NUNCA CHOVEU QUE NON ESCAMPARA

1. INTRODUCCIÓN

During the 2010s, more than 430,000 people have died around the world as a result of natural disasters. Among these, floods have taken the highest number of lives. This is why we consider it necessary to have a system that is designed to indicate in good time when the ideal conditions for flooding are present, thus preventing the secondary effects of floods. In this way, the collateral effects that floods bring with them can be minimised as much as possible, affecting the population with considerable material and sometimes personal damage.

“Nunca choveu que non escampara” consists of the design of a prototype station that controls the flow and level of water at specific points in the water basin of the area to be monitored. Developed with Arduino, it allows monitoring critical situations caused by these natural disasters and, in this way, warns when the situation of torrents and streams approaches risk levels and can lead to flooding.

In addition, our project also investigates the geographic and geological aspects that imply a higher risk of flooding for a specific area. To this end, an algorithm has been developed to predict the level of risk in a given catchment area.

The monitoring is completely wireless and has two stations, a transmitter responsible for collecting the aforementioned data and a receiver that displays and processes this information indicating the high or low risk of flooding. They are autonomous stations contained in waterproof, 3D printed structures.

2. BACKGROUND INFORMATION

A natural disaster is defined as any catastrophic event caused by nature or the earth's natural processes. The severity of a disaster is measured in loss of life, economic loss and the population's ability to rebuild. Natural disasters that actually affect people around the world tend to be of greater magnitude as the years go by. In some areas, people are not prepared for the eventuality of disasters, building hurricane or tornado shelters, for example, but property loss remains a problem and predicting many natural disasters is no easy task. Thus, there are different types of natural disasters, which are divided into four groups

- Hydrological: all those originating in water, seas and oceans. Examples are floods, tsunamis or strong waves.
- Meteorological: these are due to variations in the weather. Typhoons, cold fronts or tornadoes, among others, are some examples of this type of disaster.
- Geophysical: those that are formed or arise from the bowels of the planet or the earth's surface, such as avalanches, earthquakes or volcanic eruptions.

- Biological: these are caused by some special circumstance within the animal kingdom and affect the environment and mankind. The most important is the so-called red tide. Other examples are pests, epidemics or infections.

Floods, considered a hydrological disaster, are defined as water overflowing onto different types of land, and can occur due to heavy rainfall, storm surges or dam and dyke failures. According to the World Meteorological Organisation, floods have caused millions of deaths globally. The Atlas of Mortality and Economic Loss Caused by Extreme Weather, Climate and Water Events indicates that 79% of natural disasters are due to extreme weather or water events, caused by intense storms and the overflowing of rivers or ravines. This caused 55% of deaths and 86% of major economic losses during the period between 1970 and 2012.
Buildings, highways, motorways, avenues or roadways increase runoff by reducing the amount of rainfall absorbed by the ground, so runoff increases the potential for flash flooding. Likewise, mountains and steep hills multiply runoff, causing streams and rivers to rise rapidly, contributing to the occurrence of natural floods. Rain-saturated soil also creates and reinforces the occurrence of flash floods.

The most serious floods in Spain in recent decades are the Vallés floods, a series of floods that caused the greatest hydrological catastrophe in the history of Spain on 25 September 1962. It occurred in Barcelona due to heavy rainfall (more than 250 l/m2) that overflowed the Llobregat and Besós rivers, causing a torrential flood of water that caused between 600 and 1000 victims, thousands of injuries and several billion in losses over a period of between one and a half and three hours.

On the other hand, the flood of 19 October 1973 is considered to be one of the worst known on the Iberian Peninsula. Rainfall in the order of 600 l/m^2 was recorded in Almería and also in Granada. The Guadalentín reached a maximum flow of 3000 m^3/s and the water reached a height of 15 metres. As a consequence, there were numerous fatalities and several municipalities were devastated.
Another flood of note is the one that occurred in the Pantano de Tous. Thirty-six years ago, one of the worst cold drops in the history of the Valencian Community occurred, breaking rainfall records in Spain and taking the lives of around 40 people. On 20 October 1982, the provinces of Valencia and Alicante suffered one of the worst floods in their history. It is estimated that on that day the rains left more than 1,000 l/m2 accumulated in Muela de Cortes.

