CITIZEN SCIENCE BASED MARINE ENVIRONMENTAL MONITORING. THE MOANA60 EXPERIENCE

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Abstract – Sea water quality monitoring is an extremely important activity that following traditional methods is extremely demanding and expensive. This results often in the sea being largely under-sampled while scientific models are increasingly hungry of high resolution and high coverage data. A different approach needs to be pursued that could complement what is already available within the traditional practices with new data. The National Institute of Oceanography and Applied Geophysics - OGS developed innovative technologies that can be used within a citizen science or crowdsensing approach to monitor marine environmental parameters. These technologies consist of an acquisition and transmission device that sends data to the central OGS data collecting facility. The simultaneous installation of multiple such devices on boats of opportunity allows to create a network of mobile monitoring platforms and data management infrastructure able to acquire, store, process, validate and display in quasi-real-time georeferenced data on a web portal. This allows to share information on the quality of seawater with the scientific community but also with the public at large. If this allows the improvement of the environmental awareness of this latter and in particular of volunteers that are involved in the specific activity of data collection, at the same time this can dramatically improve spatial and temporal coverage of data. So far, the system has been installed mainly on recreational ships that covered restricted coastal areas, in the Gulf of Trieste (Northern Adriatic Sea); this work will report, instead, on an extension of the system done in collaboration with the Moana 60 Lab initiative that took place in the summer of 2021 and where it was possible to cover a large transect in the Tyrrhenian Sea between the Aeolian islands, the harbour of the city of Trapani and the Aegadian islands protected area. Recordings were accurate and highlighted interesting features especially when compared with satellite data. In addition, in the area of the Aeolian islands, the system was able to map with great precision the submarine hydrothermal vents insisting in that area.

Introduction

The United Nations Sustainable Development Goals (SDG) 2030 agenda (https://sdgs.un.org/goals) highlighted the importance of studying the sea and in particular of the coastal areas since they are key to understanding climate change and human pressure on the environment.

At the same time the costs of current technologies aiming at studying the sea can be prohibitive or at least not within reach for most scientific research institutions in particular in developing countries, so that eventually the sea remains largely under-sampled both

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geographically and temporally. Models and theories developed using a limited set of data can be problematic, so that a different perspective needs to be introduced, where the actual measurement is done by volunteers.

This can take the form of 'citizen science', where laypeople are directly involved in the acquisition process while growing their awareness of the natural phenomena they are observing, or crowdsensing, where measurements take place in an 'opportunistic' fashion enrolling volunteers mostly as platform drivers.

Citizen science initiatives are rather common in many scientific fields [1] but only few can be tracked in the case of marine environmental monitoring [2]. This is strange considering that several authors such as for example [3] highlighted that this field is very promising and following [4] it is an efficient way to avoid researchers' bias to be possibly projected on the data.

In [5] it is reported the application of a solution that covers both citizen science and crowdsourcing approaches within the MaDCrow project while focussing on the area of the Gulf of Trieste (Northern Adriatic Sea).

In that case, the slightly different perspectives of citizen science and crowdsensing were eventually bridged by the availability of data and information, while, if necessary, they can be separated depending on the availability of volunteers to take part in person to the measurements or not. In this sense crowdsensing is to be preferred when the active participation of volunteers interfere with their routines, risking being demotivating.

Within MaDCrow it was important to avoid disturbing boat owners' holidays; in this sense the crowdsensing approach was preferable and recreational boats were used as carriers of the acquisition devices only.

Putting aside the differences, the outcomes of the two approaches are similar. In both cases, in fact, the main result is to improve geographic and temporal coverage of observations.

At the same time, both approaches also have the same weaknesses that are related essentially to sensor quality and deployment. In fact, since it is not possible to provide expensive top end sensors to multiple volunteers otherwise the costs of the initiative would rise exponentially and eventually contradict the inner sense of the invoked paradigm, it is necessary to revert to cheaper sensors with lower accuracy and precision.

To partially overcome these latter problems, redundancy of data and statistical methods can help converging to reasonable values that can be further corrected if high level reference observations are available [6].

Another problem is the deployment of the sensors. Operating them manually can be problematic because they can be damaged and there is no guarantee to obtain consistent measurements. The option we chose was to install them secured to the hull of the boat in order to have the sensors at a fixed depth of approximately 1 metre from the sea surface. Of course, this depth can vary depending on several external factors such as the conditions of the sea, the draught of a boat's hull, meteo conditions or boat's roll, pitch and yaw. All this can introduce outliers in the data that, in our experience, are easy to be recognized (See figure 8) and less relevant than when sensors are operated manually.

