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ORIGINAL ARTICLE / ARTÍCULO ORIGINAL

SYSTEM WITH MOBILE AND INTELLIGENT MONITOR FOR THE STUDY OF ENVIRONMENTAL CARE

SISTEMA CON MONITOR MÓVIL E INTELIGENTE PARA EL ESTUDIO DEL CUIDADO AMBIENTAL

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Titulillo: System with mobile and intelligent monitor for the study of environmental care

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ABSTRACT

This paper describes and proposes different engineering techniques for designing an intelligent system focused on environmental protection, based on stationary and mobile subsystems for monitoring physical variables. The variables selected for monitoring were water level, flow rate, pH, vibration, and surface water temperature, which are transmitted via radio frequency to an external monitoring center and a mobile unit. This system was designed using an optimized analysis of polynomial models to correlate each measured physical variable. Furthermore, this research also integrates the measurement subsystems through wireless data transmission between the sensors and the stationary and mobile receiving centers. This allows for the consolidation of all measured data to obtain a comprehensive view of the main target, such as a lake or river. Such bodies of water can cause serious damage in cities when adequate prevention measures are not in place, as occurs during the El Niño Southern Oscillation (ENSO) phenomenon in Peru. Therefore, this research seeks to contribute to prevention efforts through the described and designed system. A mechatronic system was designed, consisting of a drone as a mobile station data analyzer. The data collection point for the proposed monitoring center could be located at a site chosen by the community that would use the proposed system. For the experiments, prototype designs were prepared to collect the data measured by the sensors, most of which relied on nanostructures attached to the drone to measure temperature, pH, and water level. This data was processed by the drone's controller and the monitoring system. The data was collected from the Rímac River in Peru between July 2024 and September 2025, with the expectation that the proposed research will be useful to the communities during future ENSO even.

Keyword: Drones – ENSO – Environmental monitoring – Smart sensors – Wireless communication.

RESUMEN

En este trabajo se describen y proponen diferentes técnicas de ingeniería para diseñar un sistema inteligente orientado al cuidado del medio ambiente, basado en subsistemas estacionarios y móviles para el monitoreo de variables físicas. Las variables seleccionadas para ser monitoreadas fueron el nivel de agua, caudal, pH, vibración y temperatura superficial del agua, las cuales se transmiten por Radio Frecuencia a un centro de monitoreo externo y a uno móvil. Este sistema fue diseñado mediante un análisis optimizado de modelos polinomiales para correlacionar cada variable física medida. Asimismo, esta investigación también integra los subsistemas de medición mediante transmisión inalámbrica de datos entre los sensores y los centros receptores estacionarios y móviles. Esto permite consolidar todos los datos medidos para obtener una visión panorámica del objetivo principal, como un lago o un río. Dichos cuerpos de agua pueden causar graves daños en las ciudades cuando no hay una prevención adecuada, como ocurre durante el fenómeno “El Niño Southern Oscillation (ENSO)” en el Perú. Por lo tanto, esta investigación busca contribuir a las tareas de prevención mediante el sistema descrito y diseñado. Se diseñó un sistema mecatrónico compuesto por un dron -analizador de datos de estación móvil-. Los datos medidos que se proponen para el centro de monitoreo podría ubicarse en un lugar decidido por la comunidad que podría utilizar este sistema propuesto. Para los experimentos, se prepararon diseños de prototipos para obtener los datos medidos por los sensores, la mayoría de los cuales se basaron en nanoestructuras fijadas al dron para medir la temperatura, el pH y el nivel del agua. Estos datos fueron procesados por el controlador del dron, así como por el sistema de monitoreo. Los datos medidos se obtuvieron del río Rímac, Perú, durante julio de 2024 a septiembre de 2025, con la expectativa de que la investigación propuesta pueda ser útil para las comunidades durante el futuro período del ENSO.