We live in A Coruña, Galicia, specifically in Ponteceso, a small town built on the marshes of the river Anllóns, consequently, every time the level of the river rises, the town floods. It should not be forgotten that it is the village itself that is built on a river, so it is impossible to avoid the action of nature, but the population could be warned and alerted to the risk of flooding in order to reduce its secondary effects.
The river Anllóns flows into an environmentally protected dune area. However, from 1960 onwards, with the construction boom, sand began to be removed from the river to be used in this area. This led to a change in the course of the river. However, in 1990 these actions ceased to be carried out, so that the sand began to accumulate and became another of the aspects that cause flooding.

The most common prevention measures in Spain are water redirection systems based on protection for doors and windows of all kinds. In order to know when conditions are ideal for overflowing, it is advisable to keep informed of weather forecasts via radio and other media, checking weather forecasts issued by official institutions. The most common are prevention measures in terms of land use and urban planning, the elaboration of technical guides to reduce the vulnerability of exposed elements in flood-prone areas, promoting the adaptation to flood risk of different economic sectors, with the aim of increasing the perception of risk among the population and improving their self-protection strategies. The continuous cleaning of river banks also reduces the risk of flooding. However, no economic systems have been found to predict floods before they occur. Once houses are flooded, water pumps are used to remove them.

3. PROJECT ASSUMPTIONS AND OBJECTIVES

3.1. Project assumptions

It is possible to reduce the secondary effects of floods through the creation of an algorithm that processes the data collected by two stations placed over a river basin. This makes it possible to warn the population in order to reduce the damage caused by floods.

3.2. Objectives

The project has three main objectives. On the one hand, to determine the ideal meteorological conditions in which floods occur in order to develop a flood prevention protocol. On the other hand, to design a prototype capable of launching an alert when risk levels increase above certain limits. These are studied with the aim of developing an algorithm to automatically establish these parameters for the area under study. Prototypes of stations are also developed in which to place the sensors to be used, which are designed and printed in 3D.

4. MATERIAL Y MÉTODOS

4.1. Materials

In order to carry out this work, a series of sensors were programmed with Arduino. These sensors are used to collect the necessary information to warn of the risk of flooding.

Station boards and sensors:

- Arduino boards
- Dupont connection cables
- Ultrasound sensor HC-SR04, which measures the distance to the water.
- Temperature and humidity sensor DHT11
- LEDs for simulating the warning system.
- LCD screens displaying the data collected by the above-mentioned sensors.

○ NRF24L01 transmitting sensors in a 2.4 GHz frequency band, by means of which the above data is sent and received.
o SD card reader

Housing design:
○ Artillery Genius 3D printer for printing the housings containing the Arduino connection.
○ PLA and PETG filament
○ Transparent vinyl

4.2. Methodology

The methodology is divided into three parts. Firstly, the hydrography of the area in question is studied. Next, a technological system for monitoring river levels is developed. Thirdly, an algorithm is developed which, based on the data collected in the first two phases, is capable of indicating when the given conditions imply a risk of flooding.

- Study of the hydrography of the area

For the study of the hydrographic basin, we began with the compilation of information, through popular memory and the search for writings, on the various floods and their level of risk over the years. Once this information was known, a search was carried out for information on the lithological, climatic, topographical and anthropic factors that influence floods, such as the type of rock, rainfall-drought or the slope of the land.

On the one hand, lithological factors, i.e., the type of rock over which the river flows, influences what is known as the runoff coefficient, which is known as the ratio between the part of the precipitation that circulates on the surface and the total precipitation, understanding that the surface part is less than the total precipitation when evaporation, evapotranspiration, storage, etc. are discounted. Thus, the more permeable the type of rock, the lower the surface precipitation, and vice versa, the lower the permeability, the higher the river flow. However, as can be seen in Figure 1, the runoff coefficient can be calculated for very specific areas but not for large areas where the slope and rock type of the terrain vary.

Coeficiente de escorrentía (Zonas Rurales).

