Research paper

Self-sustainable early warning system in river currents

Sistema auto sostenible de alerta temprana en corrientes fluviales

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Abstract

*Half of **all** natural disasters are due to floods of all kinds, leaving thousands dead and injured, as well as costly material damages. An early warning system (EWS) is an important tool to reduce disaster risk, but requires components that allow rapid communication and effective response.. Contribution of advanced technology has been fundamental in the prevention of catastrophes, but unfortunately its high cost, among other factors, does not allow its coverage to reach developing countries or to communities in areas of greater vulnerability. This was clearly evident in Colombia, where EWS exists for large-scale phenomena, but where river floods in poor municipalities meant the country's greatest tragedies in recent years. Hence the importance of designing the self-sustaining early warning system in river currents, since it combines state-of-the-art but low-cost technological elements, allowing it to operate autonomously from alternative energy sources, continuously and accurately measure the fluvial current level, and send real-time alert signals very fast and efficient wireless communication protocols via. Construction of a prototype of the system **making** it possible to test and verify the functionality and efficiency of the monitoring stations, both in accuracy and speed in measures of increasing water levels, as well as in the rapid communication of alerts to an end user, through cell phone text messaging.*

Keywords: *Early warning system (EWS), River floods, Monitoring station*

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Resumen

La mitad de los desastres naturales se deben a inundaciones de todo tipo, dejando miles de personas fallecidas y damnificados, así como costosos daños materiales. Un sistema de alerta temprana (SAT) es una importante herramienta para reducir el riesgo de desastres, pero requiere de unos componentes que permitan una rápida comunicación y la reacción eficaz de las personas en peligro. La contribución de la tecnología avanzada ha resultado fundamental en la prevención de catástrofes, pero infortunadamente su alto costo, entre otros factores, no permite que su cobertura llegue a países en vía de desarrollo ni a comunidades en zonas de mayor vulnerabilidad. Esto se evidenció claramente en Colombia, donde existen SAT para fenómenos de gran escala, pero donde las inundaciones fluviales en municipios pobres significaron las mayores tragedias del país en los últimos años. De ahí la importancia del diseño del sistema auto sostenible de alarma temprana en corrientes fluviales, puesto que combina elementos tecnológicos de última generación, pero de bajo costo. Permitiéndole operar autónomamente a partir de fuentes alternativas de energía, medir continua y precisamente el nivel de corrientes fluviales, y enviar señales de alerta en tiempo real por medio de protocolos de comunicación inalámbrica, muy rápidos y eficientes. La construcción de un prototipo del sistema permitió realizar pruebas y verificar la funcionalidad y eficiencia de las estaciones de monitoreo, tanto en exactitud y velocidad en las medidas de niveles crecientes de agua, así como en la rápida comunicación de alertas a un usuario final, mediante mensajes de texto de telefonía celular.

Palabras clave: *Sistema de alerta temprana (SAT), Inundaciones fluviales, Estación de monitoreo*

1. Introduction

Worldwide, floods are the most common natural disaster with 47% from 1995 to 2015; they have affected 2.300 million people and have caused the death of 157.000 people. 40% of the deaths from this disaster are due to storms, and 89% have happened in underdevelopped countries. The catastrophic floods account for 7% of deaths worldwide [1]. In Colombia, between 2006 and 2014, 19% of its population was affected by floods, with Antioquia being one of the most affected areas, with 5.2% of the victims of the country and the highest number of deaths due to floods and landslides: 586 deaths [2].

Flash floods often happen with few warnings, and are likely to cause secondary disasters such as landslides and debris flow. They are characterized by a rapid increase in water levels that causes a threat to the exposed lives [3]. They are usually caused by torrential rains, especially in small mountain basins, but also by the breakage of dams or levees, landslides, or even by ice blocks in rivers during winter months [4]. Likewise, impervious surfaces, such as concrete or compacted soils, together with the alterations suffered by natural drainages, create instantaneous high-energy runoff that can flood roads and buildings with great speed [4]. Floods in urban areas are a serious problem, more and more frequent, as cities grow and expand [4].

Predicting floods is complicated, since it depends on a complex mixture of components: rain, soil moisture, recent flood history, among others [5]. An early warning system is a key tool to reduce disaster risk. It prevents the loss of human lives and reduces the economic and material impact of natural disasters. To be efficient. Early warning systems must effectively disseminate alerts and warnings [4] [6].