Palabras claves: Comunicación Inalámbrica – DRONs – Energía solar – ENSO – Monitoreo Ambiental – Sensores inteligentes

INTRODUCTION

In this proposed article are analyzed the applications of smart sensors according to be used in the measurement of physical variables that give information of the effect of natural disasters (such as ENSO). In this context, there are analyzed the temperature of the external conditions, flow and water level of the rivers and lakes. The described measurement is organized by sensors stored in DRON, also the mathematical analysis, as based on advanced polynomial modeling (Calderón *et al.,* 2022), is a good advantage due to achieve optimal measurements consequently the correlation of the designed mathematical model with the identified system based on the offline identified parameters, this task needed more time for the execution of the main control system (Aström & Hägglund, 2012), which integrates every response from the other 2 DRON, it means the system is defined by 3 DRON due to achieve a 3 dimension reconstruction for every physical variable over the selected surface by the 3 DRON (smart monitoring system) (Corsi, 2014).

The following figure 1 shows a building used by some people to live, notwithstanding, there is a big disadvantage in its closeness to the river, which usually increase the water level when it is ENSO time (Lozada-Escorza, 2021). Therefore, there is quite dangerous to not have a preventive system in order to care homes in from ENSO consequences, such as it is proposed in this research. (Farfán *et al*., 2024).

Figure 1. A building close to a river in Peru, without ENSO prevention.

Moreover, every one of the DRONE is integrated by sensors based on nanostructures (DRONES were simple electromechanical systems adapted for the presented research), which help to get the physical variables measurements (temperature, water level, position) in short response time and high robustness (depending the operating range of work) (Bora, 2018; Johnson *et al*., 2021). Hence, this advantage to measure the physical variables over the river/lake surface in short response time let to execute intricate algorithms (based on adaptive Modulating Functions) according to achieve the report of the temperature, pressure, humidity, water level and flow over every chosen surface by the smart monitoring system (Stetter, 2009; Hunter *et al*., 2010). The internal communication by every DRON is given by a combination of radio frequency (RF) and infrared (IR) signals, as well as all the matrix of the measured physical variables are sent by wireless to an external user, which is depicted by the fig. 2.

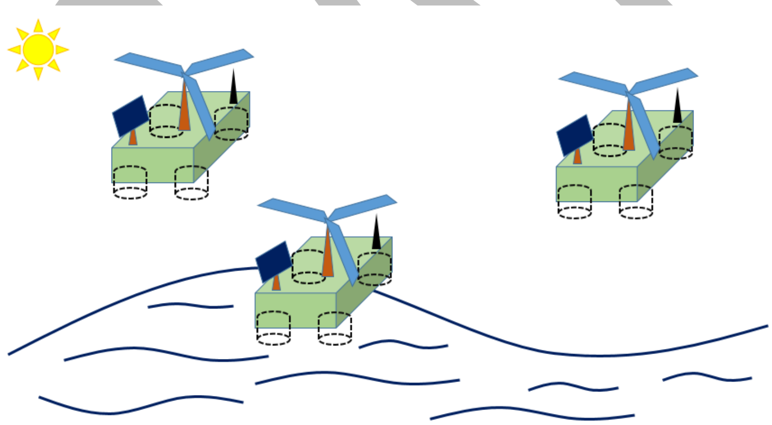

Figure 2. Representation of the smart monitoring system.

In the following paragraphs are described equations to obtain the optimal solutions for the sensors measurements data analysis, in spite of the system is multivariable. It is proposed a geometric surface by the function "f" in dependence on the variables "x_1" and "x_2" that is given by the equation (1) (Gonzales & Sánchez, 2012).

$$f(x_1, x_2) = 0 \qquad (1)$$

As well as, the equation (2) gives information of the bounding section "g" in dependence on the variables "x_1" and "x_2"

$$g(x_1, x_2) = 0 \qquad (2)$$

It is proposed a geometric surface because of the intersections between "f" and "g", hence, it was necessary the derivatives in dependence on "x_1" and "x_2" for the function "f", which is described by the equation (3).

$$df(x_1, x_2) = \frac{\partial f(x_1, x_2)}{\partial x_1}\, dx_1 + \frac{\partial f(x_1, x_2)}{\partial x_2}\, dx_2 \qquad (3)$$