Cobertura Vegetal	Permeabilidad del Suelo	Pendiente del Terreno				
		Pronunciada	Alta	Media	Suave	Despreciable
		>50%	>20%	>5%	>1%	<1%
Sin Vegetación	Impermeable	0,80	0,75	0,70	0,65	0,60
	Semipermeable	0,70	0,65	0,60	0,55	0,50

Figure 1: Runoff coefficient (Rural areas). Font: *Tutoriales al día - Ingeniería civil*. https://ingenieriacivil.tutorialesaldia.com/todo-lo-que-necesitas-saber-sobre-el-coeficiente-de-escorrentia/

Climatic factors, on the other hand, refer to the seasons of the year as well as changes in rainfall, rainy-drought periods, for example.

Topographic factors refer to the slope of the terrain, which influences the speed of the water: if the slope is <2%, the flood is classified as static, if it is >2% and <6%, it is dynamic, and if it is >6%, it is called a torrential avalanche. Thus, the most prone to flooding are relatively flat lands, such as those with unconsolidated deposits, loam, sand, silt and gravel strata; other lands subject to periodic flooding are marshy areas, with high levels of humidity in soils with the presence of lakes.

Finally, anthropic factors are those actions produced due to the direct or indirect impact of human societies.

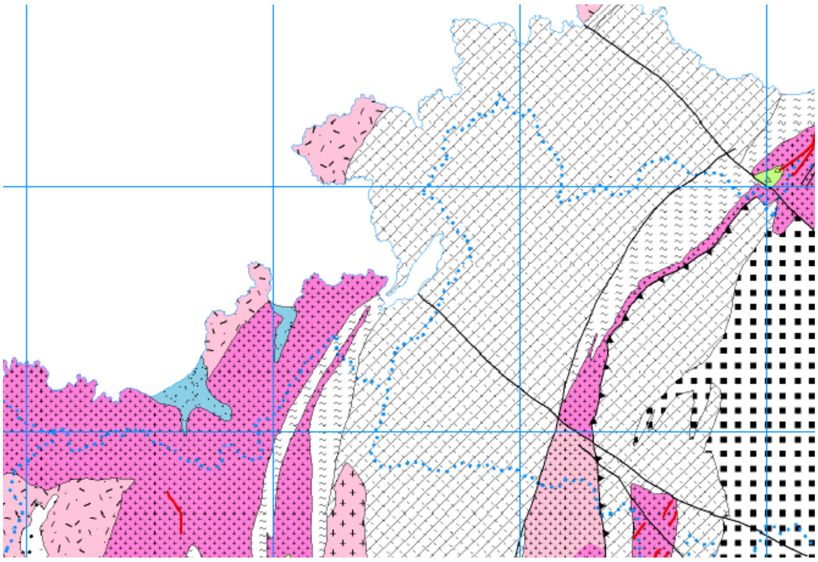

Figure 2: Hydrological map of the studied area. Font: *Mapa Hidrológico de Galicia*. (s. f.). Cartografía de Galicia. http://info.igme.es/cartografiadigital/datos/tematicos/pdfs/MapaHidrogeoGalicia_200.pdf

LEYENDA HIDROGEOLOGICA

TIPO DE PERMEABILIDAD	GRADO DE PERMEABILIDAD	DESCRIPCION	LITOLOGIA	CAUDAL MEDIO DE EXTRACCION (l/seg)
POROSIDAD INTERGRANULAR	ALTA - MEDIA	Formaciones extensas (acuiferos regionales) o locales	Depositos fluviales y depositos Tercirios	10-50 y >100
	ALTA - MEDIA	Formaciones extensas, discontinuas o locales	Aluviales, fluviales, costeros y depositos Terciarios	5-30
	BAJA	Formaciones extensas, discontinuas o locales	Depositos Terciarios y Cuaternarios indeferenciados	0.3-3
FISURACION Y KARSTIFICACION	ALTA - MEDIA	Formaciones extensas, discontinuas o locales	Calizas y dolomias	5-20
	MEDIA - BAJA		Cuarcitas	1-5
POROSIDAD INTERGRANULAR Y FISURACION	MEDIA - BAJA	Formaciones extensas, discontinuas o locales	Granitos muy alterados	1-10
	BAJA		Granitos alcalinos poco alterados, garnitos calcoalcalinos, gneises, migmatitas y metavulcanitas	0.3-3
POROSIDAD INTERGRANULAR Y FISURACION	MUY BAJA - IMPERBEABLE		Pizarras, esquistos, rocas basicas, esquistos-gneises y depósitos Terciarios muy arcillosos	<0.3