The contribution of the technology in disaster prevention has been remarkable, as are the satellite images for the mapping of risk areas and monitoring of typical storms. However, closer, cheaper and more affordable surveillance systems are required for vulnerable areas in low-income populations [5].

Among the studies found related to the early warning systems in floods, very similar methodologies are observed, where the concept of sensor networks with wireless communication is recurrent, but with the application of technologies that vary in their scope and complexity. Thus, for example, in the works of Krzhizhanovskaya and Pengel [7][8], which are part of the UrbanFlow Project, advanced computational systems are shown to model, simulate and predict precisely levels instability and flood propagation, from measurements at stations located at critical points in large areas, equipped with real-time sensors, and under internet-based applications. The most widely wireless communication protocols used between the measurement stations are the GSM (Global System for Mobile communications) and the GPRS (General Packet Radio Service) [7][8][9][10]. The SMS text message (*Short Message Servic*e) is the most used way of communication for more than a half of the world´s population [11].

Now, most flood level systems depend on the satellite to predict flood data, however, it is necessary to have a system that automatically reads the data on the site and sends an alert instantly [11]. This system detects the rise of the water level, in addition to other variables such as temperature, atmospheric pressure and rainfall, and sends alerts when there is still time to act [10].

The water level can be measured with different types of sensors and processing units. The work of Sunkpho [12] uses devices that integrate pressure sensors and Doppler Effect in the same unit, whose data is sent to a server via GPRS.

In the system presented by Subramaniam [10] a PLC (Programmable Logic Controller) is used, which communicates by GSM with remote ultrasound sensors, and sends SMS messages to the affected community, when the water level exceeds a critical level.

Chowdhury [9] also uses ultrasound sensors for its network of sensors along a river. Each sensor is located inside a vertical PVC tube, facing the surface of the water. On the sensor, at the top of the tube there is a box containing the GSM communication and processing unit. The system is completed with flood prediction software.

Other systems, however, use simpler but very effective warning methods. Thus, for example, in the work of Azid [11], an "Arduino Uno" microprocessor reads the signal from a pressure sensor that is on the top of a vertical tube, where the trapped air is compressed while the level of water inside the tube rises. Then, a GSM module is used to send SMS messages, providing timely information to the threatened population.

In the works mentioned here, the energy to keep the warning systems running is taken from the commercial electric power network, and in some cases, it is backed by a UPS (Uninterruptible Power Supply) [10]. However, most people agree that independent power systems of the electricity grid are required, especially for remote areas.

1.1 Generalities of the Early Warning Systems (EWS)

An EWS is a set of capacities needed to generate and disseminate warning information in a timely and meaningful manner, in order to allow individuals, communities and organizations at risk to prepare and act properly, and with enough time in advance to reduce damages and losses [13]. It consists in the rapid transmission data that activates alarm mechanisms in a previously organized and trained to react population [14].

Among the benefits of an EWS can be mentioned:

- They allow to act on time and in an appropriate way in case of emergencies.
- They reduce the possibility of human loss and damage to property or livelihoods.
- The information that is collected in databases allows to simulate flood scenarios and their possible results (allows to anticipate real emergencies).
- They create awareness in the populations about the need to initiate disaster reduction activities.
- They allow the strengthening of community organization with the participation of local authorities and neighbors in the event of possible emergencies [15].

According to the International Strategy for Disaster Reduction, ISDR, an EWS necessarily comprises five fundamental elements:

- **Risk knowledge:** What the threats and vulnerability to which they are exposed are.
- **Observance and monitoring:** Data collection and continuous monitoring of parameters and aspects that preceded the threats.
- **Threat analysis and forecasting:** Have a solid scientific basis to assess, anticipate and prevent threats.
- **Communication or dissemination of alerts:** Notices must arrive on time and in a clear and understandable way to people in danger.
- **Local capacities to respond to the alert received:** It is very important that the communities understand the danger, respect the alert and know how to react [4][6].

A weakness or failure in any of these elements results in the entire system failing [14]. An EWS is as effective as the actions it catalyzes. The action is an essential part of any warning system. If an alert is issued, and nobody takes the actions that the EWS was geared to trigger, then the warning system has failed [13][6].

