DEVICES FOR ENVIRONMENTAL OBSERVATIONS

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ABSTRACT
This paper describes some systems, designed and built by CNR in Messina and by Viterbo Tuscia University in its Civitavecchia laboratory, that fill the gap between traditional offshore oceanography and modern operational oceanography. The evolution of the main parts of such devices is analysed together with the pros and cons of design choices, not excluding the economic point of view that, together with instrument precision and reliability, is one of the main design constraints. Technological and scientific advancements were obtained in the state of the art, offering scientists new low cost instruments to perform research both in coastal and in harsh environment areas, exploiting the progress both in elaboration and in transmission electronic devices. The systems were designed to operate from fixed and mobile platforms, like Ships of Opportunity (SOOP) or towed vehicles. To this aim, CNR Messina set up a device able to automatically release up to eight expendable probes. Ruggedized versions of systems were built to be installed on small towed vehicles in harsh environments (Arctica). Sites at the sea-ice interface where blocks fall from glaciers due to ice melting, make it too difficult and dangerous to operate by traditional ships. During the June 2017 Svalbard campaign, a new generation water sampler, able to fill eight 500 ml bottles, was tested on field and showed a good operational performance. Various measuring instruments can be connected to the data acquisition and transmission system according to the research needs. They include multiparametric probes, expendable probes launched from SOOPs, water samplers for subsequent laboratory analysis, and any kind of device having a standard interface or providing a voltage-current signal. The land-based data assimilation can integrate the acquired in-situ data with satellite observation and the output of mathematical models.
Keywords: environment monitoring, data acquisition and transmissions systems, marine measurements.

1 INTRODUCTION

Modern operational oceanography needs a big quantity of environmental data to perform quality assessment, nowcasting activities, feeding of forecasting models and sea-truth validation of satellite acquired data.

The high cost of traditional oceanographic cruises, together with the low space-time coverage, has stimulated the development of new instruments, systems and methods able to provide scientists with quality measurements.

Among the scientific Institutions who worked to set up new low-cost instruments and devices, the Italian National Research Council (CNR) and the DEB Laboratory of Civitavecchia, Tuscia University of Viterbo must be mentioned. Both these Institutions developed some devices for environmental monitoring and experimented on field their possible use in several marine ecosystems, including temperate (Mediterranean regions such as Sicily, Apulia, Latium) and polar (Arctic Svalbard Islands) areas.

2 SOME HISTORY

The most common industrial devices in use at the beginning of the '1990s were conceived to operate from oceanographic ships and offshore buoys and often constituted a "black box", connectable only with other devices by the same manufacturer; few companies (like Sea Bird

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Electronics) offered – and still offer – very good performances both in shallow and in deep water, associated to the disadvantage of being quite expensive.

Other companies offered lower precision and cost devices, unsuitable for traditional oceanography and hardly acceptable also for what was going to become a great scientific challenge: Operational Oceanography.

In USA a range of applications for water monitoring were set up by main research institutions (Monterey Bay Aquarium Research Institute – MBARI, Scripps Institution of Oceanography, University of San Diego, California, Woods Hole Oceanographic Institution-WHOI, and others) and governmental agencies (National Oceanic and Atmospheric Administration – NOAA, National Data Buoy Center – NDBC) [1], [2].

In northern Europe single buoys and monitoring networks were set up to control water quality in aquaculture plants against the arrival of pollutants (i.e. oil spills) or to assess pollution in some particular zones like the estuary of the Elbe river, where a nuclear power plant was operating [3], while in Mediterranean (northern Tyrrhenian Sea) the French–Italian ARCOBLEU network was funded by MAST (Marine Science and Technology) Program as a pilot project [4].

In Italy, the most important installations were the platform “Acqua Alta” in Venice Lagoon and the ODAS 1 buoy, offshore the Tuscany-Ligurian coast; at that time, both the monitoring stations were more devoted to the study of meteo-marine phenomena than to water composition and quality [5].

Basically, these installations measured the main parameters characterizing sea water such as temperature, conductivity, depth, dissolved oxygen, pH, turbidity, often using a ruggedized version of laboratory sensors.