By other side, for the function "g", it is proposed a geometric surface because of the intersections between "f" and "g", thus, it was necessary the derivatives in dependence on "x_1" and "x_2", which is described by the equation (4).

$$dg(x_1, x_2) = \frac{\partial g(x_1, x_2)}{\partial x_1}\, dx_1 + \frac{\partial g(x_1, x_2)}{\partial x_2}\, dx_2 \qquad (4)$$

From equation (3) and equation (4) are obtained the equations (5) and (6), which is based on the boundary conditions. (Landau & Lifshitz, 1959)

$$df(x_1, x_2) = 0 \qquad (5)$$

$$dg(x_1, x_2) = 0 \qquad (6)$$

Therefore, it was obtained the equation (7).

$$\frac{\partial f(x_1, x_2)}{\partial x_1}\, dx_1 = -\, \frac{\partial f(x_1, x_2)}{\partial x_2}\, dx_2 \qquad (7)$$

And the equation (8).

$$\frac{\partial g(x_1, x_2)}{\partial x_1}\, dx_1 = -\, \frac{\partial g(x_1, x_2)}{\partial x_2}\, dx_2 \qquad (8)$$

From equation (7) and equation (8), it was organized the equation (9):

$$-\frac{\partial f(x_1, x_2)}{\partial x_1}\, dx_1 \frac{\partial g(x_1, x_2)}{\partial x_2}\, dx_2 = -\, \frac{\partial f(x_1, x_2)}{\partial x_2}\, dx_2\, \frac{\partial g(x_1, x_2)}{\partial x_1}\, dx_1 \qquad (9)$$

Thus, it was achieved the equation (10)

$$\frac{\partial f(x_1,x_2)}{\partial x_1} - \frac{\frac{\partial f(x_1,x_2)}{\partial x_2}}{\frac{\partial g(x_1,x_2)}{\partial x_2}} \frac{\partial g(x_1,x_2)}{\partial x_1} = 0 \qquad (10)$$

As well as, by the same procedure that was obtained the equation (10), it was achieved the equation (11).

$$0 = \frac{\partial f(x_1,x_2)}{\partial x_2} - \frac{\frac{\partial f(x_1,x_2)}{\partial x_1}}{\frac{\partial g(x_1,x_2)}{\partial x_1}} \frac{\partial g(x_1,x_2)}{\partial x_2} \qquad (11)$$

Therefore, it must be in the point (x^*, y^*) for (x, y), represented by "λ" in the equation (12).

$$\frac{\frac{\partial f(x_1,x_2)}{\partial x_1}}{\frac{\partial g(x_1,x_2)}{\partial x_1}} = \frac{\frac{\partial f(x_1,x_2)}{\partial x_2}}{\frac{\partial g(x_1,x_2)}{\partial x_2}} = \lambda \qquad (12)$$

Consequently, it was possible to identify the optimal sections of the physical variables measurements by wireless sensors of the DRON.

By other side, it is quite necessary to get understanding of the wireless data transmission that helps to interchange the measured variables, such as the information transmitted between sender and receptor. Nevertheless, in the proposed research, it was analyzed the interaction between every DRON with the user, for this reason it was studied the measurement as data transmitted, which also gave the outlook that this proposed research could be used for long distance communication tasks.

The following equation is a solution for a wave equation (13), an electromagnetic wave equation "ψ" under dependence of the position "r" and time "t", a general amplitude "A", frequency "f" and phase "ψ". (Feynman *et al*., 1962).

$$\psi(r,t) = A \sin\left(wt \pm \alpha\right) \qquad (13)$$

ASAP

Even though for the described solution, the frequency "f" can be associated with the speed of light "C" and wavelength "λ" of the wave "ψ", which is described by the equation (14).

$$f = \frac{C}{\lambda} \qquad (14)$$

As well as the equation (15), proportionate information of the general model for the speed of light that helped to generalize the equation of the wave data transmission, in which "C_0" is the initial speed of light value, "C" is the speed of light under dependence of its initial value and the source speed "v" (Magueijo, 2003).

