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A RESEARCH VISION

Monitoring of environmental variables based on the Internet of Things (IoT) and supported by the ThingSpeak platform in the Las Siras stream, in the municipality of Duitama, Colombia.

Monitoreo de variables ambientales basado en Internet de las Cosas (IoT) y respaldado por la plataforma ThingSpeak en la quebrada Las Siras, en el municipio de Duitama, Colombia

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ABSTRACT

Understanding and protecting natural environments is essential for the survival of living beings, being water one of the vital elements for humans, therefore water resources and other elements must be monitored to understand and protect their environment, this leads to apply the Internet of Things (IoT) technology for monitoring environmental variables, in the stream La Siras, in the municipality of Duitama, department of Boyacá in Colombia.

The IoT technology integrated with the ThingSpeak platform that allows collecting and analyzing data in real time, having a follow-up by reading each of the data captured by temperature, humidity and turbidity sensors, fundamental variables to evaluate the water quality and environmental conditions in the stream, the integration of the sensors through an Arduino board, which through a Wifi module sends the recorded data to the cloud on the ThingSpeak platform.

The environmental monitoring system becomes a tool that facilitates real-time decision making by helping decision makers to act and manage processes and implement environmental protection measures based on accurate and current data.

RESUMEN

Comprender y proteger los entornos naturales es esencial para la supervivencia de los seres vivos, siendo el agua uno de los elementos vitales para los humanos, por lo anterior los recursos hídricos y otros elementos deben ser supervisados para comprender y proteger su entorno, esto lleva a aplicar la tecnología Internet

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de las Cosas (IoT) para el monitoreo de variables ambientales, en la quebrada La Siras, en el municipio de Duitama, departamento de Boyacá en Colombia.

La tecnología IoT integrada con la plataforma ThingSpeak que permite recopilar y analizar datos en tiempo real, teniendo un seguimiento por la lectura de cada uno de los datos capturado por sensores de temperatura, humedad y turbidez, variables fundamentales para la evaluar la calidad del agua y las condiciones ambientales en la quebrada, la integración de los sensores mediante una placa de Arduino, que a través de un módulo Wifi envía los datos registrados a la nube en la plataforma ThingSpeak.

El sistema de monitoreo ambiental se convierte en una herramienta que facilita en tiempo real la toma de decisiones ayudando a los responsables actuar y gestionar procesos e implementar medidas de protección ambiental basadas en datos precisos y actuales

1. Introduction

In an increasingly interconnected world, environmental monitoring has become a priority to understand and protect nature's physical environment. The rapid advancement of technology, particularly the Internet of Things (IoT), has provided new opportunities to enhance real-time data collection and analysis, improving environmental conservation efforts. This paper explores how IoT integrates with the ThingSpeak platform, which acts as a centralized command center, providing data analysis and visualization capabilities. From the detection of harmful substances to the management of natural resources, this combination offers a powerful solution to address environmental challenges and contribute to the sustainability of the planet.

IoT has revolutionized the way we interact with the physical world. This technological paradigm enables the connection and communication between devices and sensors, providing unprecedented opportunities to monitor environmental variables efficiently [1]. The use of IoT in environmental monitoring has been explored in various studies, demonstrating its potential in tracking air quality [2], predicting climate patterns [3], and managing water resources [4]. The La Siras stream, with its rich biodiversity and ecological relevance, becomes an ideal scenario to implement an IoT-based monitoring system. Its significance extends beyond local conservation efforts, as it aligns with global initiatives to integrate IoT into sustainable development strategies [5].

La Siras Creek is a vital tributary in the municipality of Duitama, located in the Cundinamarca Boyacá highlands of Colombia. Its meandering course flows through mountainous landscapes, native forests, and agricultural areas. In addition to its natural beauty, it plays a crucial role in the local ecological balance, providing habitats for diverse species of flora and fauna. However, it also faces environmental challenges.

Water pollution, deforestation, and climate change affect its health and sustainability, causing it to overflow and disrupting the ecological equilibrium. Studies have shown that IoT applications in water monitoring can significantly enhance early detection and response to pollution and climate-related events [6].