Other measurements (like nutrients, bacteriological parameters, more complex chemical analyses) were performed in laboratory on water samples often collected during oceanographic cruises or in coincidence with equipment maintenance.

3 AND IN MESSINA?

Founded in 1916, the Istituto Sperimentale Talassografico CNR of Messina (Sicily, Italy) was one of the oldest marine research institutions, mainly devoted, at that time, to biological oceanography.

At the end of 1980s, the National Research Council launched the Strategical Program for Coastal Pollution Monitoring, composed of 10 operating units co-ordinated by the Istituto, and a new research line focusing on marine monitoring started, opening new perspectives in this field where further advancements are still in progress [6].

After the first experiences made using commercial devices, the basic idea was to set up new low-cost instruments, easy to deploy and maintain, offering good reliability and quality measurements; therefore, exploiting the technological progress in the field of computers and radio transmission, various systems were designed, built and used in national and European research programs [7].

The starting point was to analyze the problems encountered with some commercial devices. In fact, these equipments, basically, consisted in a group of sensors connected to an Analog to Digital converter; the base station started the measurement sending a radio signal to activate the “squelch” line on the remote radio, so powering up the subsystem that performed the measurements, sent the results using a simple analogic modem on the radio link and went back to a "sleep" state with only the radio powered.

In these systems, the measurement resolution was not very high (12 to 16 bit) and the exact regulation of the squelch level was vital for the good system operation; the used RTX equipments were commercial radios, working in VHF or in UHF.

Among the facilities, some systems were able to reply remote interrogation for a pre-defined number of times, until the reception of the required measurements or the expiration of the time-out limit.

The absence of recharging systems (e.g. solar panels) made it necessary to change the batteries of the remote station every two weeks, with the risk of stopping the measurements if, for some reason (e.g. bad meteo-marine conditions) the operation could not be performed.

Moreover, the availability of a set of full-charged batteries always ready was also necessary, so doubling the costs for these items.

To overcome the encountered shortcomings, a new system architecture was designed, complying to the following constraints:

- Availability of battery recharging facilities on the buoy
- Low-power consumption of the equipments
- Good modularity and flexibility
- Easy and reliable radio-link management

The final architecture was defined (Fig. 1), comprising:
Land station:

- A computer, usually a PC-like one, able to interact with the remote station and to store in a local or remote data base the acquired data

Sea station:

- Power supply system with batteries and recharging devices (solar panels and/or wind generator)
- Measuring system (one or more sensors or measuring devices with analogue or digital (usually RS232 or similar) interfaces
- Data acquisition system (a computer performing timed pre-defined operations), interacting with the measuring system
- Data transmission system (a radio device with modem)
- Position control system (a GPS monitoring the position of the station)

3.1 The power supply system

Depending on the connected devices, the final version consists of up to four 12 V sealed lead batteries, each with its own solar panel and charge regulator; a wind generator with separated charge regulator contributes to the energetic balance of the system; the charge regulators and

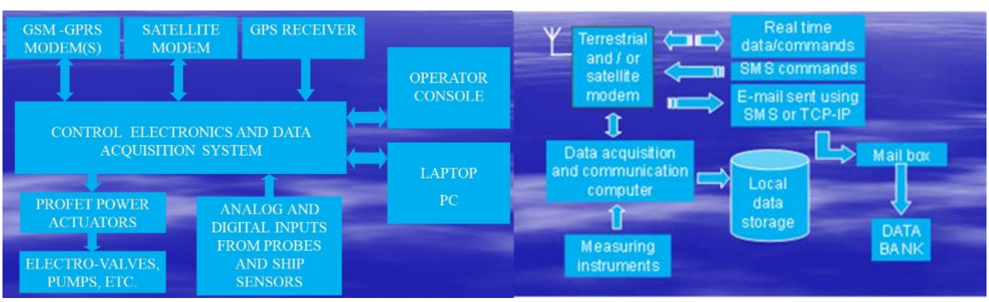

Figure 1: The general system architecture (left) and the data flow (right).

the parallel diodes are low voltage drop. The resulting output goes into one or more wide input voltage DC/DC converters, that supply the appropriate voltages and currents to the other systems. The combined use of solar panels and wind generator enables to recharge batteries also during the night and in bad weather conditions.

