Improvement of a low-cost buoy for the measurement of the sea wave weather

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***Abstract*— This article presents the result of an experimental meteorological buoy designed by the Department of Engineering of the University of Palermo, characterized by low costs and great versatility, and equipped with industrially certified measuring and detection instruments. This buoy can measure the parameters of the water column and continuously transmit the data to a remote acquisition centre. Maintenance requirements are very limited.**

Keywords—sea wave, software, buoy, marine technology

I. Introduction

Due to the world's growing demand for energy, research and policy choices have focused on new systems capable of exploiting energy from natural, economic, and renewable sources.

Over the last two decades, the energy policy of the industrialised countries has been oriented towards the exploitation of renewable sources (RES) [1]. Nowadays, the photovoltaic panels and wind turbines are the most widely used technologies, therefore consolidated, exploiting RES [2]–[4].

Research is currently investigating other types of RES, linked to the exploitation of the great energy potential related to the marine environment [5], [6]. In particular, the sea wave is considered a very promising source of energy, as confirmed by numerous studies and the different technologies presented over the years [7]–[9].

However, in order to correctly size a wave energy converter (WEC) [10]–[12], it is necessary to carry out a series of environmental assessments that provide the wave characteristics necessary for the designing of devices [13], [14].

To this purpose, several approaches are currently available:

- Buoy-mounted or deep-sea sensors to determine ocean characteristics [15]
- Extrapolation of information from space sensors considering the electromagnetic spectrum due to the reflection of visible sunlight on the waves [16]
- Forecasting using specific models (SWAN type) [17], [18]

The first technique, the most accurate, requires the installation of sensors directly on site. Meteorological buoys are devices designed to collect meteorological and oceanic data.

They can measure different parameters related to air such as temperature, atmospheric pressure, wind speed (constant and gust) and its direction. They also measure sea wave parameters such as water temperature, height, and wave period [19].

The raw data can be processed and recorded on board the buoy and then transmitted via radio, cellular or satellite communications to meteorological centres for use in weather forecasting and climate study. As introduced above, this information is necessary for following analysis, including the designing of WECs [20]–[22].

II. Case study

In this context, the Department of Engineering of the University of Palermo has proposed a buoy capable of measuring the parameters necessary for the study of waves and continuously transmitting data to a remote centre, requiring moderate maintenance [23]–[25].

This system has important advantages:

- Transmission of airborne data online
- Easy assembly and installation

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- Low cost
- Solar panels for power that do not require maintenance.

In the following Figure1, it is possible to observe the size of the buoy in question which is located within the laboratory of the Department of Engineering.

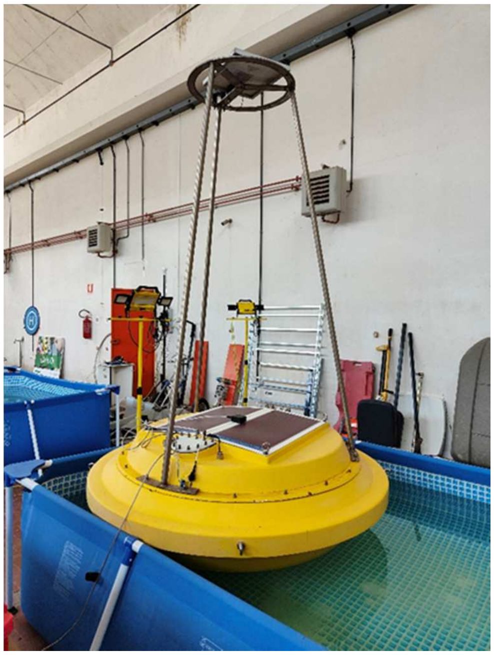

Fig. 1. The meteorological buoy

An important improvement, the main goal of this study was the installation of certified components, to achieve more reliable measurement. In particular, the main components are the IMU LSM9DS1 iNEMO STMicroelectronic module and the SIMATIC IOT2000 controller.

The iNEMO STMicroelectronics LSM9DS1 inertial module [26] is an integrated system that features a linear acceleration 3D digital sensor, a 3D digital angular velocity sensor, and a 3D digital magnetic sensor. The LSM9DS1 has a full scale for linear acceleration of ±2 g/±4 g/±8 g, a full scale for the magnetic field of ±4/±8/±12/±16 gauss and for the angular velocity of ±245/±500/±2000 dps.

