PROCEEDINGS OF SCIENCE

Low-cost Oceanographic Buoy for Evaluating the Mechanical Resistance of a Water Cherenkov Detector to be deployed on a high-altitude Natural Lake in Perú.

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The SWGO Collaboration is evaluating the possibility of deploying Water Cherenkov Detectors (WCD) in a high-altitude natural lake. For that, the first challenge is to build a bladder strong enough that could be used as a WCD inside a natural lake. A prototype bladder has been designed for SWGO and two bladders, made of different films, have been deployed for testing at Sibinacocha lake, in Peru, at 5000 masl. In order to monitor the wave intensity in the lake, a low-cost oceanographic buoy was developed using an acceleration sensor MPU6050 and a liquid sensor DS18B20. The development platform used was the Arduino Mega 2560 with off-the shelf modules to achieve a functional and autonomous prototype. A code was developed in Python to process the data and convert the acceleration values into position, allowing estimation of height variations, as a function of time, less than 1 cm. To reduce the environmental impact of the floating structure, the use of metallic materials was minimized and mostly wood, cotton, and PVC pipes were used. This buoy has been installed next to SWGO prototype bladders at the Sibinacocha lake in Peru. In this contribution we will present the details of the low-cost oceanographic buoy built to monitor lake wave intensity.

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1. Introducción

A new generation of high-energy gamma-ray detectors is being developed by the Southern Wide-field Gamma-ray Observatory (SWGO) [1], which will operate in the energy range of TeV. These water detectors are mainly based on the Cherenkov Effect and will be placed at locations with an altitude greater than 4400 m.a.s.l. in the southern hemisphere, where no other instrument of this category has yet been built. The candidate countries to host SWGO are Peru, Chile and Argentina [1, 2] with sites selected at altitudes above 4400 m.a.s.l., where SWGO could install an array of 6500 metal tank Cherenkov water detectors (WCD). However, an alternative for SWGO, is to install floating WCD in a natural lake.

The concept of lake deployment of SWGO has been described in [3], and a nature design of a prototype SWGO lake bladder is described in [4]. For this type of detector, the Sibinacocha lake (4900 m.a.s.l.), located in the Cusco region, is a candidate site [5]. The lake WCD is a new detector technique and there is a series of difficulties, one of them is the waves that occur in the lake, which can damage the bladder. That is why deploying equipment to monitor wave activity is of paramount importance at this stage of preliminary studies for these new detectors. A low-cost buoy was designed, implemented and evaluated with the aim of evaluating the mechanical resistance of bladders and quantifying the wave activity in the lake [3].

Several scientific studies require suitable sensors for in situ observation of wave levels and tracking of water masses in the ocean. However, these sensors are not commercially available or are prohibitive expensive [6]. The prices for commercial devices, such as wave measurement buoys, range from 6-50 kUSD, and have limitations in their ability to be modified for combination with additional sensors [8].

To address this issue, the use of low-cost sensors that utilise common open-source hardware and post-processing software is proposed [7, 8]. In this work, a low-cost oceanographic buoy (with a good cost-effectiveness relationship) is described, with an approximate cost of 230 USD, based on an MPU6050 IMU (Inertial Measurement Unit) and implemented using the Atmega2560 microcontroller on the open-source Arduino platform.

2. Buoy for monitoring water movement in Sibinacocha lake

2.1 Electronic Design

The operation of the electronics (figure 1) revolves around the ATmega 2560 microcontroller (Arduino), which manages the functions of obtaining data from the sensors and their respective storage on a micro-SD. The main sensors are the MPU 6050 work at 30 Sample/second, the device combines a 3-axis gyroscope (set to ±250°/sec) and a 3-axis accelerometer (set to ±2g) interconnected by an I^2C interface. and the DS3231 RTC(Real time Clock), responsible for recording acceleration and time respectively. The secondary sensors are the DS18B20 (with a range work of -10°C to 85°C, precision of 0.5°C and a interface 1-wire), DHT11 (range work 0° - 50°C and 20% - 50% RH), voltage dividers and ACS712-5A, responsible for measuring the temperature of the lake surface, the temperature and humidity of the electronics, the working voltages of the panel/battery and the current supplied/received by battery. For storing sensor information, the TF Card module was included with a 64Gb microSD memory. The power stage consists of a 20W solar