To address the latter problem, a system for monitoring variables such as temperature, humidity, and turbidity using IoT technology, supported by the ThingSpeak platform in real time, is developed to assess environmental conditions and take preventive measures [7]. The integration of IoT with cloud computing and artificial intelligence (AI) further strengthens decision-making capabilities, enabling predictive analytics for proactive environmental management [8].

This study contributes to the knowledge on IoT-based environmental monitoring and will provide valuable information for resource management decision-making. It will also serve as a model for other similar projects in vulnerable areas. By leveraging IoT and data-driven solutions, communities can develop more resilient and adaptive strategies to combat environmental threats, ensuring sustainable development for future generations.

2. Methodology

2.1. Sensor Selection

The selection of the appropriate sensors is an essential component in the configuration of the monitoring system. Taking into account three key parameters: temperature, humidity, and turbidity (Figure 3, 4, and 5). For the measurement of temperature and humidity, the DHT11/DHT22 (AM2302) sensor is selected, which offers high accuracy and stability in various environmental conditions. For turbidity, the SEN0189 sensor can provide accurate measurements of the amount of light scattered by particles suspended in the water.

Integrating these sensors with an Arduino module is the next step in the process. Arduino, being an open-source hardware platform, offers great flexibility and ease of use. The sensors are connected to the Arduino board using the analog or digital input pins. Through programming in the Arduino development environment, we can configure the system to read and process sensor data efficiently [9].

Finally, to facilitate data transmission to ThingSpeak, an ESP8266 Wi-Fi module is incorporated into the system. This module, once connected to the Arduino board, supports wireless data transmission. We can program the Arduino to send the data collected by the sensors to ThingSpeak at regular intervals using the ThingSpeak API. This monitors the Siras Creek conditions in real time and allows us to store and analyze the data over time, which could be invaluable for understanding trends and patterns in the creek conditions [10].

In the IoT world, ThingSpeak has established itself as a leading analytics platform that supports real-time data aggregation, visualization, and analysis in the cloud [11]. For the environmental monitoring project in the creek, ThingSpeak is an ideal choice due to its ability to handle large volumes of real-time sensor data, its ease of use, and its wide range of functionalities [12]. In addition, ThingSpeak offers a robust and easy-to-use API that facilitates integration with a variety of devices and hardware platforms, including Arduino [13].

By setting up an account on ThingSpeak, a cloud platform that facilitates real-time data collection and visualization, you enable real-time data collection and visualization by creating the necessary channels for sending data and its subsequent analysis [14].

Given the hardware configuration, a connection is established between the Arduino and the DHT11 and SEN0189 sensors which, being connected to the ESP8266 Wi-Fi module, establish the Internet connection and thus be able to transmit data to ThingSpeak.

Subsequently, it is necessary to create a channel where the data will be stored, configuring the necessary fields for the data to be collected. An API Key is required, which is necessary for the device to send data to the ThingSpeak channel securely. Once this process is done, the necessary code is written and loaded into the microcontroller to collect data from the sensors and send them to ThingSpeak, displaying the data by accessing the ThingSpeak channel to view the collected data in the form of graphs and tables updated in real time [15].

Therefore, sensors are installed in a strategic area of Siras Creek to measure key parameters such as temperature, humidity, and turbidity. These sensors are connected to an Arduino module, which acts as the brain of the monitoring system. The Arduino is programmed to read data from the sensors and send it to ThingSpeak via a Wi-Fi module. Once the data reaches ThingSpeak, it is stored in a pre-configured channel.

ThingSpeak plays a crucial role in this project by providing us with a platform to store, visualize, and analyze data. But it goes beyond being a data repository. With ThingSpeak, we can perform pattern analysis on the data, which helps us understand how environmental conditions in the creek change over time. This is vital for monitoring and protecting the environment in Duitama, Colombia. In addition, ThingSpeak's ability to integrate with other platforms and services allows us to create a complete and robust environmental monitoring system [16][17].