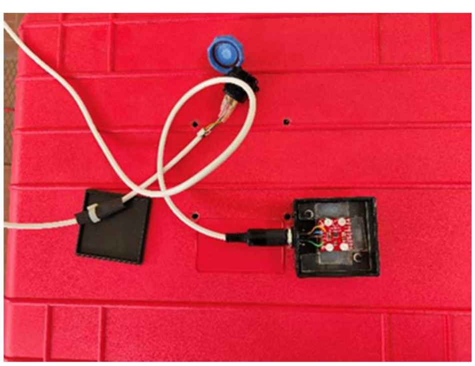

Fig. 2. IMU module used

The LSM9DS1 includes an I2C serial bus interface that supports standard and fast modes (100 kHz and 400 kHz) and a standard serial SPI interface. Magnetic sensing, accelerometer and gyroscope can be enabled or set to shutdown mode for intelligent energy management. The LSM9DS1 is available in an integrated plastic land grid array (LGA), guaranteed to work in a wide temperature range from -40 ° C to +85 ° C.

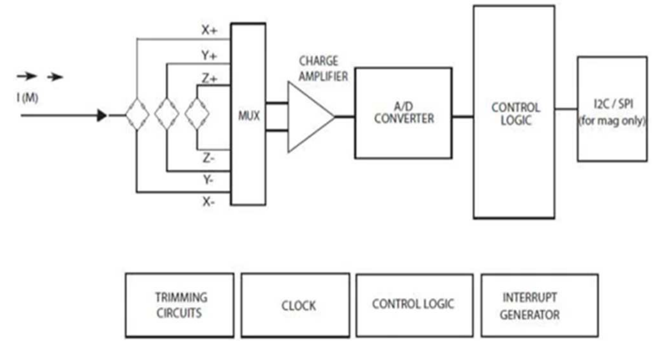

Fig. 3. IMU sensor block diagram

The Siemens SIMATIC IOT2000 gateway [27] enables the connection of additional digital and analogic inputs/outputs (I/O) in an industrial environment to IT or the cloud. It is compatible with open-source software such as Arduino IDE and Yocto Linux, and uses high-level programming languages such as Java, C++ and JSON. It allows the collection, processing, and transmission of data directly into the production environment. The system supports numerous protocols (S7 protocol, OPC UA, Modbus TCP, TCP/IP, etc.) via various interfaces, including RS232/422/485, USB serial interface, Ethernet or Wifi via mPCIe. This component is connectable through GPIO and programmable; the robust shield is equipped with CE and UL certifications and is able to work in industrial environments 24 hours a day, 7 days a week.

The available I/O range includes five 24 V digital inputs and two outputs, and two selectable analogic inputs, with a 9-bit resolution and voltages between 0 and 10 V or 0 and 20 mA. The SIMATIC IOT2000 module is based on the Intel Quark x1000 (Galileo) platform, it is equipped with 512 MB of RAM.

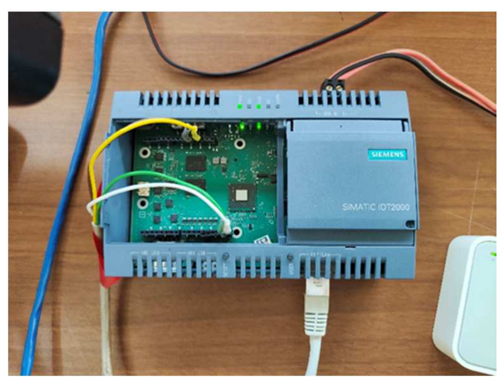

Fig. 4. Gateway used

To complete the measurement and data collection system, there is the ethernet card of the PC and an internet switch, to allow you to release the connection. All placed away from the buoy and controllable remotely. In addition, it is possible to store data via µSD, in such a way that you have an emergency backup in case of malfunction or interruption of the transmission.

III. DATA ACQUISITION AND OUTPUT

The inertia of the system causes a slow variation of the acquired data, so it is normal that the difference between one sample value and the next is quite small. It is necessary, then, the determination of the maximum variation for each type of data and then the adoption of a compression system. This is as effective as possible and that does not require large computing resources on the part of the CPU.

The installed motion sensor which, as mentioned, includes an accelerometer, a gyroscope, and a magneto-compass, all triaxial, has been tested together with the data transmission system in such a way as to verify the right functioning and carry out a pre-processing of data directly on board the buoy, in order to limit the amount of information to be sent to the control centre.

It is also essential to filter signals by implementing a Kalman filter which, as well known, is a recursive algorithm that efficiently evaluates the state of a dynamic system whose measurements are subject to noise. For the processing and real-time study of data from the buoy, the Telemetry Viewer software was developed, executed in Java, with a simple and computationally light graphic interface.

Thanks to this application, it is possible to receive the necessary information in real time with great precision and sensitivity even to the smallest movements of the buoy. The entire data bank of measurements is easily exportable on a CSV basis for later processing.