In addition, another problem that has been reported in [5] is the effect of the speed of the boat on measurements.

Notwithstanding all issues described, with the help of some simple statistics and careful installation, the system is able to produce a large amount of data that can be very helpful both to the scientific community and the general public.

In this work the system has been mounted on the Moana60 boat during a cruise in the Southern Tyrrhenian Sea, extending therefore the range of the surveyed area from coastal only, as done in the previous project, to the open sea. This allowed us to understand how it behaves in rather different environments, and to identify other possible limitations and weaknesses.

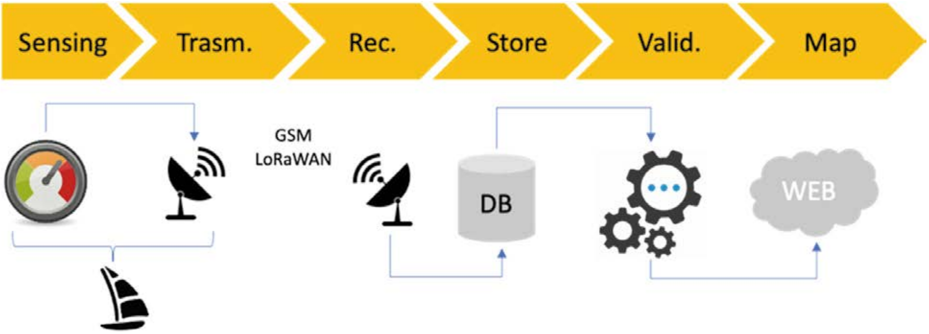

Figure 1 – The schematic workflow of the system developed to perform the study.

Materials and Methods

The system installed on the Moana 60 boat is a revised version of that used for the MaDCrow project.

As in figure 1 the schema of the system can be simplified in 6 blocks and namely:

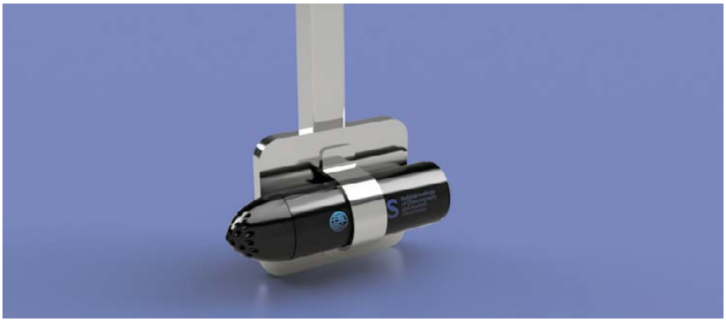

Figure 2 – The torpedo containing the sensors and how it is deployed on an aluminium arm fasted to the boat.

- ***The Sensing system.*** It is composed of the immersed container and sensors, while the acquisition electronics is located on the deck of the boat. In the previous experiences the former was not secured to the hull because it was intended to be used during short day trips in coastal areas only; in the case of this work, instead, since the system is required to be underwater during long periods of time and also in bad sea conditions, a torpedo containing the sensors was designed (figure 2) to be fastened to an aluminium arm that is secured to the hull of the boat. Sensors are located inside the torpedo in a revolver shaped structure (figure 3).

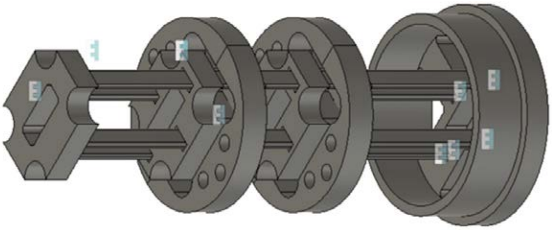

Figure 3 – The revolver shaped structure that hosts the actual sensors. The structure is then inserted into the torpedo of figure 2.

The selection of the sensors needed to achieve some characteristics defined in advance to address the crowdsourcing / Citizen Science paradigm: (i) be low-cost (less than a hundred euros per sensor), (ii) provide information about water characteristic to measure water quality, (iii) easy to use with same communication protocol with the embedded system, (iv) be small, robust and with the possibility of remain submerged in salt water for a long period of time, (v) provide easy calibration to users.