The decrease in disaster losses over the past 30 years is due in part to the improved early warning systems, many of them "high tech". However, the population is essential to ensure that the information and the alerts captured by satellites, computer models and that the other technologies reach the most vulnerable communities, and who can then act on that basis. Anticipatory warnings alone do not prevent threats from becoming disasters [13].

Before floods, there are two types of EWS:

Centralized systems. They use information from satellites, remote sensors and telemetric networks. They can capture data from the earth's surface without the need for direct contact. They usually have high costs.

Community systems. They are easy to use because their instruments are basic and do not require specialists to read, record and transmit data. They are based on the active participation of volunteers from the communities. They are more sustainable due to their low costs [15].

EWS are processes that work all the time, since this depends on their capacity to inform about the imminence of a danger with short time in advance, and they must be continuously improved, learning from previous experiences [15].

It should be understood that an EWS is much more than a measuring instrument, or communication, or than scientific knowledge for forecasting threats and issuing alerts. Achieving the long-term operational sustainability of an EWS requires political commitment and lasting institutional capacity, which in turn depend on public awareness and appreciation of the benefits of an effective EWS [14][6].

1.2 Early Warning Systems in Colombia

Colombia, through agreements with the United Nations, belongs to international networks for the forecasting and warning of different natural phenomena, and since the 1960s has implemented hydro meteorological monitoring networks, within the framework of the World Meteorological Organization, WMO [16].

There are national EWS for large-scale phenomena, managed by national entities such as the IDEAM - Instituto de Hidrología, Meteorología y Estudios Ambientales, DIMAR - Dirección General Marítima, OSSO - Observatorio Sismológico y Geofísico del Suroccidente and SGC - Servicio Geológico Colombiano.

Some regional systems installed by the CAR - Corporaciones Autónomas Regionales such as the SIATA - Sistema de Alertas Tempranas del Valle de

Aburrá. Other large cities such as Bogotá and Manizales have developed complementary warning systems for the monitoring of threats of natural origin [16].

However, the recent floods in Mocoa (Putumayo) in 2017, with 166 deaths, and in Salgar (Antioquia) in 2015, with 104 deaths, and thousands of victims of these and other tragedies, remind us that efforts are still needed in areas of less favored populations. The country is very diverse and complex, and many of the catastrophic phenomena have very small characteristics that are not reflected in the national monitoring and forecasting systems, so it is necessary to look for alternative measures that allow the populations to be safe from the sudden floods and other natural phenomena.

1.3 Self-sustainable early warning system in river currents

The main objective of this project was the design of an early warning system powered by alternative energies, which allows monitoring abnormal levels in fluvial currents in real time and transmitting alerts via wireless, to help prevent disasters caused by avalanches and floods [5].

2. Materials and methods

The self-sustaining early warning system is conceived as a chain of monitoring stations along a river current, developed with cutting-edge technology and low cost, both in its implementation and in its maintenance. It was proposed to use solar radiation as an energy source, so that each station works autonomously, since they were designed so that they can be located on the riverbank, in remote areas or areas that are difficult to access.

With its own solar power system, each station makes measurements of the water level of the fluvial flow every certain time (initially a sampling time of one minute was programmed). The stations operate independently, but can communicate with each other via wireless, using the ZigBee protocol (XBee modules). The total number of stations will depend on the length of the fluvial flow to be monitored, and the conditions of the terrain, since there could be obstacles that interfere in the communication between the monitoring stations. In this way, the chain of stations forms its own communications network, as shown in Figure 1.