Figure 1: Monitoring system



Source: Own elaboration.

2.2. Sensor Deployment

The deployment of sensors is a critical component in this project, ensuring continuous environmental monitoring and real-time flood risk assessment. The strategic placement of sensors in populated areas along the stream is essential, as rising water levels or sudden changes in water quality can pose significant risks to local communities. The system is designed to detect anomalies early, providing automated alerts and real-time data visualization to facilitate timely responses from authorities and decision-makers [18].

For accurate environmental monitoring, multiple sensors are deployed, each with specific capabilities: Temperature and Humidity Sensor (DHT22): Used for climatic condition monitoring, with an accuracy of $\pm 0,5^{\circ}C$ for temperature and $\pm 2-5\%$ for humidity.

Turbidity Sensor (SEN0189): Measures water clarity by detecting light scattering from suspended particles in Nephelometric Turbidity Units (NTU).

Water Level Sensor (JSN-SR04T): An ultrasonic sensor used for water level detection, providing non-contact measurement with an accuracy of ± 3 mm [19].

To ensure accurate readings, a calibration process was conducted before deployment: Temperature and Humidity Calibration: Compared with a high-precision hygrometer and adjusted for local environmental conditions.

Turbidity Sensor Calibration: Verified using standardized solutions of 0 NTU (clear water) and 1000 NTU (highly turbid water) to define response curves.

Water Level Sensor Testing: The accuracy was validated by placing the sensor at predefined distances in a controlled water tank environment.

Once installed, the sensors continuously transmit real-time data to ThingSpeak, an IoT analytics cloud platform. The choice of wireless communication protocol is crucial for ensuring reliable data transmission. The following technologies were considered: Wi-Fi (ESP8266): Offers a low-cost,

easy-to-use solution but requires proximity to a network router.

LoRa (Long Range Wireless Protocol): Enables long-distance, low-power transmission, suitable for remote deployments. NB-IoT (Narrowband IoT): Provides cellular-based connectivity for high reliability in areas without Wi-Fi [20].

For this project, Wi-Fi-based data transmission was selected due to its availability and lowcost implementation. The ESP8266 module is programmed to: Establish a Wi-Fi connection to the local network.

Read data from all sensors at predefined intervals (e.g., every 10 seconds).

Format sensor readings into structured data packets. Send the data to ThingSpeak via HTTP GET requests [21]. To ensure reliability and long-term stability, extensive field tests were conducted between January and April 2024. These tests focused on: Physical Integrity: Verifying that sensor enclosures withstand rain, dust, and temperature variations.

Power Consumption Optimization: The ESP8266 was programmed with deep-sleep mode, reducing energy consumption while maintaining reliable data transmission.

Wireless Connectivity Testing: Signal strength was analyzed to optimize data transmission and minimize packet loss [22]. Once data is uploaded to ThingSpeak, real-time dashboards provide visualizations of temperature, humidity, turbidity, and water levels. To enhance decision-making, an alert system was implemented: If turbidity exceeds 100 NTU, an email and SMS notification is triggered.

If the water level rises above a predefined safety threshold, a flood warning alert is sent to authorities.

If the Wi-Fi signal is lost, the system logs the failure and attempts automatic reconnection [23].

Figure 2: Sensor location area



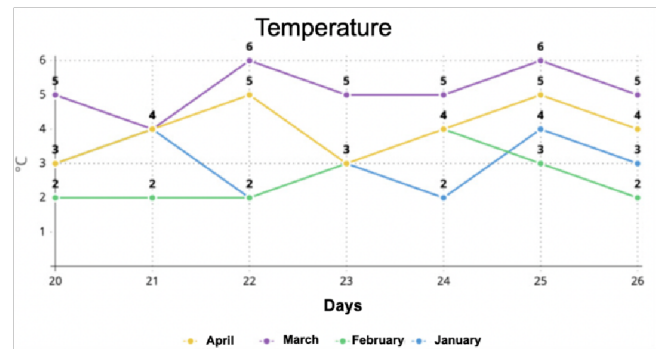
Source: Own elaboration

2.3. Data Analysis

The initial phase of data analysis focuses on data collection and preparation. Sensors strategically placed along the stream collect temperature, humidity and turbidity data (Figure 3, 4 and 5). These are transmitted to ThingSpeak via wireless connections. Once in ThingSpeak, the data undergoes a cleaning and preprocessing process.