After a huge market research we individuated low-cost off-the-shelf devices produced by Atlas Scientific. They manufacture a kit with Temperature, pH, Salinity and Dissolved Oxygen probes and I2C boards. Every sensor makes use of a different operating principle (e.g.: pH probe uses the difference in concentration of hydrogen ions between a glass membrane to create a small amount of current proportional to it), an electronic board translates the sensor output to an isolated digital value with I2C communication. The advantage of this protocol is that all the sensors can be connected in parallel to the embedded system using a bus with 2 wires.

The selection of these sensors accomplish all the requirements mentioned before but other producers and technologies could also satisfy them. By the time we started this project it was hard to find another set of sensors that fulfil all the requirements, we found higher price solutions, closed proprietary systems or probes that are hard to integrate with the Cocal acquisition system. But in the future, with new technologies emerging, other models from other companies can replace Atlas Scientific sensors.

The system currently hosts Temperature, pH, Salinity (EC) and Dissolved Oxygen (DO) senses. As mentioned before, the pH sensor uses a difference in concentration of hydrogen ions between a glass membrane. Salinity instead uses an AC voltage applied to two electrodes, more free electrolytes the water contains more electrical conductivity is measured. On the other hand, galvanic dissolved oxygen uses a polymeric membrane to defuse oxygen molecules and produce a small amount of voltage in a cathode inside the sensor. The temperature sensor is a platinum RTD rod which has a linear correlation between resistance and temperature. Every probe is connected to a specific board through an SMA connector with I2C output. The sensors are calibrated at the -Oceanic Calibration and Metrology Center of OGS which is certified and using calibration liquids provided by the manufacturer.

The torpedo outlet allows the connecting wires to be fastened to the aluminium arm and to reach the deck where the acquisition and transmission circuits are located in a box (Figure 4) which is connected to the boat power supply. Other sensors can be used with small modifications of the revolver container. Each single measurement is georeferenced using the GPS embedded in the system. Previous experiences [5] suggest that the maximum speed for sensing pH values correctly is 13 km/h. When the vessel exceeds this speed measurements are flagged. The maximum speed allows to set the maximum sampling distance which is approx 200 metres since the sampling rate is 1 minute. Every half an hour we make a temperature correction to EC, pH and DO sensors and a conductivity correction to the DO sensor.

This low-cost system does not have a fault detection system or a redundant acquisition block, this would increase costs and consumption in the acquisition and transmission box, but we are studying how to solve this problem in the database side to provide a solution.

Figure 4 – The acquisition and transmission box. Measurements can be read in real time from the LCD display and are sent via mobile telephone and LoRa connectivity.

- *Transmission*. The transmission system is hosted in the box containing also the acquisition circuits. In this work, since the distance from the coast is supposed to be larger than in the previous experiences, together with standard GSM communication, the transmission system was also redesigned in order to use LoRAWAN technologies that allows it to cover longer distances. To store data, GSM creates an HTTP request to an influxDB database, while in the case of LoRa a LoRaWAN infrastructure is provided by The Things Network. Encrypted data are accessible by MQTT and a server agent called Telegraf.

  As indicated before measurements take place every minute, georeferenced and timestamped data is sent to the database using GSM and LoRa transmission, for a data backup we added an internal data logger using an SD card, this allows to have data stored in case of missing transmission.

- *Storage*. Once received the data are stored into an InfluxDB database running on a virtual machine that is regularly mirrored in a back-up site outside OGS. InfluxDB is a dedicated Internet of Things (IoT) time series database for real time data processing.
- *Validation*. Data is further subject to a validation process. Outliers and positioning errors are automatically identified, and the relative measurements Flagged in the database. It is not possible for the system to identify when a sensor is at fault, as mentioned before, out of range data is flagged. To avoid the above-mentioned issue of velocity biassed measurements all values corresponding to velocities above 13 km/h are also flagged as problematic and do not reach the production dataset. When reference measurements are available, for example when the boat passes close to an oceanographic buoy, the system corrects the values for the possible drifts of the sensors [6].
- *Visualization*. Data uploaded in the database can be visualized in real-time using the Grafana dashboard, from where it can be freely downloaded within an open data perspective. Data can be seen on a map and simple interactive statistics tools are also made available via the dedicated portal.

Moana60 Spirit of Community A.P.S is a non-profit organization born in 2020 (www.moana60.com). The association is named after the sailboat *Moana 60*, an eighteen-meter boat built in 1992 by Vittorio and Franco Malingri to participate in the Vendée Globe, a non-stop, solo round-the-world race. *Moana 60* has been engaged in numerous regattas around the world and later adapted to crewed sailing. Since 2020, with the establishment of the Moana 60 Spirit of Community association, it has been engaged in projects aimed at carrying out social, cultural, environmental and sustainable nautical tourism activities.

