An Advanced Flood Detection System Through Integrated Environmental Sensors and Real-Time Data Analysis

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Key Words: Torricelli's Theorem- Multi-Sensor System – Regression line – Node-RED

Abstract

The project focused on two Grand Challenges in Egypt: Improving science and technology for everyone and reducing the effects of climate change. Climate change has made these floods worse, threatening communities and infrastructure. A solution was chosen: a flood early warning system. The system uses sensors to measure water level, flow rate, Temperature, humidity, air pressure, and water speed. The goal was to detect floods early and warn people in time to take action. The system's design included certain needs. Sensors had to be accurate, strong, and able to work in tough environments. The system also needed to show real-time data and send alerts if a flood was likely. A prototype was built using a transparent tank to simulate a river or reservoir. Sensors were connected to a microcontroller **(ESP32-WROOM-32U)** to collect and process data. Tests were done by a stimulation for flood conditions. The system successfully measured changes in water levels and sent warnings when danger levels were reached. The results showed that the system worked well and met its goals. In conclusion, the project proved that an early warning system for floods can help reduce damage caused by floods. This system can save lives, protect buildings, and reduce economic losses. It is a simple yet effective solution that can be used in flood-prone areas, helping communities prepare for the impacts of climate change.

Introduction

Egypt faces some challenges in mitigating the effects of climate change, especially with increased flood risks within vulnerable areas, as shown in Figure 1. These challenges require innovative strategies in disaster prevention, in addition to those related to resilient infrastructure. This challenge forms the core of the current Capstone project in the semester regarding leveraging technology to enhance: Public safety. Previous solutions have been researched, studied and analyzed in terms of their relative strengths and weaknesses. Improved flood prediction and community safety through a self-sustaining sensor network with local risk mapping and replication was improved in Honduras. Due to its complexity and resource requirements, it is not scalable further. In Jakarta, meanwhile, an IoT-based system was implemented using Raspberry Pi functions as a microcomputer for central control, collecting data from a water level sensor to measure water height, an ultrasonic sensor for further monitoring, a DHT11 sensor to monitor temperature and humidity, and an alarm as an audible warning device. Although the solution was cost-effective and automated, its narrow deployment and limited scope reduced its effectiveness. The solution will be selected by the team to work on the above-mentioned limit based on scalability and real-time processing. The proposed design incorporates IoT, advanced data analytics and enhanced communication channels to provide the required reliable and adaptive flood warning system. Design requirements: multi-sensor integration, signal processing, real-time monitoring, data visualization, energy efficiency and data storage. A prototype was designed integrating DHT11 sensors for both temperature and humidity, water level sensors for monitoring water level, BMP 280 atmospheric pressure, YF-S201C transparent water flow sensor required to calculate water velocity according to the flow rate law: V=Q/A and ESP32 controllers to actuate and transmit such data. The chosen prototype solution is cost-effective and energy-efficient to address the weaknesses identified in the previous solutions. In this context, the team set out to develop an inexpensive flood detection system that ensures efficient data collection, cost-effective hardware, and predictive analytics to meet local and national needs. The design process consistently emphasizes user accessibility, community engagement, and integration with existing infrastructure.

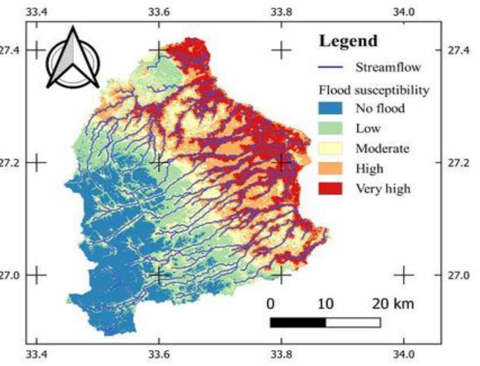
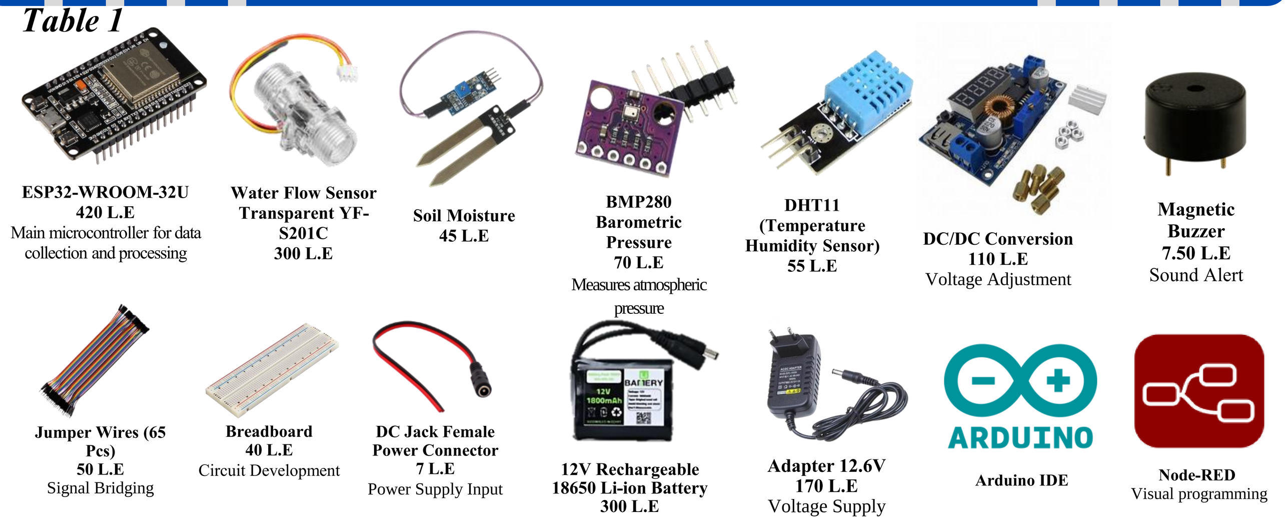


