those sizes (μ). Then, a Gaussian distribution is applied to this time with a mean (σ) and variance (z), which can be configured to obtain more dispersed values and create a more random environment or less dispersed values to generate a less variable simulation scenario.

$$wait\_time = \mu + \sigma z \tag{1}$$

Once the node has waited for the calculated time, it publishes the image on the "/view_image_topic" topic. This topic is where the user expects to visualize the image.

By using this approach, we can perform simulations and analyze the ideal image size according to the environment conditions.

In figure 10 we can see the simulated environment with the Girona500 in the CIRTESU tank 2, and we can see in the right upper corner the image published by the simulator node after having applied the necessary delay depending on the size of the image.

Fig. 10: Girona500 simulation

IV. Conclusion

In summary, the article describes the characterization of an acoustic sonar for underwater communication. We use two modes of communication, immediate and burst, and we perform experiments to analyze the bandwidth, delays, and transmission times of different image sizes in the CIRTESU tank 2.

We also develop a ROS node to simulate the transmission via the acoustic modem and calculate the waiting time for a given image size. The experiments showed that communication issues can arise due to reflections caused by walls, and we plan to repeat the experiments in a real scenario 3. The study provides valuable insights into the use of acoustic sonar for underwater communication and can help researchers and engineers optimize the use of this technology in different scenarios.

V. Acknowledgment

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