3.2 The measuring system

Both marine and meteorological sensors were used, all connected using serial interfaces.

The marine sensors (stand alone or assembled in a multiparametric probe) included water temperature, conductivity, dissolved oxygen, fluorescence, turbidity, pH, while the meteo sensors were connected to an intermediate conditioning and controlling system, in turn communicating with the main data acquisition system (Fig. 1).

3.3 The data acquisition system

Almost all of the developed data acquisition systems were based on a PC-like architecture, that evolved from the first version based on a 286 CPU mounted on a double eurocard board, up to a recent one, based on Pentium CPU mounted on PC-104 (IEEE 696 standard) boards, and to the most advanced version based on Arduino boards. Additional boards that were mounted as needed included analogue interface boards (A/D converters), multi-serial RS232 boards, solid state disks, digital I/O boards. The system was controlled using a specially created set of macro-commands, that will be presented in a subsequent chapter (Fig. 2).

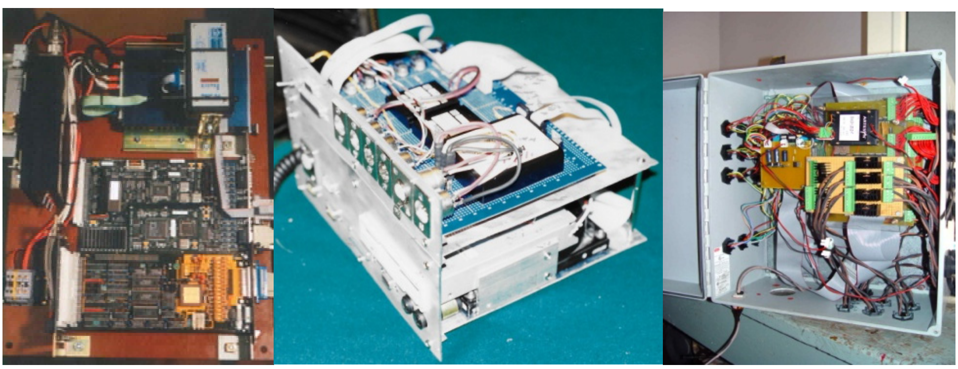

Figure 2: The Venice Lagoon System electronics (left), the PRISMA2 version (centre), and the "SAM" version (right).

3.4 The data transmission system

Various tests were performed to overcome the initial difficulties encountered with the first commercial systems used.

A first version, developed to be used for the "Sistema Lagunare Veneziano" (Venice Lagoon System), assembled a CTE TNC 24 packet radio modem controlled by a Z80 microprocessor with a quartz frequency controlled 1 W UHF RTX connected to an RF power amplifier and to a directional antenna for the remote station and an omnidirectional one for the base station [8].

Some considerations are associated to the use of this kind of accommodation:

- First of all, the use of radio frequency must be authorized by the competent Ministry.
- It is necessary to have a land base station in a suitable location, possibly high on the sea, and free from obstructions towards the remote station.
- The antennas must see each other.
- The additional attenuation due to the marine water "spray" must be taken into account.
- To minimize the required transmission power it should be necessary to use directional antennas having a good gain, but this is not always possible for two reasons: the size of the buoy and its movement caused by wind and streams.
- The maximum theoretical distance between the antennas is a function of their height over sea, and it is limited by the buoy size and the land base station location, where municipal laws could limit the presence and height of antennas.
- Antennas pointed low on horizon receive a lot of unwanted noise.

The use of "intelligent" packet modem has allowed to overcome some of the above limitations, using intermediate buoy stations as "repeaters".

A significant progress was reached with the introduction in Italy of the GSM mobile telephony. A first application, designed for the "PRISMA2" (Research and Experimentation Program for the Protection of the Adriatic Sea) program, used a Motorola Cellular Phone, driven by a specific PCMCIA data interface card; this equipment was then substituted by Nokia products, offering a better performance and simpler programming [9].