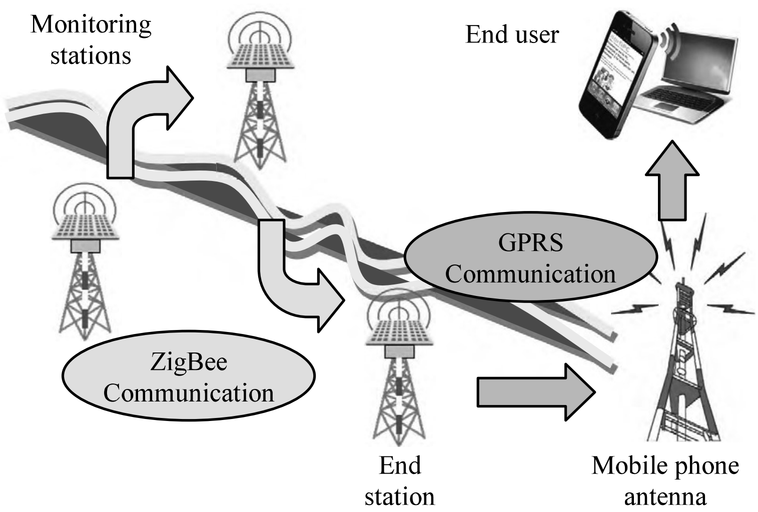

FIGURE 1. SCHEME OF THE SELF-SUSTAINABLE EARLY ALERTS SYSTEM IN RIVER CURRENTS.

SOURCE: OWN CONSTRUCTION.

Additionally, the last station in the chain, the closest to a populated area, has a GPRS communication module to connect to a mobile telephone antenna and send a message to the end user.

2.1 Development of the prototype of the monitoring stations

To test the self-sustaining early warning system in river currents, a prototype was built with two models of monitoring stations: one basic, only with ZigBee communication, and another with the additional GPRS communication module.

Each of the stations has three subsystems that make it up. The first is the central card, responsible for controlling the station and sending the warning signals, either to the next monitoring station in the chain, or to the mobile telephone antenna if it is the final station. The second is the sensor and the structure for measuring the water level, and the third is the solar power source (Figure 2).

2.1.1 Central card (control and communications)

The main card is an Arduino Mega 2560, which has the possibility of adding more modules (shields). In this case, for the wireless communication, an XBee PRO module was used, which is directly coupled to the Arduino card, and once programmed it will allow the work of communication between the stations of the system (Figure 3). In addition, a GPRS communication module (SIM800L card) is added to the last station.

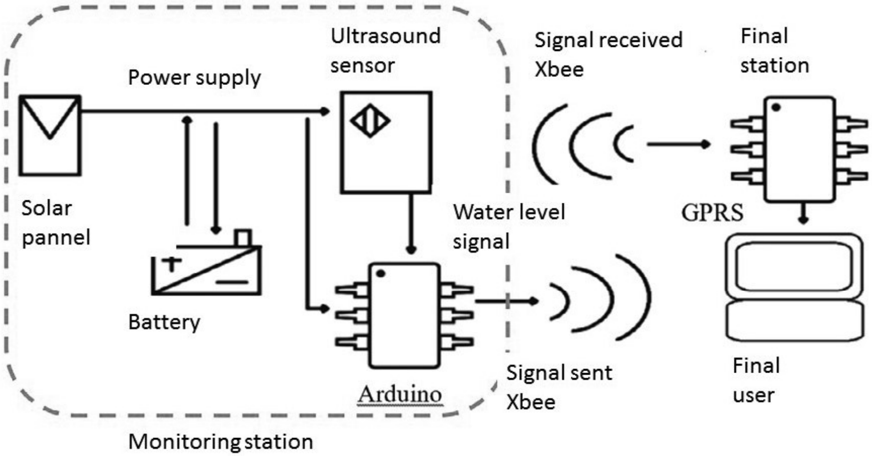

FIGURE 2. GENERAL SCHEME OF COMPONENTS OF A SYSTEM MONITORING STATION.

SOURCE: OWN IMAGE.

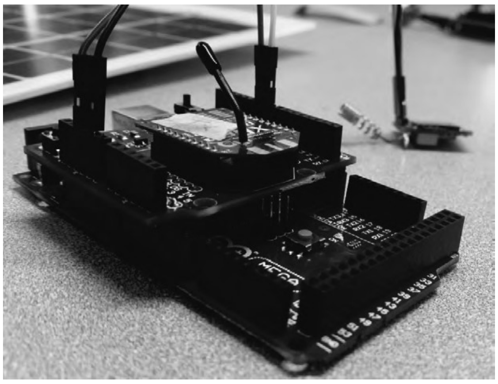

FIGURE 3. XBEE COMMUNICATION MODULE (TOP PLATE) FOR ARDUINO MEGA 2560 (BOTTOM PLATE).

SOURCE: OWN PHOTOGRAPHY.