Figure 3: Legend of the hydrological map of the study area. Font: *Mapa Hidrológico de Galicia*. (s. f.). Cartografía de Galicia. http://info.igme.es/cartografiadigital/datos/tematicos/pdfs/MapaHidrogeoGalicia_200.pdf

Figures 2 and 3 show that in the area under study the predominant rocks are slate, schist and schist-gneiss, whose porosity is practically nil, making them impermeable materials. Therefore, the runoff coefficient of the area (fraction of water of the total rainfall that actually generates surface runoff once the soil is saturated) is very small, a lithological characteristic that should be highlighted. In addition, the river basin is studied, as well as its average flow.

The probability of a peak discharge event occurring in an area is based on knowing the peak flow, i.e., the maximum volume of water flowing through a sector at a given time. The estimation of this peak flow can be done by empirical methods, by formulae and by statistical methods, which are based on the idea that floods occur with a certain regularity over time and can therefore be treated statistically and require a large amount of climatic and gauging data (at least 30 to 40 values are needed).

Next, an environmental, geographical and geological study of our area of residence (Ponteceso) was carried out as a reference area for the project and development of the risk algorithm, focusing on the mouth of the river Anllóns and the variation of the riverbed over the last decades. This led to the conclusion that the abandonment of the dredgers favoured the stagnation of the sand and, therefore, the variation of the river bed. See the following comparative images in Figure 4, showing the river mouth in the dune area over the last decades.

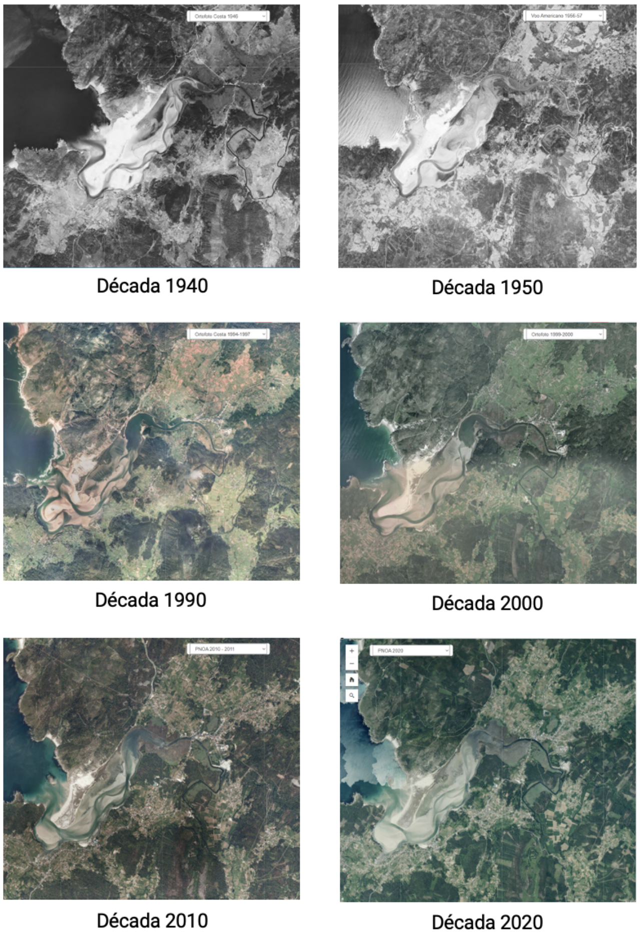

Figure 4: Comparison of the mouth of the river
Font of de figures: *Comparador de entidades cartográficas*. (s. f.-b). Xunta.
https://mapas.xunta.gal/visores/comparador/

- <u>Development of the technological system</u>

Following the search for all the necessary information on flooding in the study area, we proceeded with the development of a technological system that allows for the control of river level variations. In this way, two stations have been designed, the emitting station, responsible for monitoring the water levels, and the receiving station, responsible for processing the data received and indicating the level of flood risk. These stations are placed on the riverbed and allow data to be obtained at the different points studied and described above.