Figure 5 – Moana 60 Lab sailing boat.

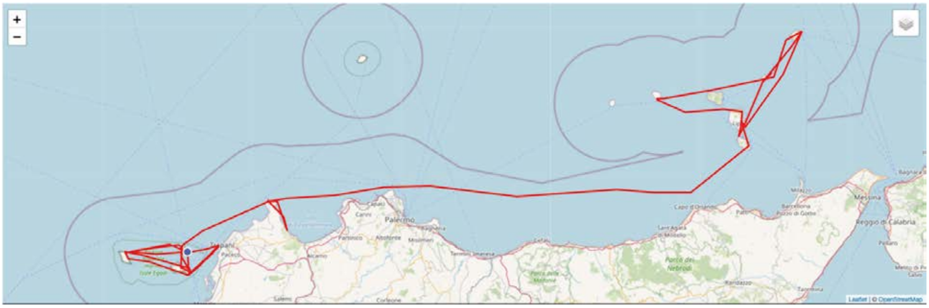

Figure 6 – The survey of the Moana 60 boat started on 28/7/2021 in the area of the Aeolian island and proceeded westward until the Aegadian islands were met on 17/8, after this, several short trips were made between Aegadian island and the city of Trapani. On august 30 the system was disassembled.

Results

After an initial phase of preparation that has been severely influenced and unfortunately reduced by the COVID pandemic outburst, we were able to focus on a research cruise in the sector of the Tyrrhenian Seas corresponding to the northern part of the Sicily Island starting from the Aeolian Island sailing westward all the way towards the Aegadian Islands.

The covered area comprised several stopovers in various ports, both commercial and touristic, populated areas and marine protected areas. An overall map of the survey can be seen in figure 6.

As a first result of the experience, it was possible to understand that the developed system can be applied also for long cruises at open seas and that the new deployment of structure is sufficiently robust. We experienced a couple of malfunctions of the electronics that were solved simply rebooting the system. In some areas the GSM coverage was very poor but also LoRaWAN coverage in that area was minimal, since satellite communication cannot be considered for the costs it can have, we have already developed a new version of the system with local storage of data that allows to avoid missing any measurement. Some outliers have been recorded and are visible in figure 8 (yellow boxes). It is to mention that, since the sensors were always active, these artefacts were mostly recorded while harboured and are probably related to human activities or maintenance.

Discussion

The Tyrrhenian basin is bounded by Corsica and Sardinia, on the west, Sicily on the south, and the Italian peninsula to the east and north. It is the result of the retreat of the Apennines-Calabrian subduction system that started in the Late Miocene and that lead to the back-arc extension and magmatism located in the basin [7]. The Tyrrhenian basin reaches 3600 m of depth while the bathymetry of the basin restricts circulation to two main channels:

the wide Sardinia Channel between Sardinia and Sicily and the Corsica channel to the north. The circulation through the Sardinia Channel is part of a complex exchange of water masses between the central basin of the Western Mediterranean, the Eastern Mediterranean, and the Tyrrhenian Sea. Although they tend to be modified in the basin and are not separated by clear high-gradient boundaries, the water masses of the Tyrrhenian Sea are commonly classified by their temperature, salinity and are named after their place of origin.

The water masses that are significant for this study are the Atlantic Water masses that can be found in the first 200 m from the surface and that originate through the Strait of Gibraltar [8]. Its hydrographic properties are modified by evaporation during its path along the North African coastline [8] and when in the Tyrrhenian sea follows its cyclonic circulation. Other water masses are very important in the area but cannot be sampled by the system we propose because generally can be found only at depths below 200 m.

Temperature recordings show an excellent match with sea surface temperature available from Copernicus Marine Service (Figure 7) while our system is able to provide much higher resolution both in time and space. It shows to be able to follow diurnal trends and to clearly highlight an increasing temperature trend from West to East that is coherent with satellite data and the literature