The Arduino and the modules share two communication pins RDX and TDX. The SIM800L has a port to insert a SIM card (Subscriber Identification Module card) of a telephone operator that has coverage in the monitored area (Figure 4).

The data supplied by the sensor are taken and compared by the Arduino; if a critical or risk level is detected, an alarm signal is sent by means of the XBee communication module to the next station in the chain, and this in turn to the next, until arriving at the last station, equipped with a GPRS communication module. Whenever there is a signal of coverage, an SMS with the alarm will be sent to an end user (Figure 5), or to a service center, for the corresponding monitoring of the river current.

The programming of the Arduino was done in the language of the Arduino IDE program version 1.8.5.

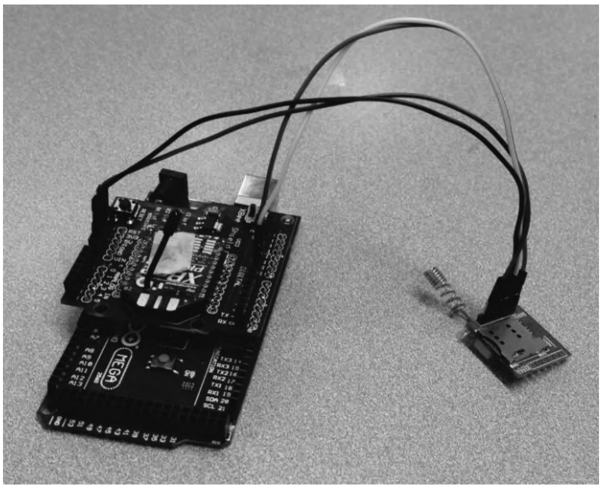

FIGURE 4. ARDUINO MEGA 2560 (ON THE LEFT) CONNECTED TO THE SIM800L (ON THE RIGHT).

SOURCE: OWN PHOTOGRAPHY.

FIGURE 5. EXAMPLE OF A TEXT MESSAGE (SMS) SENT BY MEANS OF THE GPRS MODULE.

SOURCE: OWN PHOTOGRAPHY.

2.1.2 Water level measurement

To measure the water level of the fluvial stream to be monitored, an ultrasound distance sensor reference HCSR04 was used, which emits an ultrasonic signal (at approximately 40kHz), receives the produced echo and converts it into an electrical pulse, whose duration is the time between the emission pulse and the echo impulse (Figure 6). This proximity detector works free of mechanical friction and detects objects at distances between 2 cm and 450 cm, with a resolution of 0,3 cm. Its connection is very simple, respecting other level sensors, since it only has four wires, two for power and two for signal. The Arduino card communicates with the ultrasonic sensor by means of an output pin, to send it a pulse (greater than 10µs) to start the measurement, and another input to receive the return pulse delivered by the sensor. The read signal and the calculation of the distance made by the Arduino, allows being very precise in the measurement of the water level, detecting changes of level less than 1 cm, in less than 1 ms.

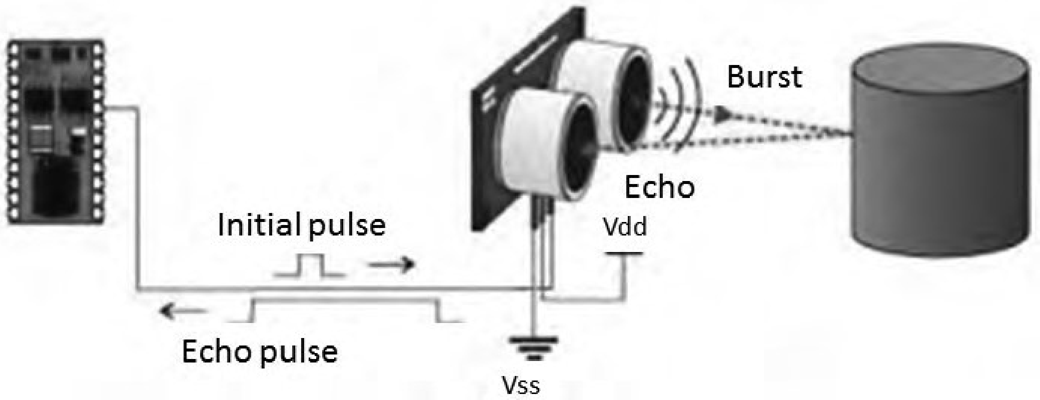

FIGURE 6. PRINCIPLE OF OPERATION OF THE ULTRASONIC SENSOR

SOURCE: HTTP://SEBALABS.BLOGSPOT.COM.CO/2015/09/ARDUINO-08-MEDIR-DISTANCIA-CON-SENSOR.HTML

To reduce the interference in the measurement, the sensor will be located on the top of a PVC tube of 6,35 cm (2,5”) in diameter and 1,5 m in length, whose lower end will have perforations and will be in contact with the river current.