$$C_0 = C\,(1 + \frac{v^2}{C^2}) \qquad (15)$$

By energy conservation, in the equation (16) can be proposed the equilibrium between the kinetic energy of the source at speed "v", mass "m", with its gravity energy. For which, the gravity constant is "G", "M" is the mass of the gravitation interactive body for the wave source, as well as the position between the wave source with the gravitation interaction body is "r" (Medina, 2009).

$$\frac{1}{2} m v^2 = \frac{GmM}{r} \qquad (16)$$

Hence, the minimal speed to escape from the gravitation interactive body is given by the equation (17), as a reduction of the equation (16) (Medina, 2010).

$$v^2 = 2\frac{GM}{r} \qquad (17)$$

It means that replacing the equation (17) in the equation (15), it was obtained the equation (18).

$$C_0 = C\,(1 + 2\frac{GM}{rC^2}) \qquad (18)$$

From the equations (14) and (18) replaced in the equation (13), it was obtained the equation (19).

$$\psi(r,t) = A\sin\left(\frac{\frac{2\pi}{\lambda}C_0}{1+\frac{v^2}{C^2}}t \pm \alpha\right) \qquad (19)$$

Or by another hand, the equation (19) can be proposed through the equation (20).

$$\psi(r,t) = A\sin\left(\frac{\frac{2\pi}{\lambda}C_0}{1+2\frac{GM}{rC^2}}t \pm \alpha\right) \qquad (20)$$

Therefore, by the equation (20) it was possible to generalize the communication signal, which can be under relativistic effects or long-distance separations among emitter and receivers.

The equation (21) shows the intensity “I”, and “I_0” as its initial value, “x” is the wavelength, and “α” is the light absorbance coefficient.

$$I = I_0 e^{-\alpha x} \qquad (21)$$

The electrical field intensity “E”, its initial value “E_0”, frequency “w” in the time domain “t”.

$$E = E_0 e^{iwt} \qquad (22)$$

The electrical force depending on the electrical charge “q”.

$$F = qE \qquad (23)$$

By Newton Second Law (Person, 1995)

$$m\frac{d^2}{dt^2}X(t) + mw^2X(t) = F \qquad (24)$$

Replacing previous equations (22) and (23) in (24)

$$m\frac{d^2}{dt^2}X(t) + mw^2X(t) = qE_0e^{iwt} \qquad (25)$$

A proposed solution is given by the equation (26)

$$X = X_0 e^{iw_0t} \qquad (26)$$

ASAP

Therefore, replacing equation (26) in (25)

$$m\frac{d^2}{dt^2}(X_0e^{iw_0t}) + mw^2(X_0e^{iw_0t}) = qE_0e^{iwt} \qquad (27)$$

It was obtained the equation (28)

$$X_0 = \frac{qE_0e^{iwt}}{m(w^2-w_0^2)e^{iw_0t}} \qquad (28)$$

Replacing (28) in (26), it was obtained the equation (29)

$$X = \frac{qE_0e^{iwt}}{m(w^2-w_0^2)} \qquad (29)$$

This article aims to design and develop an environmental monitoring system based on drones and the use of advanced sensors, with a focus on measuring physical and chemical variables in bodies of water.

MATERIALS AND METHODS

Hence, the described equations above give the main reference to get understanding of the light absorbance of the designed solar cells, which also improve the optimal power transmission to the main designed mechanical system. Thereby, there were prepared own transducers based on amorphous nanostructures due to get short response time and high robustness in the physical variable's measurements. (Ku *et al*., 2023).

The figure 3 shows one of the prepared samples for the designed transducers based on nanoholes of Anodic Aluminum Oxide (AAO), there were deposited structures of Titanium Dioxide (TiO_2) owing to prepare nanowires of this on the range 1000 nm to 10 000 nm, even though the prepared sample by anodization and electro chemical deposition contained more nanostructures in the range 8 000 nm to 10 000 nm (Keller *et al*., 1953; Al-Kaysi *et al*., 2009).