Below, a data collection carried out in the laboratory over a period of one minute is reported. It is possible to notice the great sensitivity of the sensor, which allows the monitoring even the smallest oscillations of the parameters under examination.

The developed software allows the real-time study of the 3D movements provided by the IMU sensor and in particular returns the values of linear acceleration in g, angular velocity in dps and magnetic field in gauss.

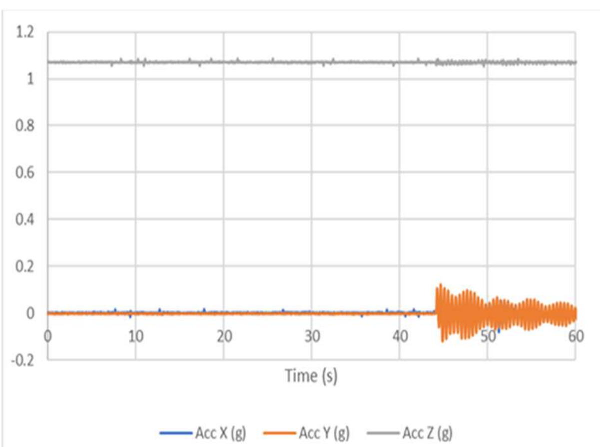

Fig. 5. Example of acceleration detection

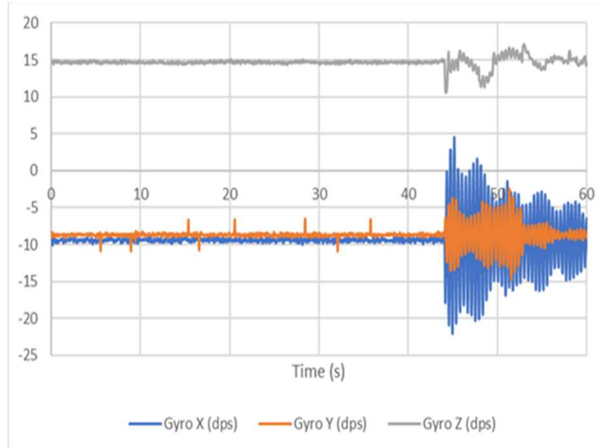

Fig. 6. Example of angular velocity detection

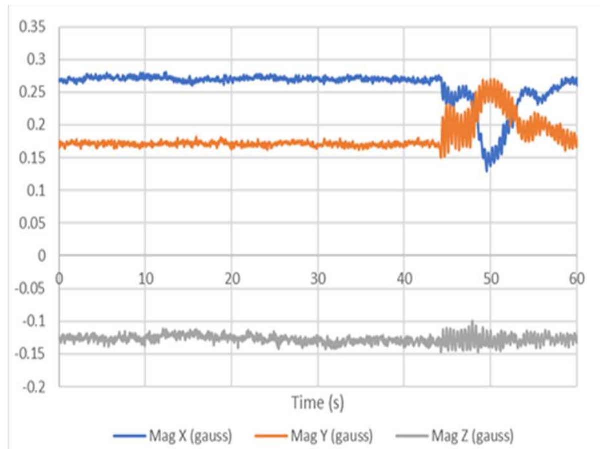

Fig. 7. Example of magnetic field detection

From the analysis of trends of the parameters under examination, it is possible to observe, at about 45 seconds, the variation on measurement as a result of an external stress applied to the buoy.

IV. AUXILIARY FUNCTIONS OF THE SYSTEM

The system, in addition to the acquiring, storing and transmitting data, performs other important functions:

- If errors or unexpected blocks occur, an automatic recovery (watchdog function) and restoring of the best system configuration (time, location, and historical data), using the RAM scratchpad, are performed.
- Verification of the validity of data, comparing with the average value of the previous data
- Checking of the connection status of GSM and GPS before sending data
- Checking of the correct reception of data from the remote system
- Warning promptly in case of tampering or opening of the buoy and signalling in emergency situations, like abnormal movements of the buoy from the point of installation

- Setting a remote time for sending data and remote execution of some basic parameters
- Reporting any faults of solar panels and warning in case of low battery charge.

All these functions are performed directly by the on-board software. Other specific alarm functions, or the management of different events, can be entrusted to the Internet Server in case the buoy no longer transmits for a certain period. Such messages can be sent via e-mail, or text message to a predefined number, from the system itself in case of critical alarms.

V. Conclusion

This article presents the results of tests carried out on an experimental meteorological buoy in which certified components have been inserted that allow greater accuracy of detection and calculation.

By processing data, it was possible to study the response of the system to small oscillations. This can be the basis for more specific studies concerning the behaviour of the buoy subject, for example, to waves of different height and period, in order to allow the definition of the state of the sea for a possible installation of a WEC.

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