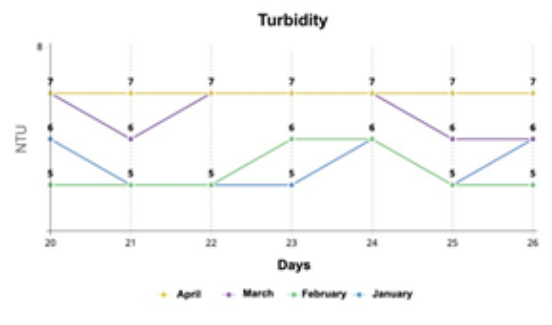
With the data prepared, we proceed to Exploratory Data Analysis. This is an important step in understanding the structure and relationships inherent in the data. The last phase of data analysis is the interpretation and communication of the results. Here, the technical results of the models are translated into understandable and actionable information. An interactive dashboard is also implemented in ThingSpeak (Figure 6) that gives users access to explore the data, providing clear and useful information that can be used to make informed decisions about the management and protection of the stream.

Figure 3: Temperature behavior results



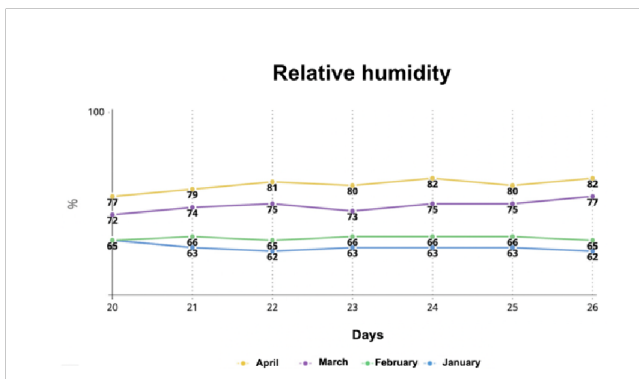
Source: ThingSpeak

Figure 4: Temperature turbidity results



Source: ThingSpeak

Figure 5: Turbidity behavior results



Source: ThingSpeak

Figure 6: Dashboard



Source: ThingSpeak

2.4. Alerts and Notifications

An essential part of the system is the configuration of alerts and notifications. These are designed to inform us when the data collected by the sensors exceeds certain predefined thresholds. For example, if the temperature or turbidity in Siras Creek exceeds a certain level, the system can send an alert to inform us of this situation. Real-time notifications are a key feature of the system. Thanks to wireless connectivity and the ThingSpeak platform, it is possible to receive real-time notifications on the devices whenever an alert is triggered [24]. This is conducive to responding quickly to any changes in environmental conditions. [25]

Alerts and notifications are crucial to the success of the project as they allow us to monitor conditions in the creek efficiently and effectively. By receiving real-time alerts, we can take immediate action to protect the environment if potentially harmful conditions are detected.

In addition to simply receiving alerts, we also perform an analysis of the alerts received. This helps to better understand conditions in the stream and to identify any patterns or trends in the data. For example, if we receive regular high turbidity

alerts after heavy rains, this could indicate that soil erosion is a problem in the area.

Once we receive an alert, the next step is to determine the appropriate action. Depending on the nature of the alert, this could involve further testing, modification of sensor parameters, or even physical intervention in the stream. For example, if we receive a high turbidity alert, we might need further testing to determine the cause and take necessary action to mitigate the water level at that point [26]. Thus, alerts and notifications inform us about current conditions and guide us in actions to prevent future overflows [27] [28].