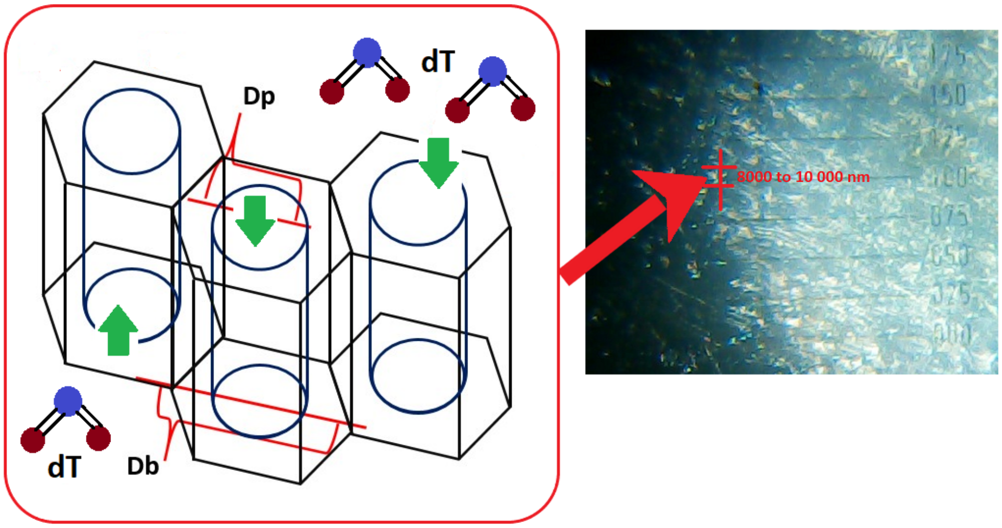

Figure 3. Representation of the AAO nanoholes prepared to receive TiO_2 as part of a real sample.

After to prepare the samples for the transducers, there were organized the position sensors, the water level sensor, the small solar cells in order to integrate to the pH sensor (from ARDUINO company), charger batteries, and the RF measurement data transmitter around a small DRON (Figure 4).

Figure 4. DRON used to integrate the sensors.

It was used, also, another DRON, which had the task to measure its position, as well as the water level of the river. In fact, the showed DRON had a better performance for the experimental tests outside the laboratory owing to it had robustness in front intense windy time (Figure 5).

Figure 5. Aerial measurement system with robustness.

Ethic aspects: This article has not ethical conflicts in the proposed research, which was cited every bibliographic reference for every analysis described.

RESULTS AND DISCUSSION

The described materials used for the experimental results helped to prepare position and water level smart sensor, which complement to the ARDUINO sensors in order to give the pH of the river. The matrix of data is analyzed to be sent to external users by RF from the DRON, furthermore, this is restructured by the advanced sensors and a microcontroller due to prepare the main data matrix of the measurements (Andrade-Gutiérrez, 2022).

The integrated system (DRON, the advanced sensors, the solar energy subsystem and the RF communication subsystem) starts the monitoring task activating the supplier energy charger subsystem (based in small solar cells based in nanostructures), in spite of the system keeps external chargeable system, but the DRON solar energy subsystem stores energy to supply on the microcontroller and advanced sensors while the DRON uses the energy from the main battery. The DRON activates the position sensor and the water level sensor while the DRON is over the river, as well as the pH sensor by periods (it happened when the DRON comes near the river according to keep in contact the pH sensor with the water), the position and the water level sensor work together owing to get a spatial recognition of the trajectory and place to measure the required physical variables.

The communication system of the DRON operates with the measurement data achieved from every sensor as well as execute an advanced predictive/adaptive algorithm for the filtered data that can help for users, which get the information to interpreted the presence of ENSO (Intrieri *et al*., 2012; Yovera-Puican, 2023).

The following figure 6 shows the energy absorbance by the solar panels to store electrical energy on the batteries of the designed system, which get energy from the solar panels prepared by nanostructures (Lei *et al*., 2007). The quantity of saved energy got a steady state with approximated 0.4 W, the used balance was among its energy conversion with its consume by the designed sensors during 30 minutes (Unzicker & Presuss, 2015).