1. Transmitting station

The transmitter station has a HC-SR04 ultrasonic sensor, which is used to measure the distance from it to the water, a DHT11 temperature and humidity sensor and an LCD screen on which the collected data is displayed. Also included is a wireless communication system NRF24L01 with a frequency of 2.4 GHz that allows communication with the receiving station. See Figure 5.

The SR04 sensor has a pair of ultrasonic transducers that are used to determine the distance of the sensor from an object placed in front of it, in this case water. It works by emitting an ultrasonic sound from one of its transducers, waiting for the sound to bounce off an object present (the obstacle) and the echo is picked up by the second transducer. The distance is proportional to the time it takes for the echo to arrive. Knowing that it can reach distances of up to 5 metres, we avoid having to look for a submersible one to put it in the water.

The DHT11 sensor measures temperature and humidity, has high reliability and stability thanks to its calibrated digital signal. It allows us to know better the atmospheric weather of the place since, later, a complete weather station will be added to determine when there will be heavy rains.

The NRF24L01 wireless communication system integrates all the electronics and functional blocks required to establish radio frequency communications between two or more points at different speeds on a single chip. Thus, it is suitable for transmitting the data collected by the ultrasonic sensor and the temperature and humidity sensor to the receiver.

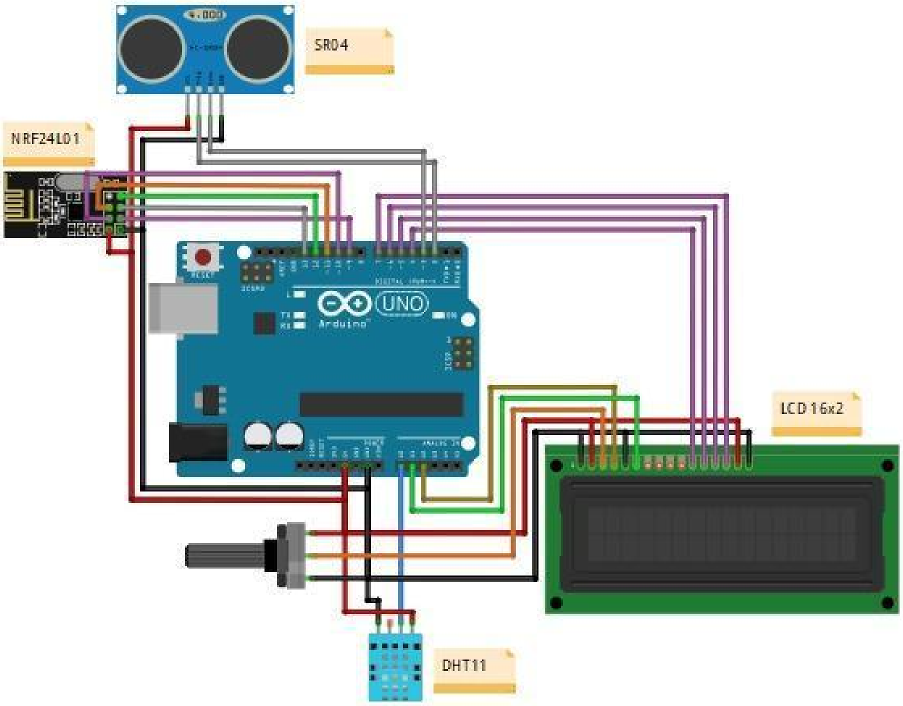

Figure 5: Transmitting station wiring diagram

The code used for the Arduino programming of the emitter module is as follows:

```
//Incluímos todas as librerías
#include <SR04.h>
#include <dht_nonblocking.h>
#include <LiquidCrystal.h>
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>

//Definimos pins
#define DHT_SENSOR_TYPE DHT_TYPE_11
#define TRIG_PIN 2
#define ECHO_PIN 3

//NRF24L01
const int pinCE = 9;
const int pinCSN = 10;
RF24 radio(pinCE, pinCSN);
const uint64_t pipe = 0xE8E8F0F0E1LL;
float data[3];

//DHT
static const int DHT_SENSOR_PIN = 14;
DHT_nonblocking dht_sensor( DHT_SENSOR_PIN,