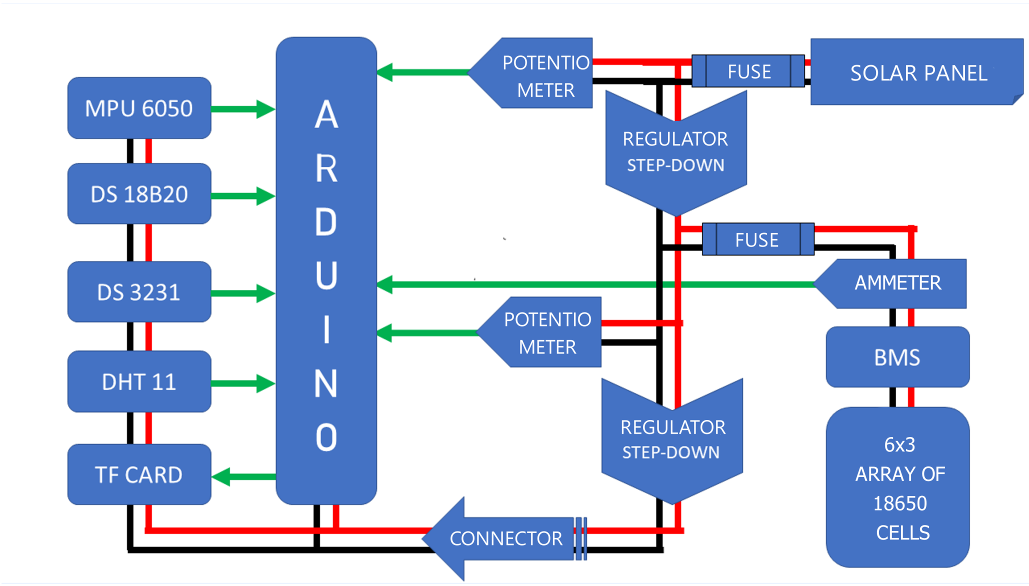

Figure 1: Electronic assembly diagram of the buoy

panel, two Step-Down regulators in series, a 6*x*3 array of 18650 cells with their respective BMS (1x3S 12V 18650 10A BMS) and 2A fuses for protection on the panel/battery

2.2 Description

The electronic part of the buoy prototype (figure 2, middle) was mounted inside a splash-resistant junction box (20*x*20 *cm*) following the scheme presented in figure 1. We have used acrylic plates as support for the components, all connections were made using cables soldered to connectors as needed. The battery was mounted using hot melt silicone and insulated with duct tape. The cables that required external output were installed with hermetic cable output accessories and the interior of the box houses two 5g packets of silica-gel to reduce humidity and increase data quality and lifespan of electronic components.

In the structural part, we started from the CAD design of the prototype (figure 2, left), using the expression of hydrostatic thrust, we can obtaining a flotation capacity of 16.4 kg for three 4" x 70 cm PVC floats and a load of 7.8 kg for the structure, floats and electronics, giving a safety margin of 8.6 kg.

The structural part was made of wood, PVC pipes, and cotton ropes, using synthetic glue and enamel paint as coating and waterproofing material(figure 2, right).