The most recent implementations (such as the Automatic Multiple Launcher for Expendable Probes funded by the European Union within the FP5- MFSTEP program; the buoys designed for the "SAM" project funded by the Italian Ministry for University and Research [10], [11] and for Civitavecchia (Latium) C-CEMS buoy [12]) use integrated modems (external or PC104 boards), able to work also in GPRS, so permitting low cost data transmission, as described in a subsequent paragraph.

3.4.1 The data transmission methods

The first commercial systems devoted all the (very rudimentary) controls to the same data acquisition software; the introduction of packet radio modem embedded in the modem itself all the controls, including latency, number of retransmission trials, error management.

The first GSM modems enabled to send SMS between the base and the buoys, so transmitting in a bi-directional way both commands (from a specifically written set of macro-commands) and data (coded to fit in the 160 characters length of SMS standard); a special service offered by the Telecom provider transformed the SMS's into e-mail messages. Of course it was possible also to make point to point connections, for instance for system maintenance, paying the service on a time basis.

The arrival of GPRS and new modems, embedding Internet connection routines, enabled to significantly lower the communication costs, sending directly e-mail messages paying on a data volume basis.

The use of mobile telephony networks allowed to avoid problems arising with private radio links, including the availability of a base station on site, allowing to receive data and to control buoys from anywhere in the world.

3.5 The data acquisition system

3.5.1 The hardware

The Data Acquisition System is based on one or more computer boards, interfacing with measuring devices (sensors or analytical instruments either using serial interfaces, or analogue 0–5 V interfaces), GPS, telecommunication devices (terrestrial or satellite modems...), mass memory devices (usually solid state disks) [13], [14].

I/O interfaces are included to control the connected devices power supply.

The first systems used a double eurocard size 286 CPU board, plugged with serial and analogue interfaces boards, the most recent mount a Pentium family CPU assembled on a PC 104 (IEEE 696) standard board, complemented with all the interfaces and communication devices boards, including GPS. Cheaper Arduino boards are also in use, generally to control single devices or to coordinate data acquisition and transmission activities not requiring high elaboration speeds.

3.5.2 The firmware

The software is based on a set of macro-commands, enabling to fully control the computer and the connected devices using the local keyboard, the base station computer, or simply a mobile phone.

All the macro-commands start with the letter "Z", followed by a character identifying the kind of command and, if necessary, by the command parameters identifying, for instance, the sensor or I/O port involved, the switching on or off of an alimentation line, and so on.

The macro-commands can be combined in "sequences" using a simple text editor and stored in the remote station, where an "event machine" routine runs in an endless loop waiting for the arrival of commands from the local keyboard or from the communication devices, or for the occurrence of an event like a timed sequence or the reach of a geographical point.

Timed events can be programmed on a 10-minute interval basis and can be each different from the others.

Each of the above conditions starts a "parser" module, that reads the sequence file line by line, interpreting and executing the pre-coded commands.

During the time between operations, the system can enter a low power consumption "sleep" state, waiting to be awakened from commands or sequences execution.

The commands include:

- System control and diagnostic commands
- Instrument management commands
- Data acquisition commands
- Telecommunication management commands.

The firmware was written in compiled Microsoft Basic, with some routines in Assembly, running in ROM-DOS (an operating system very similar to MS-DOS) environment; the most recent version uses Arduino's embedded development system language.

The systems continuously monitor the position, launching an alarm message in case of buoy unmooring.

The choice of the above software architecture makes the system really modular, simplifying the integration of new devices and the "mission programming".

3.6 Special devices

An interesting development was obtained in the frame of the FP5 EU-funded MFSTEP (Mediterranean Forecasting System Towards Environmental Prediction) program (2003–2006) [15]. Two devices for the use on Ships of Opportunity (SOOP, also called VOS, Voluntary Observing Ships) were designed and built. The first was an expendable probe measuring temperature and fluorescence, the other a device conceived to manage its release.