DHT_SENSOR_TYPE );

//ULTRASÓN
SR04 sr04 = SR04(ECHO_PIN,TRIG_PIN);
long distancia;

//LCD
LiquidCrystal lcd(15, 16, 4, 5, 6, 7);
byte cerito[8] =
{
 0x0E,
 0x0A,
 0x0E,
 0x00,
 0x00,
 0x00,
 0x00,
 0x00
};

byte bateria[8] =
{
 0x0E,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F
};


void setup( )
{
 //NRF24L01
 radio.begin();
 radio.openWritingPipe(pipe);

 //LCD
 Serial.begin(9600);
 lcd.begin(16, 2);
 lcd.createChar(0, cerito);
 lcd.createChar(1, bateria);
 lcd.home();
}

//DHT E ULTRASÓN
static bool measure_environment( float *temperatura, float
*humidade )
{
 static unsigned long measurement_timestamp = millis( );

 if( millis( ) - measurement_timestamp > 500ul )
 {
  if( dht_sensor.measure( temperatura, humidade ) == true )
  {
   measurement_timestamp = millis( );
   return( true );
  }
 }

 return( false );
}


void loop( )
{

 float temperatura;
 float humidade;

 if( measure_environment( &temperatura, &humidade ) == true )
 {
  //MONITOR SERIE
  distancia = sr04.Distance();
  Serial.print( "T= " );
  Serial.print( temperatura, 1 );
  Serial.print( " ºC, H= " );
  Serial.print( humidade, 1 );
  Serial.print( " %, dist = " );
  Serial.print( distancia );
  Serial.println(" cm");

  //LCD
  lcd.setCursor(0,0);
  lcd.print( "T=" );
  lcd.print( temperatura,1 );
  lcd.write(byte(0));
  lcd.print( "C H=" );
  lcd.print( humidade,1 );
  lcd.print( "%");
  lcd.setCursor(0,1);
  lcd.print("Dist=" );
  lcd.print( distancia );
  lcd.print("cm  ");
  lcd.setCursor(15,1);
  lcd.write(byte(1));
  delay (1000);

  //NRF24L01
  data[0] = temperatura;
  data[1] = humidade;
  data[2] = distancia;
  radio.write(data, sizeof data);
  delay(1000);
 }
}
```

2. Receiver station

The receiving station, on the other hand, has another LCD screen that shows the data received, the wireless communication sensor NRF24L01 and a series of LEDs that light up when the level reaches a certain point, studied for each case. The LED system is representative and very visual, however, an early warning system is sought through the use of IOT technology. See Figure 6.

In this case, the NRF24L01 sensor is in charge of receiving the data and the three LEDs are in charge of indicating the level of risk.