2.1.3 Energy supply

In order to feed each station in a self-sustainable way, clean technologies were also considered, a solar panel (photovoltaic) was chosen to support a 7.4 V / 1300 mAh double cell battery (3.7 V per cell). The panel used is from 18 V to 0.28 A which provides a maximum power of 5 Watt (Figure 7).

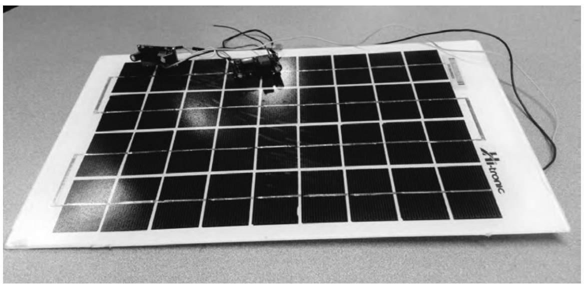

FIGURE 7. PHOTOVOLTAIC PANEL OF 5W.

SOURCE: OWN PHOTOGRAPHY.

The output voltage of the panel is connected to a regulator, which delivers a voltage of 3,7 V to power each of the cells of the battery. From the sum of the voltages of the two cells, a total of 7,4 V is obtained at the battery output. According to the specifications of the manufacturer, the battery needs between 2 and 3 hours to make a total charge, and it is discharged in 15 hours. The discharge is much slower than the load, since the current supplied from the battery to the device is much smaller than the one supplied in the charge.

The battery voltage will not have any problem to power the Arduino card, since it works between 5 V up to 24 V; the other elements are connected to the card, and this in turn will supply the necessary voltage and current. With the ultrasonic sensor there was no problem since its power is at 5 V (Figure 8).

For the SIM800L card, the working voltage is between 3.4 V to 4.4 V. As the Arduino card has only two power supplies of 3 V and 5 V, a diode was added to the output of the 5 V so that the voltage drops to 4.3 V.

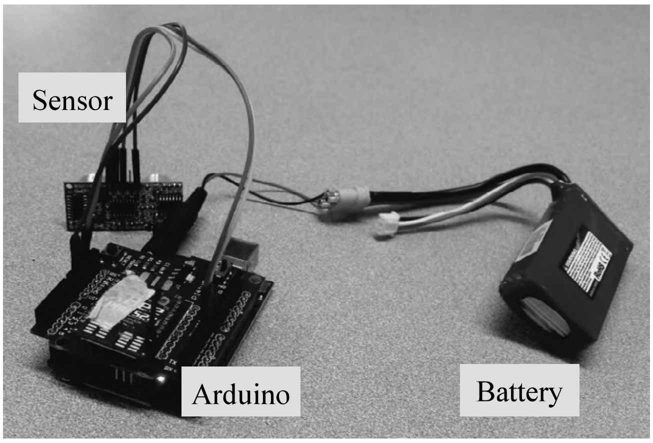

FIGURE 8. BATTERY DUAL CELL OF 7,4 V CONNECTED TO THE ARDUINO MEGA 2560.

SOURCE: OWN PHOTOGRAPHY.

2.1.4 Completing the monitoring station prototype.

To contain and protect the electronic assembly against shock, it was decided not to make a box of extremely solid consistency. A stainless steel box with polyethylene inner walls was used, which allows better shock absorption than other solid materials (Figure 9).

In the upper part of the box, the solar panel is installed horizontally, and the whole assembly is located on the PVC pipe of the measurement stage, surrounded by a support structure for field installation. Figure 10 shows the final appearance of the prototype of the monitoring station of the self-sustainable early warning system in fluvial currents.