2.3 Firmware Design

Data is stored in two plain text files (*.TXT), one for movement data and another for secondary sensor's data. The buoy's firmware was programmed in the Arduino IDE integrated development environment, following this operating structure:

- Single execution upon powering on the equipment.
  Library and variable initialization >> Module and sensor initialization and configuration >> Time update if PC connection is available

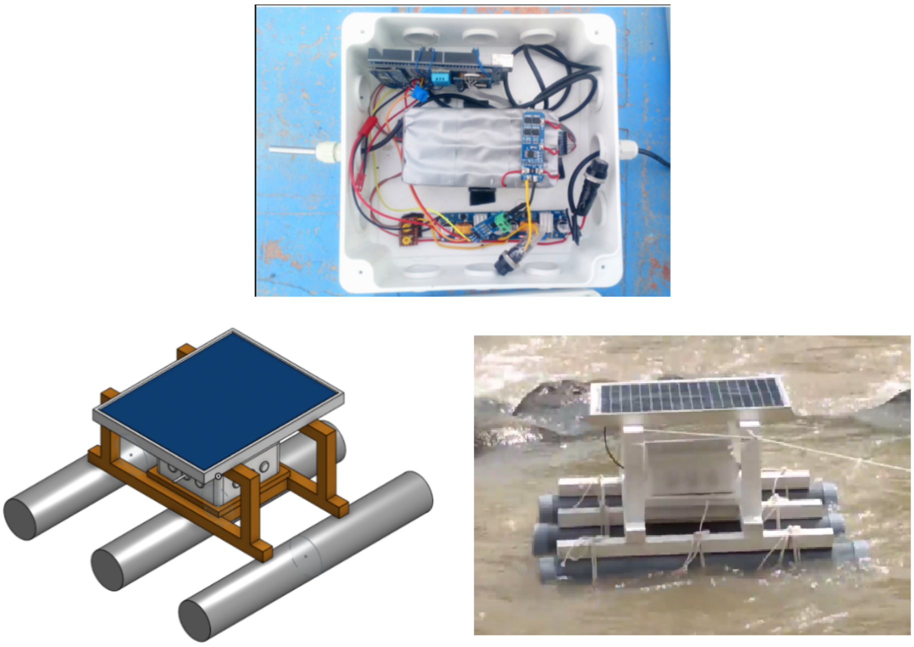

Figure 2: Top: assembly of electronics. Bottom Left: CAD design of prototype. Bottom Right: constructed prototype and in test.

- Indefinite cyclic execution.
  Obtaining time from the RTC. >> Obtaining data from the MPU6050 >> Storing movement data >> If 60 seconds have elapsed: obtaining data from secondary sensors >> If 60 seconds have elapsed: storing data from secondary sensors

Where acceleration data is collected at a approximately rate of 30 samples/second, and secondary sensors (temperature, humidity, voltage and current) at 1 sample/minute.

3. Accelerometer, sensor MPU6050

3.1 Calibration of the accelerometer, MPU6050 sensor

To verify the calibration of the accelerometer (MPU6050), the one-dimensional motion system of a printer (figure 3) was modified to perform oscillations of a constant period. The MPU6050 sensor was installed on the motion support and an ultrasonic distance sensor was installed

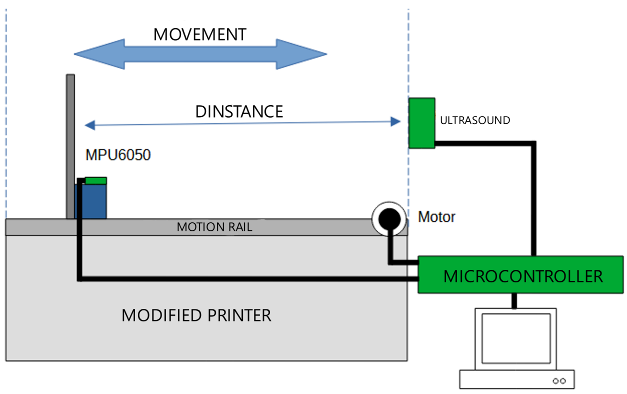

Figure 3: Assembly diagram to test the MPU6050 module

at one end of the rail. Using a microcontroller, the data was recorded on a computer.