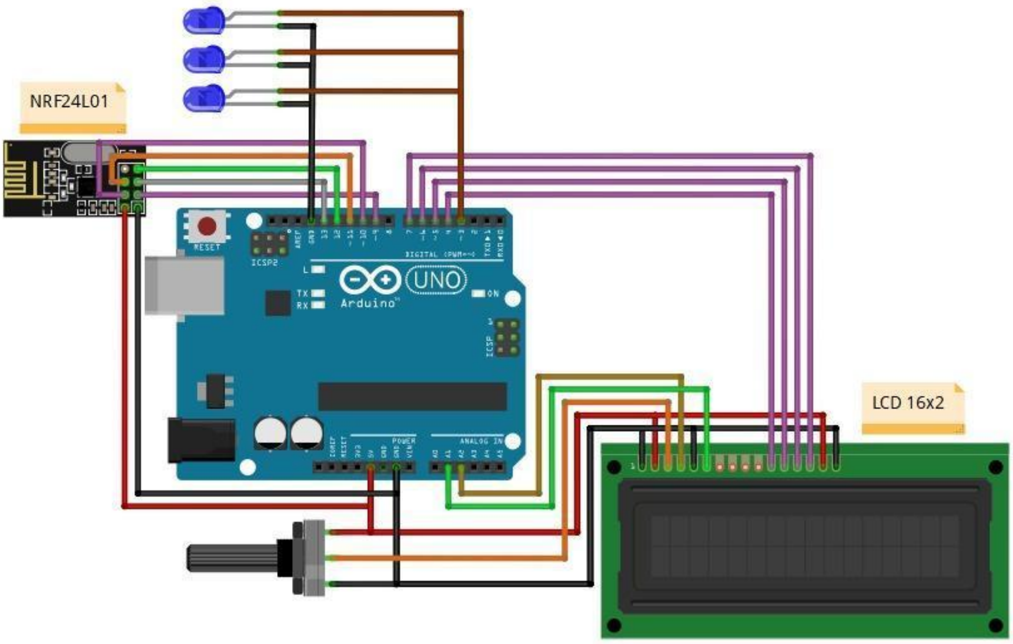

Figure 6: Wiring diagram of the receiving station

The programming done in Arduino for the receiver module is as follows:

```
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <LiquidCrystal.h>
#define LED 3

const int pinCE = 9;
const int pinCSN = 10;
RF24 radio(pinCE, pinCSN);
LiquidCrystal lcd(15, 16, 4, 5, 6, 7);
byte cerito[8] =
{
 0x0E,
 0x0A,
 0x0E,
 0x00,
 0x00,
 0x00,
 0x00,
 0x00
};

byte bateria[8] =
{
 0x0E,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F,
 0x1F
};

const uint64_t pipe = 0xE8E8F0F0E1LL;

float data[4];

void setup()
{
  radio.begin();
  Serial.begin(9600);
  radio.openReadingPipe(1, pipe);
  radio.startListening();
  lcd.begin(16, 2);
  lcd.createChar(0, cerito);
  lcd.createChar(1, bateria);
  lcd.home();
  pinMode(LED, OUTPUT);
}

void loop()
{
  if (radio.available())
  {
    radio.read(data, sizeof data);
    Serial.print("T= " );
    Serial.print(data[0]);
    Serial.print(" ºC, H= " );
    Serial.print(data[1]);
    Serial.print(" %, dist= " );
    Serial.print(data[2]);
    Serial.println(" cm");

    lcd.setCursor(0,0);
    lcd.print( "T=" );
    lcd.print( data[0],1 );
    lcd.write(byte(0));
    lcd.print( "C H=" );
    lcd.print( data[1],1 );
    lcd.print( "%");
    lcd.setCursor(0,1);
    lcd.print("Dist=" );
    lcd.print( data[2] );
    lcd.print("cm  ");
    lcd.setCursor(15,1);
    lcd.write(byte(1));

    if (data[2]< 20)
    {
     digitalWrite(LED, HIGH);
    }
    else
    {
     digitalWrite(LED, LOW);
    }

  }
  delay(1000);
}
```

3. Station design

After programming the electronics of the system to house the components, the respective stations were created in 3D. A waterproof housing was designed and printed in which all the previously programmed sensors were inserted. For the design of the housing, the AutoCad program was used and the final adjustments prior to printing were made with Simplify3d.

Another highlight of the design is the search for low permeability or waterproof materials that protect the electronics, preventing damage, such as PETG filament, transparent vinyl coating or Epoxy resin varnishing.