3.6.1 The T-FLAP and the ECO BLUBOX

The original idea of expendable probes, measuring water temperature and sending data on board using a couple of very thin wires, was developed in the '60s and was initially used in submarine warfare and later in scientific applications. These devices, still in use, called XBT, contained a temperature sensible device (thermistor), that was excited by a small current generated in a control box on board the ship; to allow the free sinking two coils of wire, one included in the XBT tail and the other in the on board XBT case, de-reeled and the depth was calculated as a function of time [16].

The new expendable probe, T-FLAP (Temperature Fluorescence Launchable Probe) – designed by the Marcelli's research team at the DEB Laboratory of Civitavecchia of the Tuscia University – integrates a temperature sensor with a fluorometer, to measure chlorophyll 'a' for the determination of the phytoplankton biomass. Differently from the XBT that included no active parts, an integrated electronic system manages all the functions of the probe, including the serial data transmission on board the ship [17].

Starting from this device, a compact system for continuous surface water monitoring was obtained (The Eco Blue Box), that comprises, in a waterproof container, the T-FLAP core, a GPS receiver, a water pump to supply the measurement cell and the needed accessories, the data acquisition and storage system, the connection for the on demand communication system (GSM-GPRS or Satellite modem). The small size and low electrical consumption of this arrangement make it suitable also for installation on small sail boats (Fig. 3).

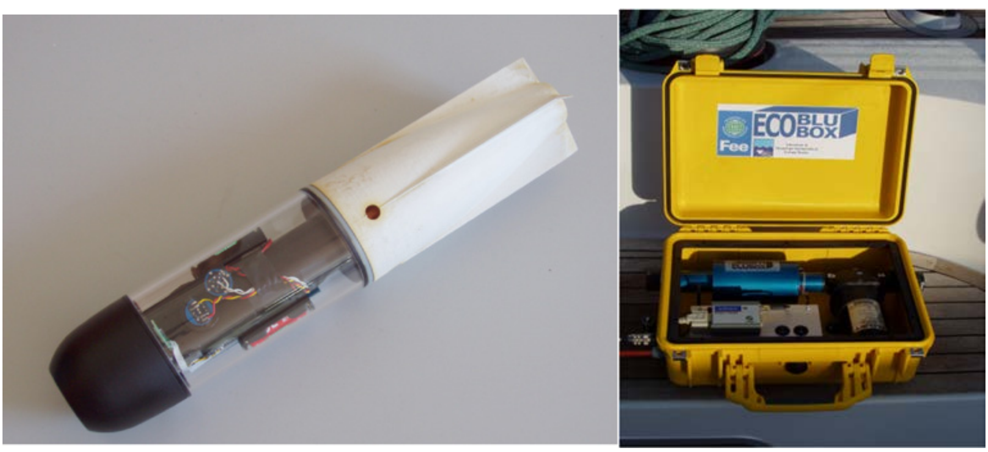

Figure 3: The T-FLAP (left) and the ECO BLUBOX (right).

3.6.2 The expendable probes launcher

This device was designed in the frame of the MFSTEP program to automatically deploy from SOOPs up to eight expendable probes (either commercial standard XBTs or T-FLAPs) [18], [19].

It uses the standard electronics already described, integrated with a special XBT driving board.

The embedded GPS continuously monitors the ship position; when a predefined point (northern of, southern of, eastern of, western of) or time is reached, a deployment routine starts, opening the security lock of the selected launch tube, then the tube door, and starting a data acquisition routine.

The device uses pneumatic actuators controlled by electro-pneumatic valves to lock and move the launch tube doors (Fig. 4).

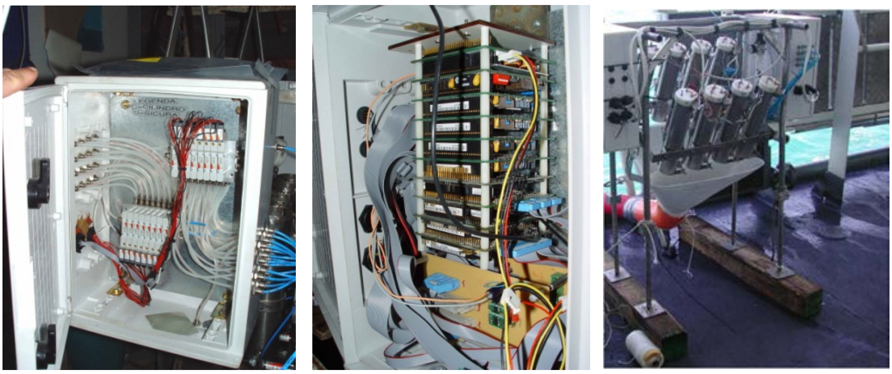

Figure 4: The pneumatic valves (left), the control electronics (centre), and the whole multiple launcher for expendable probes (right).