3.2 Accelerometer data processing

The accelerometer signal is integrated twice. In the first integral, acceleration is transformed into velocity, and in the second integral, velocity is transformed into displacement. In each integration process, there is an integration constant that introduces an error or drift into the conversion process. To eliminate the drift observed in Figure 4, a second-degree polynomial function is fitted to obtain the drift curve which is subtracted. In parallel, an average of the position data obtained directly by the ultrasonic sensor is performed, which is shown as a reference in Figure 4. Both curves, that of the accelerometer converted to position and that of the ultrasonic sensor, are presented in figure 4. The efficiency of the drift subtraction process (introduced by the acceleration-to-displacement conversion process) can be observed. The positions obtained with the ultrasonic and MPU6050 accelerometer agree within a range of less than 1 cm throughout analysed period.

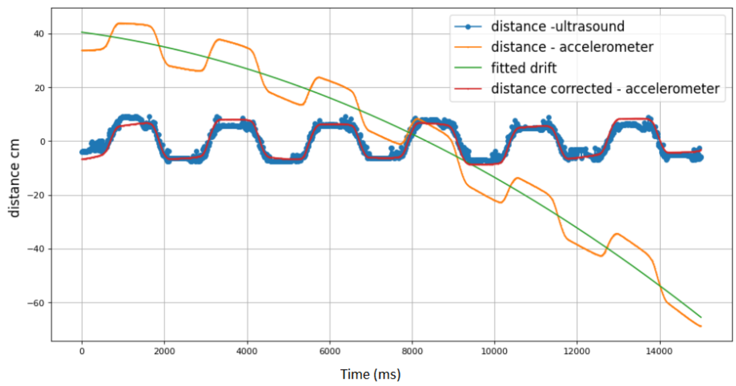

Figure 4: Analysis of the data obtained from the redesigned printer system using the motion sensor (accelerometer) and the ultrasonic sensor.

4. Results and Discussions

4.1 Functionality Tests

The MPU6050 accelerometer test was carried out in a water reservoir with waterfalls. Measurements were taken in two stages of 30 minutes each, at 3m and later 6m from the waterfall.

Figure 5 shows the graph of the acceleration intensities recorded during the entire test, allowing visually discerning two wave intensities.

Also on the right side of figure 5, we show the graph of temperature and humidity data from the DHT11, DS18B20 and MPU6050, during rainy season. The lack of data in the first few days was due to overheating from direct contact of the panel with the electronics box. The higher temperature of the MPU6050 is due to its continuous operation.

In figure 6, voltage data related to the solar panel and battery are presented, in the graph on the left, the daily work cycle is presented, highlighting moments of charging, waiting and discharging

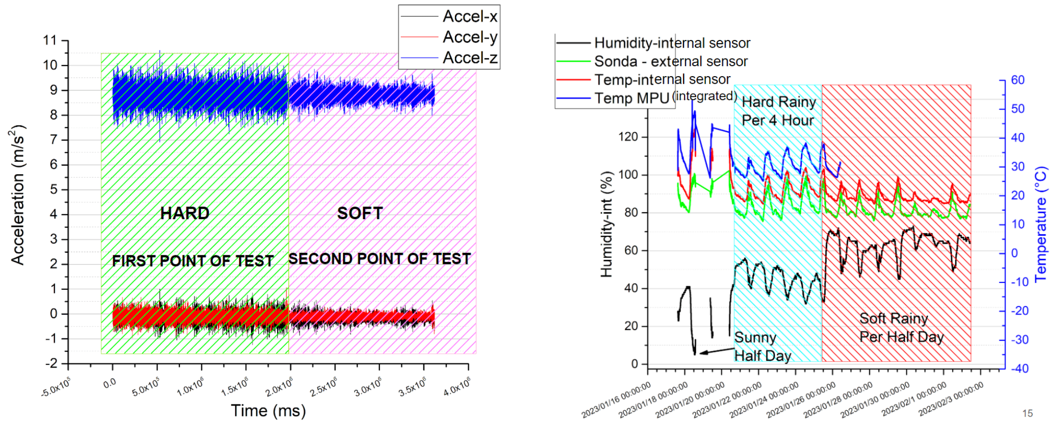

Figure 5: Left: data obtained from a waterfall of approximately 3m drop. Right: test data from temperature and humidity sensors for approximately 20 days.

