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Electronic Design of an Early Warning System for Flood Monitoring and Detection Using Internet of Things

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***Abstract*—Flash floods generate serious consequences for infrastructure, the environment, the socioeconomic environment, and, fundamentally, people's lives. Therefore, monitoring these floods to reduce the risks in the various susceptible regions is essential. The combination of various factors, together with the lack of adequate information and accurate predictions, has prompted multiple investigations to create maps and forecasts that facilitate prompt aid to affected people. In this context, this article presents the development of a prototype using the Internet of Things (IoT) to improve the monitoring and management of flash floods.**

***Index Terms*—Flash floods, internet of things.**

I. Introduction

Floods continue to be one of humanity's most significant challenges, generating severe impacts in terms of loss of life, damage to infrastructure, economic consequences, and long-term effects that often result in adverse social repercussions [1]. Flash floods are particularly dangerous because they usually occur without warning. They are caused by slow thunderstorms, thunderstorms that move repeatedly over the same area, or heavy rainfall from hurricanes and tropical storms [2].

Often, these consequences trigger considerably notable social adversities [3]. Extensive research has been carried out on the effects and assessment of damage caused by events of both human and natural origin, including extreme hydrometeorological phenomena [4-8]. According to CENAPRED [8], tropical cyclones represented 51% of these effects, followed by rains and floods with 26% and earthquakes with 11%. All these phenomena accentuated the vulnerability of the population where they impact.

In recent years, Mexico has faced a series of floods that have generated devastating economic and human consequences due to these natural events [8, 9].

II. State of the Art

Different works based on the Internet of Things (IoT) for flood management show significant advances in early detection, real-time monitoring, and accurate warnings [10-12]. In recent years, research and development have focused on these solutions, which aim to improve communities' resilience to extreme weather events such as flash floods. In the work presented by Jayashree [13], an IoT-based flood detection system is proposed that uses water level sensors and wireless communication technology to monitor and predict floods in real-time. This system has proven effective in the early detection of floods and in reducing response times by authorities.

Another study [14] presents an IoT-based approach for monitoring dams and water containment structures. Using vibration sensors and wireless communication technology, this system can detect and prevent possible failures in structures, improving the safety of communities near bodies of water.

Furthermore, recent research has explored emerging technologies such as artificial intelligence and machine learning to improve the accuracy of flood predictions based on data collected by IoT sensors [15-17]. These advances show the potential of IoT-based solutions to revolutionize flood management and improve community resilience to extreme weather events.

Overall, IoT-based solutions for flood management show significant progress in early detection, real-time monitoring, and accurate alerts, with an increasing focus on integrating emerging technologies to improve the effectiveness and reliability of these systems. [18-22].

Internet of Things (IoT)-based solutions for flood management offer advantages such as real-time monitoring, early flood detection, and the ability to send alerts to authorities and residents in affected areas. However, these solutions also face some drawbacks and limitations.

Drawbacks include the need for a robust and reliable communications infrastructure and dependence on power availability and network connectivity. Additionally, implementing IoT systems for flood management can be expensive, which may limit their adoption in resource-limited areas [23].

Other limitations include managing large volumes of data generated by IoT sensors, which may require sophisticated data storage and processing systems. Addressing data privacy and security issues is also essential, especially when dealing with sensitive information about the location and conditions of people affected by floods [24].

In summary, although IoT solutions offer significant benefits for flood management, it is also essential to consider and address potential drawbacks and limitations to ensure their effectiveness and long-term viability.

The development of the early warning system for flash floods is based on state-of-the-art sensors that detect changes in water levels and adverse weather conditions. These sensors include:

– Water level sensors: These can be ultrasonic or pressure sensors and accurately measure changes in water levels in real time.