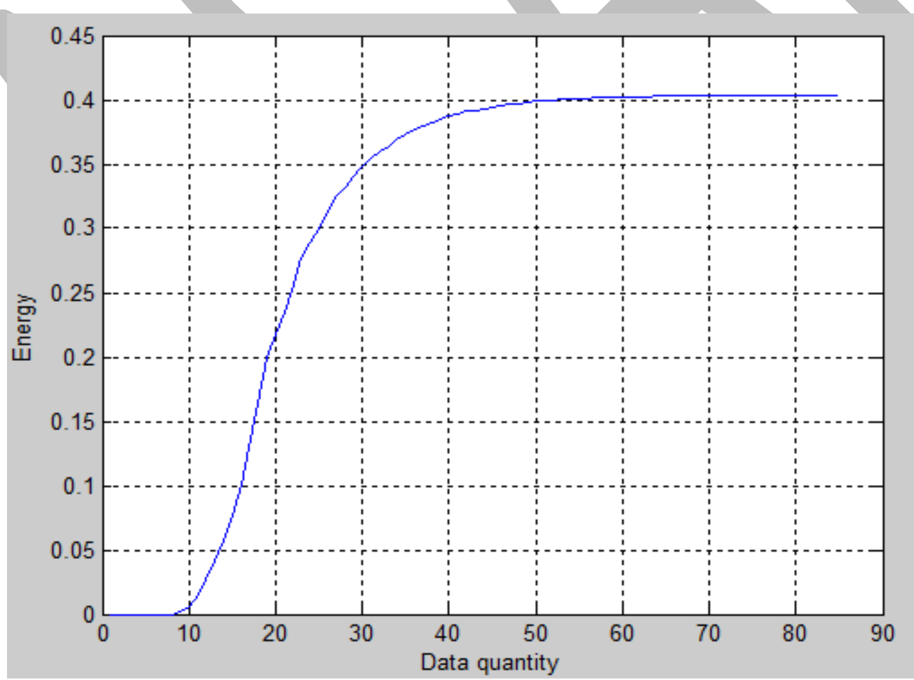

Figure 6. Solar energy absorbance.

The following figure 7 shows the position and water level measured by the DRONE, which was achieved by experiments around 20 meters up of water trajectory (along Rimac river, Santa Clara, Perú) during 20 minutes approximately as well as this measured data was sent by RF to an external user at 100 meters of distance (this value was evaluated previously by laboratory procedures). The blue color curve provides information on the water level measured from the drone in centimeters, while the red color curve provides information on the drone's position in meters.

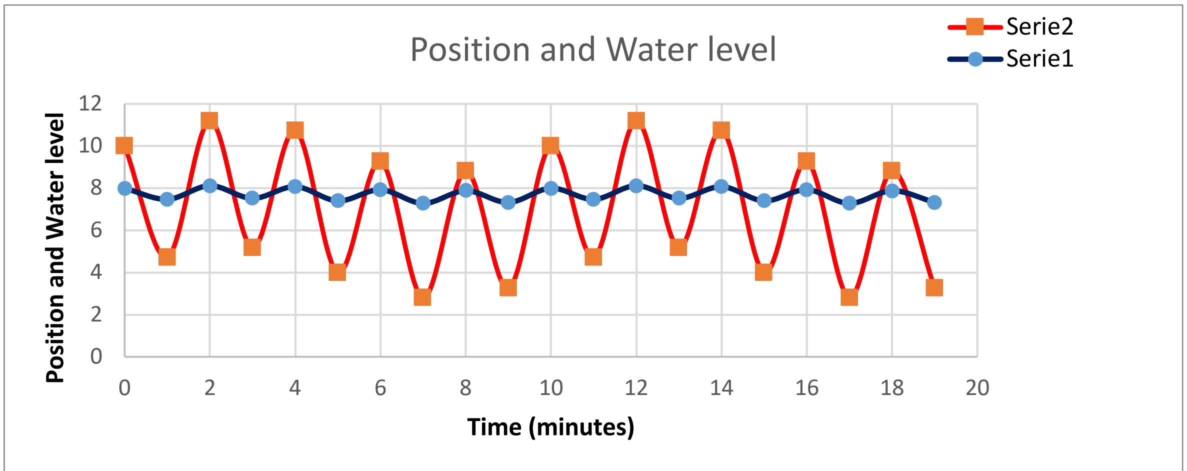

Figure 7. Measured data by the designed system.