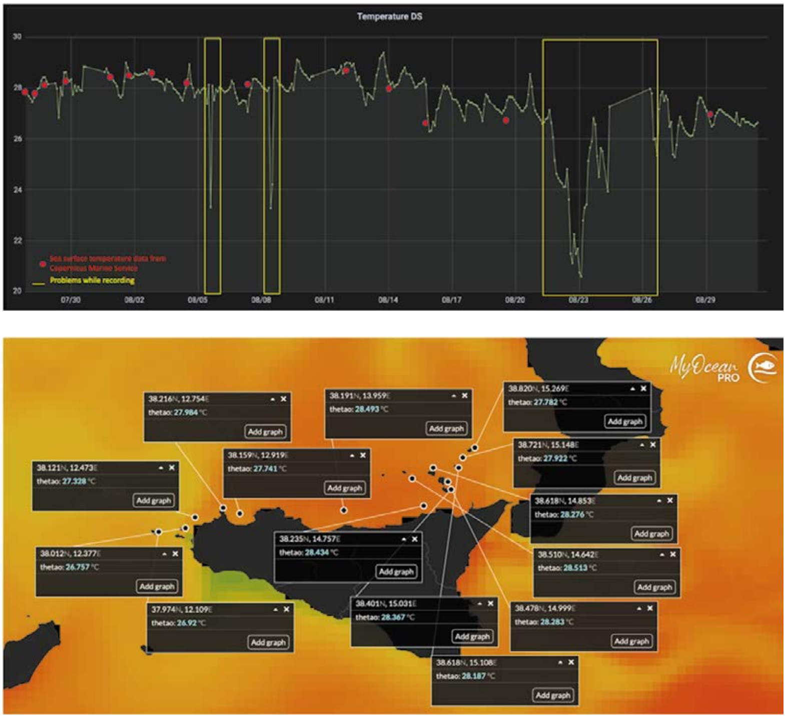

Figure 7 – (Upper) Graph of the temperature recorded by the system with comparison (Lower) with the sea surface temperature available from Copernicus Marine Service showing very good.

Another interesting result has been drawn in relation to hydrothermal vents in the Aeolian island area. There, the calc-alkaline volcanism and the connected hydrothermal systems resulting from the subduction of the African plate under the Eurasian plate, is active from 1 Ma up to now [9]. From the recordings, a clear decrease in pH and rise in temperature can be mapped that can be associated with the intense hydrothermal activity reported for example by [10].

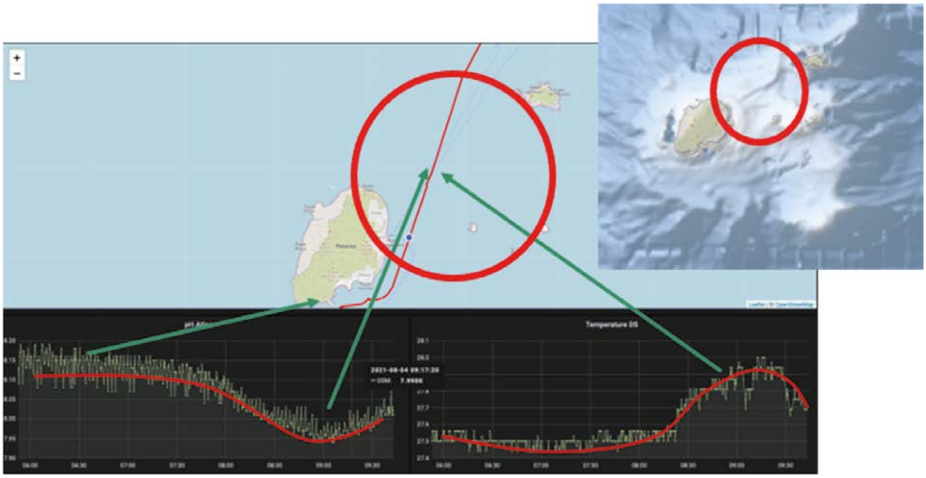

Figure 8 – (map on the left) highlights an area where pH values decrease (bottom left) while temperatures rise (bottom right); (upper map) bathymetry of the area.

Conclusions

In this work we demonstrated that a well-designed low-cost citizen science/crowdsensing system can effectively monitor the most common marine water quality parameters and that such a system can identify both regional trends and local anomalies, which makes it reasonably eligible to be used for environmental studies. In the example here reported the system was used during its recreational route to identify hydrothermal vents in the area of the Aeolian islands and demonstrated to be highly efficient and to provide data with very high resolution. At the same time the experience allowed us to focus on several issues such as the deployment of the acquisition system on private sailing boats, which of course is a very complicated topic since owners are very careful not to ruin the hulls of the vessels and generally do not want to be bothered by cumbersome instruments on deck. The developed solution allows to minimize the impact of the sensors and maximize the results that can be obtained. Starting in spring 2022, the boat will follow a route from Venice to Crete, passing through Croatia, Montenegro, Albania, and the Greek Islands in the Ionian Sea and will again use the system described here to collect an even larger dataset of marine measurements.

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