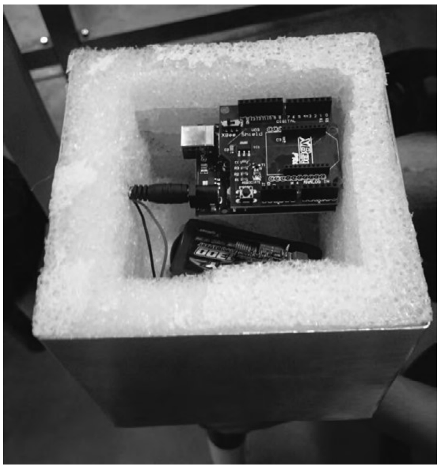

FIGURE 9. INTERNAL STRUCTURE OF THE PROTOTYPE OF THE MONITORING STATIONS.

SOURCE: OWN PHOTOGRAPHY.

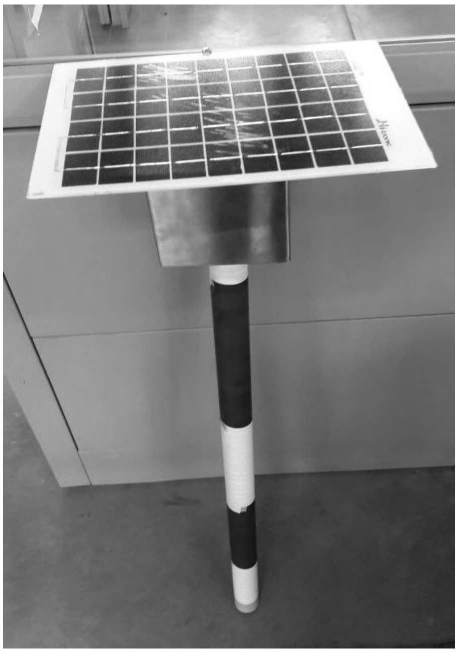

FIGURE 10. FINAL APPEARANCE OF THE PROTOTYPE OF THE MONITORING STATIONS.

SOURCE: OWN PHOTOGRAPHY.

3. Results and discussion

Worldwide, the flood control standards of major rivers have been significantly improved; however, flood problems of medium and small rivers, especially the risk of flash flooding in small mountain basins, has become increasingly serious [3]. This is why the self-sustaining early warning system presented in this paper was designed thinking that it could be implemented in remote areas, with populations of low economic resources and whose national EWS coverage is scarce or nonexistent; that is, for the most vulnerable populations.

The implementation of a chain of monitoring stations along the river stream has the purpose of monitoring the increasing water level at critical points, and sending an alarm signal before the water rises and the possible flood arrives at a population at risk. In this sense, the ideal is to have monitoring stations as far as possible, upstream, to have more reaction time. That is why there was also the need to have power and communication systems that did not depend on urban networks, and on the contrary, they could operate efficiently away from electricity networks and telephone antennas. The total number of stations will then depend on the length of the fluvial flow to be monitored and the conditions of the terrain, since there could be obstacles that interfere in the communication between the monitoring stations.

From the point of view of the components of a EWS, the work presented here focuses on the stages of monitoring and communication of alerts by the EWS.

Unlike other developments referred to in this article, the design of the monitoring stations is focused on an Arduino card, and not on a PLC or a server whose processing capacity is greater, but which makes the EWS very expensive and complex. Although the system with Arduino is simpler and cheaper, it does not mean that it is of low quality. In fact, it is an advanced electronic system that allows great versatility and variety of tasks. In particular, it permits the proposed monitoring stations a high speed in the reading and processing of the water levels, and in their subsequent transmission via wireless, to the point of being able to send a water level data every 5 ms or less.

The use of the ultrasonic distance sensor HCSR04 has advantages such as small size, it is very economical, and the non-contact with the water surface, which translates into easy installation and minimal maintenance, in addition to its aforementioned measurement accuracy. The disadvantage compared to those of other systems referred to, may be limited in scope to about 4 m distance, but taking into account that the water level measurements will be done upstream, when the crescent just begins, this range can be enough.