The following figure shows the temperature measured over the river surface by non-contact heat transmission. These measurement results stem from the mathematical analysis discussed in previous chapters and are robust, based on the correlation between theoretical and experimental mathematical modeling. The advanced sensors on the DRONE, which use nanostructures, provide a short response time. This response time is much shorter than that of other electromechanical sensors, ensuring optimal data is gathered.

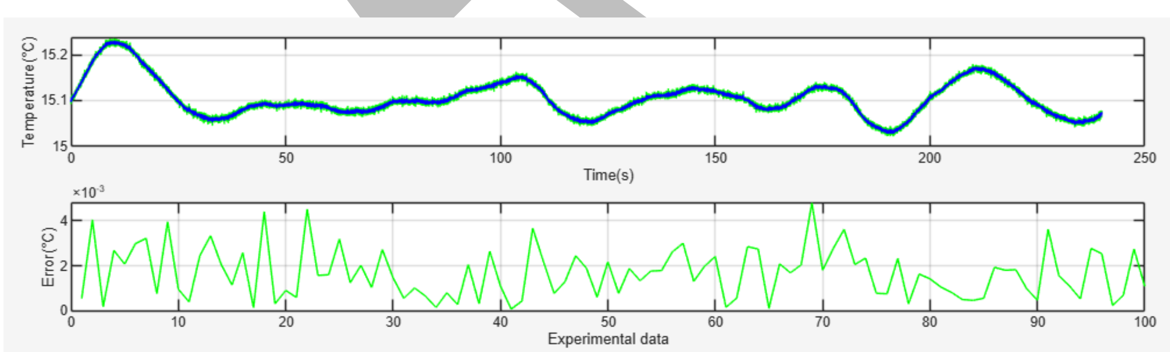

Figure 8: Temperature of the river surface.

The presented research addresses important issues related to the designed DRONE for monitoring applications, which arise from environmental tasks. The following figure 9 illustrates the designed DRONE scheme for monitoring physical variables, as described in the preceding paragraphs. The DRONE flies along a river and avoids crossing a swirl. Its automatic response finds an optimal trajectory to leave the swirl after measuring environmental physical variables, for which the DRONE was designed and detailed in this article.

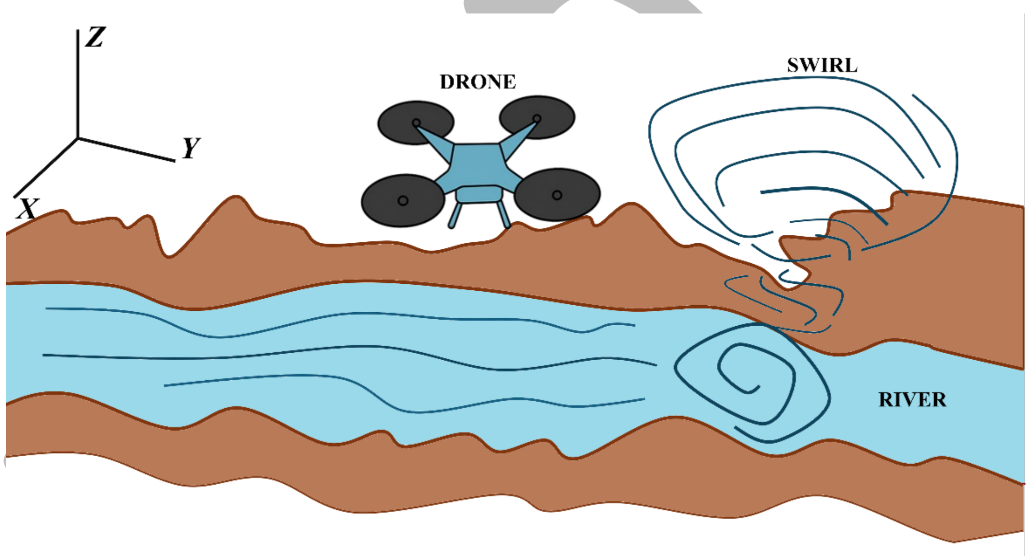

Figure 9. Scheme of the DRONE in activity.