Figure 5: The “SAM” water sampler (left), the Arctic version (centre), and its electronics (right).

3.6.3 Water samplers

To perform water quality laboratory analysis, for instance to detect the presence of biological contaminants (such as *Escherichia coli* or bacterial pathogens), it is necessary to have devices able to collect and preserve water samplers for further examination in laboratory (Fig. 5).

The first device of this kind was built at CNR in the ‘90s of the past century. It consisted in a frame, hosting six 250 ml bottles, filled via a rotating distributor moved by a step motor, directing the water flux given by a peristaltic pump either into a bottle or to a circuit washing position. To preserve the samples, the bottles contained 10 ml of formalin.

This device worked on a first version of a buoy moored in Messina (Sicily), under the control of the buoy computer [20].

A more sophisticated version of water sampler was developed at the beginning of the current century, to be used on new buoys. It hosted eight 250 ml bottles, connected to the water circuit by electro-valves opening the water intake and the air outlet of each bottle; three peristaltic pumps provided the sea water, the preservant, the fresh circuit washing water. Also this version was controlled by the buoy computer [21].

Another version, derived from the previous, but customized to work in Arctic harsh environment and able to fill eight 500 ml bottles, was developed in 2015 and used during oceanographic cruises at the Svalbard Islands, hosted on a small catamaran towed by an unmanned surface vehicle [22], [23]. The use of a towed vehicle enabled to study the ice-water interface going very near to glaciers, where falling ice blocks would be dangerous to manned boats [24]. This version of water sampler incorporates a control computer, similar to those above described.

3.6.4 Sliding devices

The need to perform measurements at various (subsuperficial) depths, withdrawing also water samples for laboratory analyses, led to the development of two sliding devices: the T-FISH (Towed FISH), able to be towed from small boat and to pump on board a continuous flow of marine water [8] and the SAVE (Sliding Advanced Vehicle) collecting 50 ml of sea water in small cavities in an appositely designed water sampler [25]. Both the vehicles were able to measure main physico-chemical water parameters (Fig. 6).

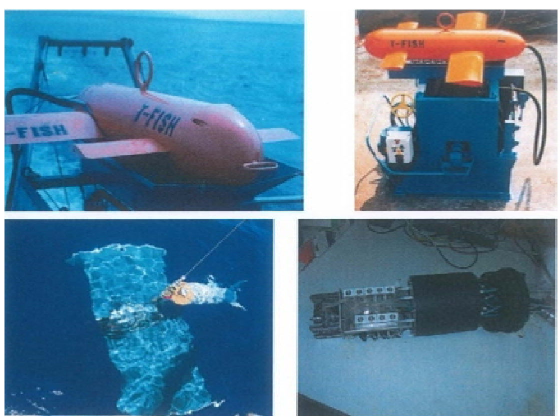

Figure 6: The T-FISH (upper) and the SAVE with its water sampler (lower).

4 CONCLUSIONS

During the last two decades, substantial technological and scientific advancements in the state of the art have been reached, offering scientists new low-cost instruments to be operative both in coastal and in harsh environment areas. All the above-reported technologies offer new tools fundamental to improve the reliability and the performance of currently available systems for both environmental monitoring as well as operational and forecasting oceanography.

An important result was obtained by the integration of the above described systems, together with the combined use of satellite observations and mathematical modelling, into the C-CEMS (Civitavecchia Coastal Environmental Monitoring System [26]–[29]).

Studies are still continuing to further enhance their performance and to develop new low cost, high precision, measuring systems.

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