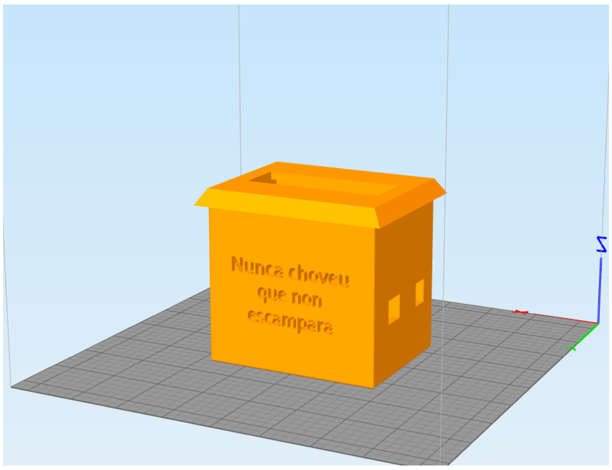

Figure 7: Simplify3d design of the transmitter station

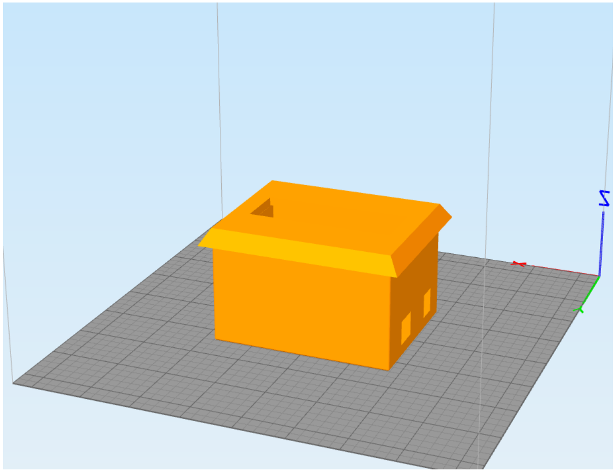

Figure 8: Simplify3d design of the receiver station

- <u>Algorithm design</u>

Design of an algorithm to predict the level of flood risk from studied parameters.
Taking into account these data:

- River slope
- The season of the year
- The runoff coefficient from the river flow, the intensity of precipitation and the surface of the basin.

After entering them, they are analysed, and the risk level, high, medium or low risk, is displayed accordingly.

The mentioned algorithm is the following:

```
print('A continuación se le pedirán unos datos para el cálculo del riesgo de inundación. No introduzca mayúsculas ni acentos. \nPulse enter para confirmar cada dato\n')

valor_riesgo = 0 # Se define variable

# Se le pregunta al usuario los siguientes parámetros. Se le da a enter cada vez que se introduce cada uno

estacion = str(input('Estación: '))
pendiente = float(input('Pendiente en porcentaje: '))
Q = float(input('Caudal del río en m3/s: '))
I = float(input('Intensidad de precipitación del área en m/s: '))
A = float(input('Superficie de la cuenca en m2: '))

coef_escorrentia = Q / (I*A) # Cálculo el coeficiente de escorrentía

print('El coeficiente de escorrentía de tu área es:',coef_escorrentia, '\n') # Se muestra en pantalla el coeficiente de escorrentía

# Cálculo del riesgo sobre 1 según el coeficiente de escorrentía
```

```
if coef_escorrentia >= 0.7:
   valor_riesgo = valor_riesgo + 1
if coef_escorrentia > 0.4 and  coef_escorrentia < 0.7:
   valor_riesgo = valor_riesgo + 0.75
if coef_escorrentia <= 0.4:
   valor_riesgo = valor_riesgo + 0.5

# Cálculo del riesgo sobre 1 según el la pendiente

if pendiente >= 6:
   valor_riesgo = valor_riesgo + 1
if pendiente > 2 and pendiente < 6:
   valor_riesgo = valor_riesgo + 0.75
if pendiente <= 2:
   valor_riesgo = valor_riesgo + 0.5

# Cálculo del riesgo sobre 1 según la estación

if estacion == 'otoño':
   valor_riesgo = valor_riesgo + 1
if estacion == 'invierno' or estacion =='primavera':
   valor_riesgo = valor_riesgo + 0.75
if estacion == 'verano':
   valor_riesgo = valor_riesgo + 0.5

# Decisión del riesgo

if valor_riesgo >= 2.5:
   print('RIESGO ALTO DE INUNDACIÓN')
if valor_riesgo >= 1.25 and valor_riesgo < 2.5:
   print('RIESGO MEDIO DE INUNDACIÓN')
if valor_riesgo < 1.25:
   print('RIESGO BAJO DE INUNDACIÓN')
```

5. RESULTS

The stations incorporating the sensors are finished and different ways of waterproofing them are being tested to ensure their correct operation.
A detailed study of the basin in which our town is located and of the parameters that influence overflows has been carried out. This has enabled us to design a first algorithm (pending validation in terms of rainfall).
The system is currently in a testing phase to determine the ideal conditions and to refine the algorithm's adjustment parameters, thus allowing the warning system to be put into operation in a short period of time.
Once the test phase has been completed, a study will be carried out to be able to apply the work to other areas with other types of flooding, such as more intense floods.

6. CONCLUSIONS

The station works as expected and allows collecting the necessary data to warn of flood risks. The communication between the stations works well. In addition, the algorithm, although unfinished, fits our needs for the moment. We need to continue testing in order to perfect the algorithm and obtain the definitive values for its perfect functioning. At the moment we only have empirical values.

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