In fact, the DRONE has the possibility to fly by its own controlled trayectory (autopilot), as well as figure 10 illustrates the road from L1 to L3 that can be a chosen solution by the autopilot of the designed DRONE. This proposal can be optimal due to its return path is a half circumference, which is possible to get while the Thrust force "E" is perpendicular to the aerodynamic force "Fa" (geometrical property), meaning that keeping "b" at 90 degrees warrants the half circumference trajectory according to return from L1 to L3. However, while the swirl increase in intensity due to height, it is verifiable that the optimal angle between the plane of the path L1 to L2 must be 45 degrees over the plane of the road L1 to L3. Therefore, the proposed DRONE by its autopilot is a consequence of the algorithm designed by the mathematical analysis described in the presented article; furthermore, the advanced instrumentation (such as, for example, the sensors based on nanostructures) helped to get an optimal system that can be useful for communities in response to El Niño phenomena (Velásquez *et al*., 2024).

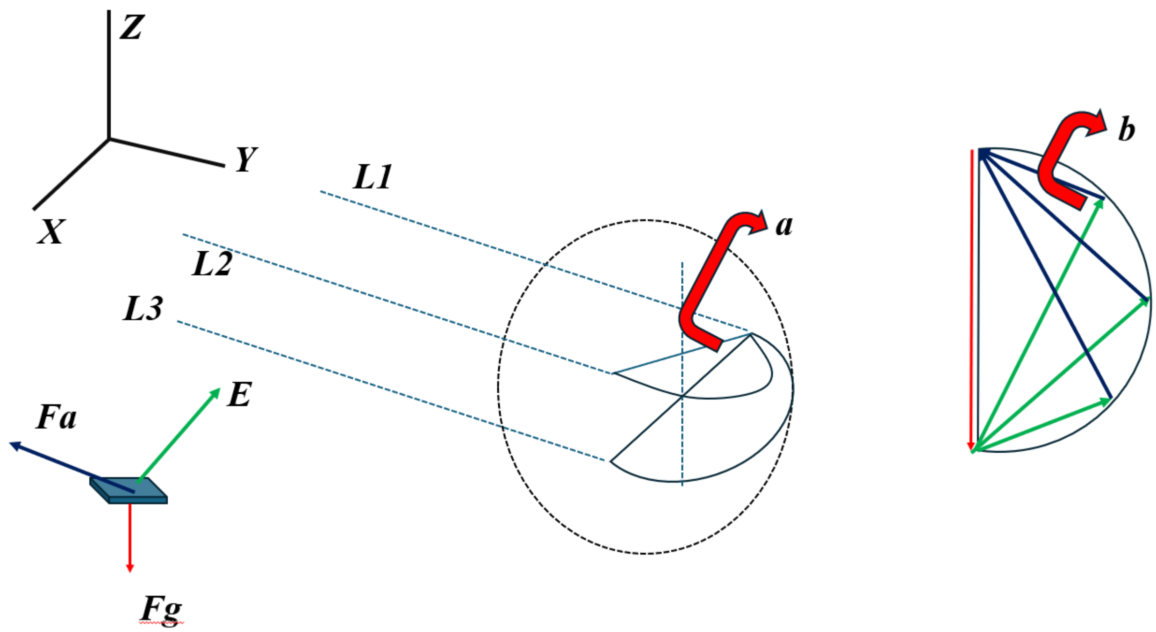

Figure 10. Scheme of the DRONE in activity (geometrical interpretation).

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