3. Results

The data show that the temperature measured in degrees Celsius (°C) remains constant throughout the months, ranging between 20 and 26 degrees Celsius. There is no clear trend of increasing or decreasing temperature over time.

Turbidity measured in Nephelometric Turbidity Units (NTU) appears to increase slightly from January to April. In January, values range from 5.7 to 6 NTU, while, in April, values range from 7.2 to 7.8 NTU. This could indicate an increase in the amount of suspended particles in the water over time.

Relative humidity measured in percent (%) also seems to increase from January to April. In January, values range from 62% to 65%, while in April, values range from 77% to 82%. This could indicate an increase in the amount of humidity in the air over time.

A significant correlation is identified between the simultaneous increase in turbidity, temperature and relative humidity indices with the increase in stream levels. This suggests that these environmental parameters can be reliable indicators of hydrological changes in small water bodies. Understanding these dynamics is crucial for action to prevent possible flooding, highlighting the importance of continuous and accurate monitoring of these variables.

The sensors installed in the target area are designed to collect data on temperature, humidity and turbidity and transmit it in real time to ThingSpeak, providing a continuous, real-time view of the environmental conditions in the creek. This data collection is critical to the project, as it provides the information we need to understand and protect the environment in the creek.

The system also includes a real-time alert and notification system. If data collected by the sensors indicate that conditions in the creek are changing in a way that could be detrimental to the environment, the system sends an alert to project managers. This allows them to respond quickly to any changes in environmental conditions, and to take action to protect the environment if necessary.

Through data collection and analysis, the project provides us with the information we need to improve environmental management in the stream. For example, if the data indicate that the water quality in the stream is increasing, we can protect the stream environment by checking for significant amounts of solid waste or if the constant rains have raised the water level.

Finally, we hope that the project will help increase awareness and education about the importance of environmental protection. By sharing the data and findings with the local community and the general public, we hope to inspire others to take action to protect the environment. In addition, by providing a real-time view of conditions in the creek.

4. Conclusions

The integration of IoT-based environmental monitoring has demonstrated its high effectiveness in providing real-time insights into environmental conditions, offering early warnings for potential flooding events and ecological risks. The ability to continuously monitor key parameters such as temperature, humidity, and turbidity has proven invaluable for environmental decision-making and preventive management strategies.

The successful deployment of IoT sensors in the Siras Creek study area has enabled the continuous collection of reliable and accurate environmental data. The correlation between increased turbidity and heavy rainfall events highlights the need for proactive erosion control to maintain the ecological integrity of the creek.

The integration with the ThingSpeak platform has facilitated automated data processing, allowing for the detection of patterns and trends. This capability provides a deeper understanding of environmental variations, which is essential for long-term ecological monitoring. The implementation of a real-time alert system has enabled rapid responses to significant environmental changes. This system has demonstrated great potential for improving disaster preparedness, reducing response times, and allowing for the implementation of early intervention measures to minimize environmental damage and risks to nearby populations.

While the project has proven to be highly beneficial, certain challenges and areas for improvement have been identified: The increasing reliance on IoT sensors requires robust data security measures to prevent unauthorized access and ensure data integrity. Additionally, enhancing interoperability between different sensor types and platforms would facilitate greater scalability and data integration.

Future iterations should focus on improving sensor calibration, reducing measurement errors, and optimizing energy consumption. The adoption of low-power wireless protocols

(such as LoRaWAN or NB-IoT) could extend sensor battery life, enabling more sustainable deployments.

The positive impact of this monitoring system suggests a favorable opportunity for expansion. Extending the sensor network to other sections of the creek—or even to other nearby water bodies—could provide a more comprehensive view of regional hydrological and environmental health.

Incorporating machine learning algorithms could significantly enhance predictive capabilities, allowing for automated anomaly detection and more accurate flood forecasting models. The successful implementation of IoT-based environmental monitoring has paved the way for data-driven decision-making in ecological preservation and disaster prevention. By continuously refining and expanding this system, it is possible to optimize environmental management strategies and ensure a more resilient response to climate-related challenges.

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