The wireless communication through the XBee modules (ZigBee protocol), converts each monitoring station into an antenna and thus configures a communication network independent of the GSM, GPRS or satellite system used in other EWS. Only the last station, the closest to the population at risk, under the coverage of mobile telephone antennas, is equipped with an additional GPRS communication module, to send an SMS message with the alert to an end user or a service center [5]. This is also a dedicated network, so the alarm signal goes directly to the final station, without the need to transfer to "routers" or other intermediate elements. Theoretically, ZigBee achieves transmission speeds of the order of 1 Mbps and with GPRS of 50 Mbps [5]. The maximum distances between the stations will depend on the XBee modules used. The most common allow distances less than 1km, but there are modules for communications up to 24 km.

On the other hand, the disadvantage of the communication network obtained with respect to the other EWS is that it depends on only one form of communication, and a failure in one of the monitoring stations could interrupt the communication to the end user.

The water level measurement tests, as well as the communication between the two models (Basic Station and Station with GPRS) of the built prototype, were made at the laboratory level in facilities and green areas of the IU Pascual Bravo.

In the basic station model, the distance tested from the sensor to the water surface inside the PVC pipe, submerged in turn in a pond to simulate the rise of the water level of a river current, was the range of 5 to 150 cm, with errors less than 2%.

For the communication test, the two models of monitoring stations were separated at a distance of approximately 30 m, a SIM card of the telephone operator UNE-TIGO was used, and the station was configured with GPRS to send an SMS with each data received from the basic station. As a result, an immediate response was observed in the transmission of the basic station, which made the water level measurement every minute, towards the station with GPRS. However, the arrival time of the SMS message to a previously selected mobile phone was very variable. In some cases, the response was a few seconds, but there were moments where it took more than 1 minute.

This is explained by the telephone network congestion of the selected operator.

In the Colombian case, because it is located near the equatorial line, the main climate is tropical, which means that most of the territory, with the exception of some mountain peaks, "is hit directly by the rays of the sun and the average energy that radiates on Colombian soil is 3000 W/m^2 " [17]. Which is an advantage for solar panels, since they only need 1000 W/m^2 to supply the total power it generates.

During the hours of highest incidence of the sun (12 am to 3 pm), the panel will be able to deliver its power to 100%; for the hours with lower solar incidence, the panel will deliver a percentage depending on the power with which the sun radiates it.

Finally, it is important to complement the system by detailing the characteristics of the location of the monitoring stations, thresholds of the fluvial current levels (knowledge of the risk), and the development of computer programs together with the sending of traffic light alerts (alert green, yellow, orange and red) for analysis, forecasting and disaster prevention. Logically, the work and training of the beneficiary communities is essential for the EWS to be complete.

With the messages and data that will arrive to the command center, or to the default telephone of the user, a detailed follow-up of the tributary can be made and generate historical of the growth of the rivers, both in times of rain and in times of sun. This data, combined with other meteorological data, can be used with software applications to predict possible flooding.

A catastrophe can occur in a matter of hours or minutes. The state-of-the-art technology and the wireless transmission of the designed system, provide reliability and security, since they have the capacity to transmit data in real time in a very efficient and faster way than with other systems.

Although, the network of [12] the proposed system does not depend on the internet service, the sensors used are more economical. [12] they use a UPS, and do not have alternative power. The network is in a flood area and this system follows a current.

4. Conclusions

With the self-sustainable early warning system for river currents, continuous monitoring can be carried out in real time, at low cost, at specific points along a fluvial stream, allowing the identification of critical water levels and efficient alerting of possible overflows, and floods, thus preventing a catastrophe.

Each monitoring station of the designed system has a mega Arduino card as a central element; it is in turn an antenna for the Xbee-GPRS communication network. It operates autonomously from a power source with a 5W solar panel and a battery of double cell of 3.7V/1.18A, and continuously measures the water level of the monitored fluvial stream, by means of an ultrasonic sensor, with a range of up to 1.5 m.

When exceeding a water level limit measure, an alert signal is transmitted by each of the stations by means of Xbee modules and in a range up to 1 km. The last station, close to the population at risk, uses a module GPRS to send a text message (SMS) to a cell phone of a call center.

In general, an early warning system was designed for abnormal levels in fluvial currents, with a self-sustainable, economical, efficient and reliable feeding, able to detect a flood risk and give an alert before a catastrophe occurs.

The designed network of water level monitoring stations can, in the future, be improved and combined with the measurement of other hydro-meteorological variables, as well as with computer analytical programs, to make it a much more complete and reliable disaster prevention system.

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