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TABLE I
PHASES OF PROTOTYPE DEVELOPMENT

Steps	Description
1.- Requirements	Identify system objectives
2.- Existing solutions	Realize a state-of-the-art
3.- Design the electronic circuit	Create an electronic design
4.- Manufacturing	Assemble the prototype
5.- Testing	Check its operation
6.- Error correction	Identify and correct problems
7.- Document the design	Document product development

TABLE II
ATMOS 41 CHARACTERISTICS

	Characteristics
Sensors	12 weather sensors
Temperature	-40 a 60ºC
Voltage	3-15 VDCC

Fig. 1. ATMOS 41 station

– Weather station: Equipped with sensors to measure temperature, humidity, wind speed, and precipitation, among other vital parameters.

The advantages of these modern sensors include greater accuracy, response speed, reliability, and coverage.

III. METHODOLOGY

For the development of the early warning system, the following phases were implemented:

1. Sensor Selection and Configuration:

Water Level Sensors: Ultrasonic and pressure sensors were chosen for their accuracy and ability to measure real-time changes.

Weather Stations: Stations with advanced sensors were selected to measure key parameters such as temperature, humidity, wind speed, and precipitation.

2. Integration of Sensors with the IoT Platform:

The sensors were integrated into an IoT platform that allows real-time data collection and analysis. Algorithms were developed for data processing and the generation of early warnings.

3. Deployment and Field Testing:

The devices were deployed in areas prone to flash flooding. Tests were carried out to evaluate the system's accuracy, response speed, and reliability.

4. Evaluation and Optimization:

The collected data was monitored, and the system parameters were adjusted to improve performance. Improvements were implemented based on the results of field tests.

IV. MATERIALS AND METHODS

The development of a flood monitoring and detection system was carried out using an IoT electronic prototype. The process is guided by seven fundamental phases described in Table I.

The IoT prototype is based on a development plan implemented with five essential modules:

1. 32-bit microcontroller: A base platform for executing operations and system control.
2. The ultrasonic sensor module is responsible for measuring key variables such as water level, flow, and speed.
3. Power modules: Ensures self-sustainability through a charge controller, rechargeable battery, and solar panel.
4. The 4G communications module facilitates the transmission and reception of data without cables, allowing efficient communication.
5. Power stage: Includes switching regulators to provide stable voltages (3.3V, 5V and 12V) necessary for various components.

This comprehensive approach ensures a complete and adequate system for flood monitoring with potential application in river environments.

Additionally, other sensors are required to complement the monitoring station. Among them, we have the following:

A. *ATMOS 41 station*

The ATMOS 41 is an all-in-one air quality sensor manufactured by Kestrel. This sensor measures critical environmental parameters, including temperature, relative humidity, dew point, barometric pressure, wind speed, wind gust and direction, solar radiation, heat index, and globe temperature. It is a portable and rugged device that provides accurate, real-time readings, making it ideal for various applications, from agriculture and meteorology to indoor and outdoor environmental monitoring; technical specifications are shown in Table II.

Figure 1 shows the external conformation of the Atmos 41 station.

B. *ToughSonic 14 ultrasonic sensor.*

The ToughSonic 14 ultrasonic sensor, manufactured by Senix Corporation, is designed to measure distances and levels of liquids or solids accurately and reliably in difficult industrial environments. Its technical specifications are shown in Table III.

C. *Arduino ATMEGA 2560*

A processing module is responsible for processing and conditioning the signals the sensors and the communication module receive. Table IV shows the technical specifications.

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TABLE III
CHARACTERISTICS OF THE TOUGHSONIC 14 ULTRASONIC SENSOR

Specifications	Output
Maximum range	10 metros
Temperature	-40 a 70ºC
Update Rate	20 HZ (50ms)
Voltage	3-15 VDCC

TABLE IV
CHARACTERISTICS OF THE ARDUINO ATMEGA 2560.