of the battery and solar panel. In the graph on the right, a linear function is adjusted to the section of the battery voltage curve corresponding to the discharge stage, which is extrapolated to the BMS cut-off voltage of the battery, thus estimating approximately 6 days of operating autonomy.

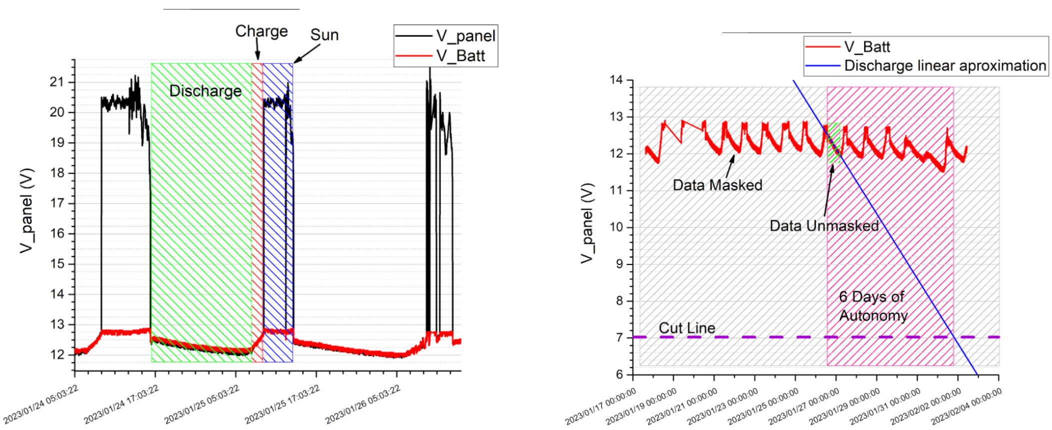

Figure 6: Left: Detail of voltage data from solar panel and battery for one day. Right: detail of graphical analysis for estimating prototype autonomy.

4.2 Field Tests

The field test was carried out at a nearby lake. The buoy prototype was left collecting data for a period of 2 hours. Figure 7 shows the graphs of acceleration in the Z axis and its respective conversion to position for a oscillating period of 2.5 seconds with its respective adjustment curve for the subtraction of the approximation error. Figure 8 presents the corrected position curve, in which an approximation of the amplitude of the lake's wave under the interaction of a gentle breeze in the morning hours can be seen.

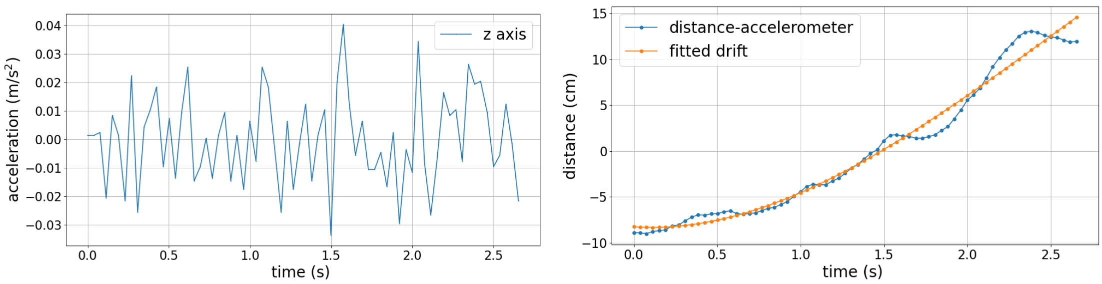

Figure 7: Left: acceleration values in the Z axis. Right: position values and adjusted curve for approximation error.