Specifications	Output
Digital I/O pins	54 (15 PWM)
Analog I/O pins	16
Communication pins	4 UART
Voltage	5 VDC

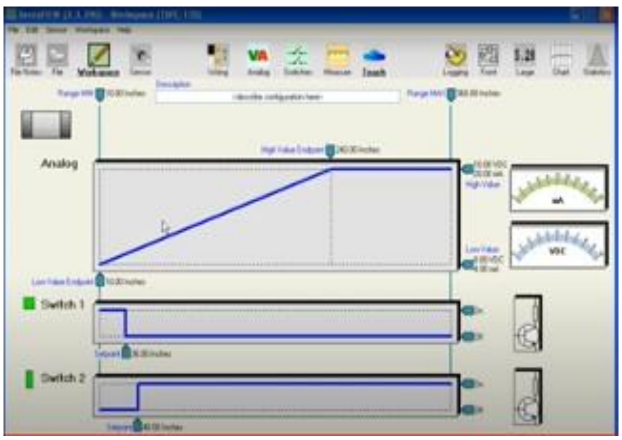

Fig. 2. Calibration of the ToughSonic 14 sensor

Fig. 3. XCTU software.

TABLE V
CELLULAR NETWORK CONNECTION CONFIGURATION

Specifications	Command
Turn on the module	AT+CFUN = 1
Enter the SIM card PIN	AT+CPIN = XXXX
Network selection by name	AT+COPS = 1,2 “XXX”
Configure the data profile	AT+CGDCONT = 1, “IP”, “XXX”

D. DIGI XBEE 3 LTE-M Cellular Modem

This module is a high-speed wireless communication device that offers cellular connectivity in industrial and commercial applications. Below is a summary of its main features.

LTE Cat 1 Cellular Communication: This module is designed to connect to broadband LTE cellular networks, enabling high-speed data transfer in industrial and commercial applications.

Global Network Support: It is compatible with global cellular networks, allowing it to be used in various applications worldwide.

API Interface: This package includes an API interface that makes integration quick and easy for a wide variety of systems and applications.

Power Management: This module includes advanced features for power management, enabling long battery life and operation in low-power, low-power environments.

V.DEVELOPMENT

For the integration of the prototype, all the sensors described are individually configured as follows:

A. ToughSonic Ultrasonic Sensor

This sensor detects the river's water level growth. It sends ultrasonic pulses and detects the reflected echo to measure the distance between the sensor and the object in front of it.

The sensor's transducer detects the reflected echo and measures the time it takes for the echo to return. Depending on the sensor configuration, the sensor can output in analog or digital format.

With the configuration software, you can program up to Sixty parameters are organized by functionality, range, sensitivity, sample rate, outputs, output filters, etc. Figure 2 shows the calibration of the sensor.

LTE module is a wireless communication device used in fourth-generation mobile networks (4G LTE) for data transmission. To configure the parameters of this radio, it is necessary to use the XCTU software, developed by Digi International. With it, it is possible to configure, diagnose, and update our communication module. Figure 3 shows the main screen of this software.

VI. RESULTS

Figure 4 shows the prototype's final integration, with a protected box in the center and its respective solar power panel.

At the top left is the Atmos sensor, while at the top right is the Toughsonic sensor. The latter, thanks to its ultrasonic technology, plays a crucial role in measuring river flow. In addition, a solar cell has been incorporated in the upper part, which provides the system with a self-sufficiency capacity that contributes significantly to its autonomy and efficiency in collecting meteorological and river data.

After operating tests of the prototype, we have corroborated the system's functionality and reliability, ensuring its ability to carry out precise and effective monitoring of meteorological and river variables in natural environments.

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TABLE VI
CONFIGURATION OF COMMUNICATION PARAMETERS

Specifications	Command
Set the baud rate	AT+IPR = 115200
Configure the UART interface	AT+UART = 0,1,0
Enable transparent mode	AT+IPMODE = 1
Enable sender identification	AT+IDNET = 1

TABLE VII
SECURITY SETTINGS

Specifications	Command
TLS/SSL security protocol	AT+USECPRF = 0,1,1
Enable secure data sending.	AT+USECSEND = 1

Fig. 4. Final prototype

Fig. 5. Web monitoring and database platform

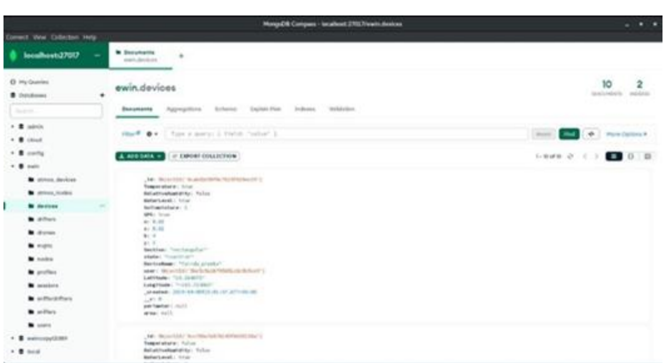

Fig. 6. Devices Web Platform

The graphic representation presented in Figure 5 corresponds to the main interface of the flood warning and prevention platform, which is available to the public.

The web interface offers a dynamic real-time visualization of the information from the deployed flash flood monitoring stations. It displays data from water level sensors and weather stations, highlighting changes in water levels and adverse weather conditions. In addition, the interface shows interactive maps with the location of the platforms and dynamic graphs that represent the evolution of the collected data. It also incorporates visual alerts to notify risk situations in real-time.

On the website, we have a data section called "devices," which is specifically dedicated to prototype nodes. In this section, a structure is presented that includes various fields related to measurement variables, such as temperature, relative humidity, water level, and soil humidity. In addition to these measurements, detailed information on the type of terrain and soil in which these nodes are located is offered. All this can be seen in Figure 6.

Information about the current operational status of these nodes complements the collected data. Like how Atmos nodes are registered, this section also includes the registration date for each station. This approach makes tracking and efficiently managing these monitoring devices easier, allowing for more effective control of the information collected.

The website has another data section called "reports," as shown in Figure 7. In this section, users can view each node and their latest collected data, organized according to their status.

A calendar in the upper left corner stands out, allowing more efficient data management when selecting the desired day. In addition, options are offered to generate reports in different formats, such as Excel, CSV, and PDF. Quick options are also provided to copy or print the main data displayed immediately.

Below are graphs of the flow obtained from different stations from April to June.

To calculate the flow, it is necessary to use the following formula:

$$Q = \frac{\Delta h}{\Delta t},$$

where:

- Δh is the difference in water level between two consecutive measurements.
- Δt is the difference in time between those two measurements.

Figure 8 shows the amount of data transmitted by the “Node 14” device over one month. Data transmission is usually continuous and stable. However, there is significant variability in the data coinciding with the period in which rains occurred.

Figure 9 shows the amount of data transmitted by the "Node 14" device during May. During this period, continuous rains were recorded, which significantly increased the river flow's activity. This variability in transmitted data directly coincides with precipitation events, indicating that the increase in data transmission is correlated with adverse weather conditions. This behavior suggests that the device responds effectively to changes in the environment, providing crucial information during heavy rainfall events that affect river flow.

Figure 10 shows the amount of data transmitted by the "Tairda Node" device during the month of June.