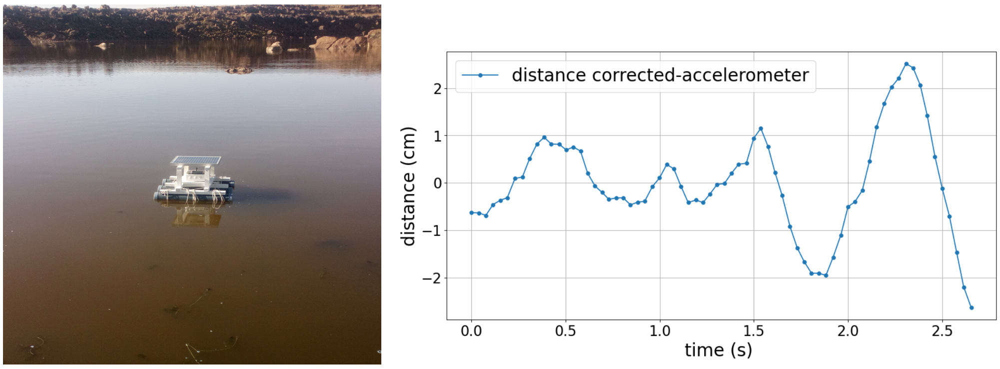

Figure 8: Left: photo of prototype during test in Lagunas Ticclla. Right: corrected position curve of MPU6050 with respect to Z axis to evaluate water wave motion.

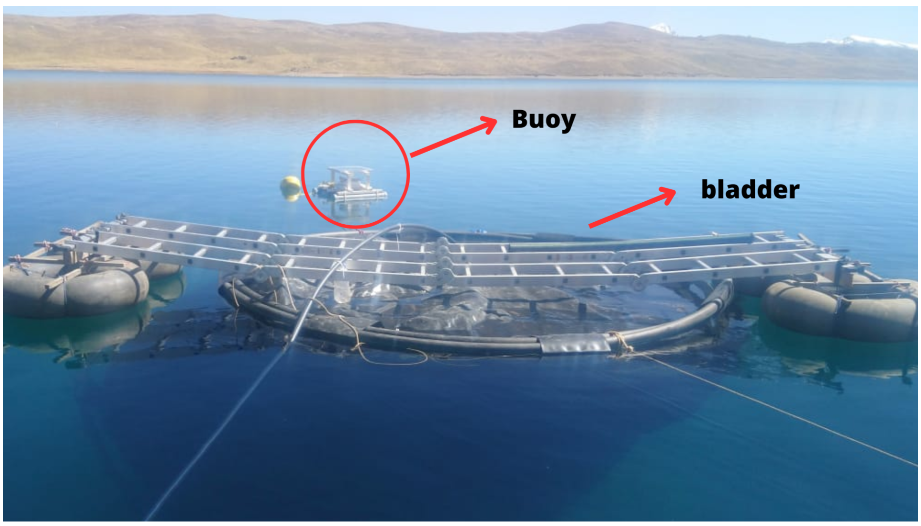

Figure 9: Deployment of buoy in Sibinacocha Lagoon-Cusco along with bladder

Since July 5th-2023, two bladders have been deployed in Sibinacocha Lake in Cusco - Peru (See figure 9), to study its mechanical resistance. Next to the bladders our buoy is registering the wave activity, with a sampling rate of 30 data per second. Likewise, it is planned to install a second buoy that will have light sensors, which will be positioned inside the bladder to monitor any external light signal due to some tearing of the bladder.

5. Conclusions

We analyzed the feasibility of using commercial sensor modules such as MPU6050 for field work application, being able to verify its measurement reliability and data quality delivered. The implementation of this module together with other modules allowed the development of a buoy for deployment in a lake with the purpose of monitoring the waving motion for long periods of time.

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