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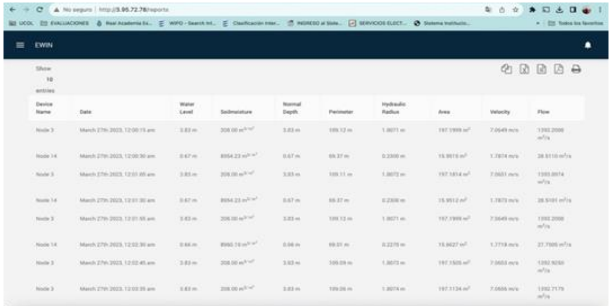

Fig. 7. Web reporting platform

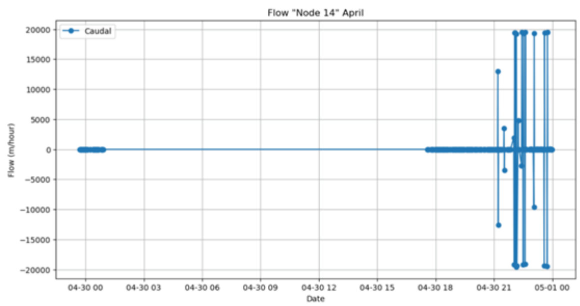

Fig. 8. Flow of Node 14 in April

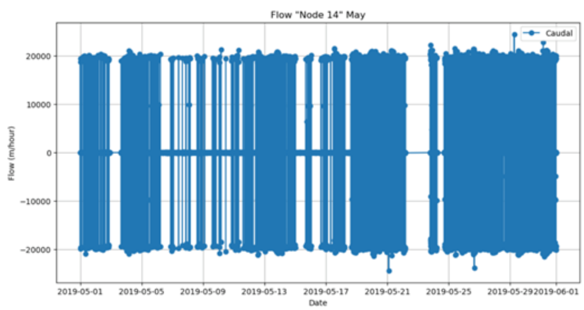

Fig. 9. Flow of Node 14 in May

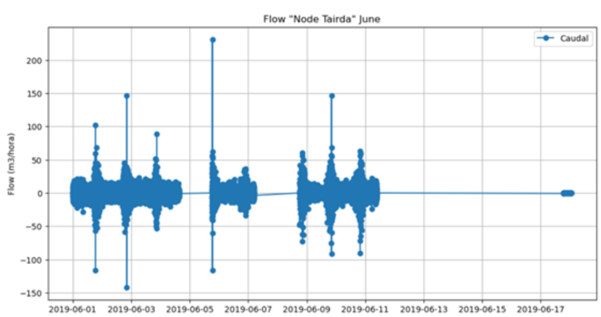

Fig. 10. Flow of the Tairda Node in June

Although little rain was recorded in this period, it is observed that the river flow remains high and constant initially. Subsequently, a stabilization and gradual reduction in flow is noted. The device monitoring these variations provides valuable data for water resource management and flood prevention.

VII. Conclusions

This prototype is significant, given that its main objective is to mitigate the risks linked to flooding and safeguard communities and vulnerable assets. Throughout its development, extensive research has been carried out, followed by prototyping and testing to establish a reliable and effective system. Below are the highlights of the prototype:

Accurate Flood Prediction: The project has improved the ability to forecast floods accurately. Advanced sensor technology and algorithms enable early and reliable detection of changes in water level.

Reliability in early warnings: The system has proven reliable in issuing early warnings. Testing and validation in real-world conditions have built confidence in its ability to detect flooding and send timely alerts.

Real-time data integration: Electronic design facilitates effective real-time data integration, streamlining decision-making for authorities and affected communities.

Accessibility and usability: The user interface is intuitive and accessible to various users, guaranteeing the availability of alerts and information for those interested.

Durability and resistance: The system has proven to be resistant to adverse weather conditions, making it appropriate for implementation in outdoor environments.

Risk and damage reduction: Successful system implementation can significantly reduce flooding risks and impacts, minimizing material damage and human losses.

Cost-benefit assessment: A cost-benefit preliminary evaluation has been carried out, highlighting that, although the initial investment is considerable, the benefits in lives saved and harm avoided outweigh the long-term costs.

In summary, this early warning system for flood monitoring and detection constitutes a significant advance in protecting communities against flood risks. Combining advanced technology with a reliable, affordable system can save lives and reduce flood damage. However, ongoing implementation, training, and maintenance efforts are needed to ensure its long-term effectiveness.

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