Fig.1: Flood susceptibility map of Hurghada generated using the LightGBM algorithm, demonstrating high prediction accuracy (97%).

Materials

Table 1



The materials utilized in conducting the solution.

Methods & Test Plan

Connection

The construction of the prototype began with assembling sensors into an electric circuit, specifically on a breadboard, as shown in Figure 2. Jumpers were used to connect all the components of the project. Next, the functionality of these components was tested using a laptop to ensure they operated correctly. Finally, the required code [here] was written and uploaded to achieve the desired objective

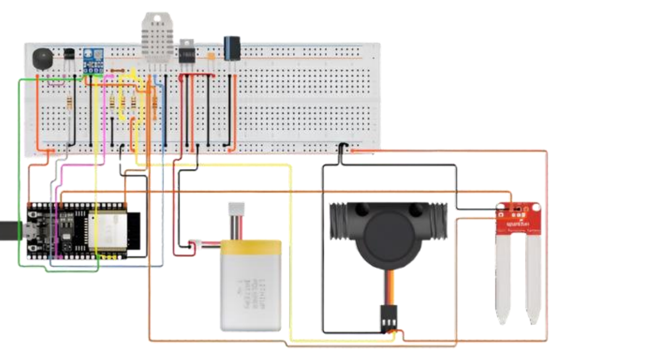
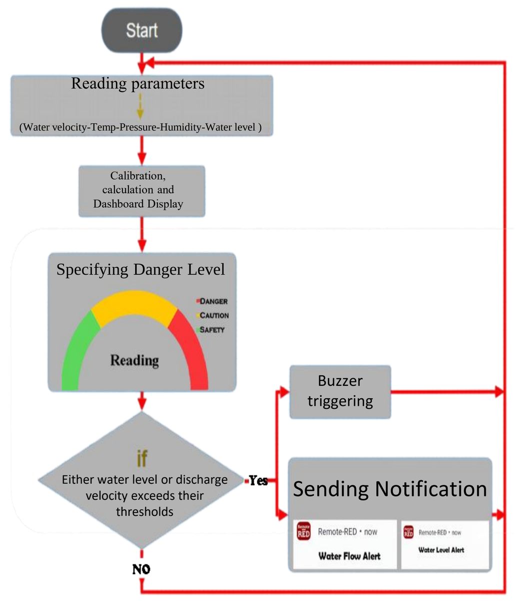


Fig. 2: illustrates the circuit design

Designing

After completing the connection stage, the next step is creating the final product with two primary objectives. The first is ensuring for an appropriate placement of the sensors, either on the designated box or other available components. Secondly, Adjust the codes of every sensor to work properly with the other sensors, and give correct readings in their new fixed position. Additionally, the ESP32 and the mobile phone were connected to the same Wi-Fi network for data transmission to the app's dashboard. This setup also enabled alert notifications and buzzer activation when needed. We used the Node-RED as a visual programming tool ideal for IoT and real-time data applications. by integrated process involved:

- Establishing MQTT communication to transmit real-time data.
- Creating flows to interpret the data and identify the flood risk based on the chosen parameters that we measure and give reading according to defined functions.
- Configuring notifications to alert the users of impending flood risks if the sensor readings reach dangerous conditions



Flowchart

Test Plan

In our project, the test plan mainly focuses on testing the functionality of each sensor and its ability to detect different factors. As shown in Figure 3&4. The test plan is divided into two branches: 1-Testing the ability of sensors to detect surrounding factors

- BMP280 Barometric Pressure: Tested by blowing on the sensor to create higher external pressure, then checking for increased pressure readings.
- DHT11: Exposed to hot water vapour to measure both temperature and humidity. The sensor was left in the vapour until it recorded high readings for both parameters.
- Flow Rate and Water Level Sensors: Tested by pouring water to reach the maximum height, observing the response of the water level sensors, and calculating the danger level percentage. The changes in flow rate and velocity were monitored using the Water Flow sensor Transparent YF-S201C.

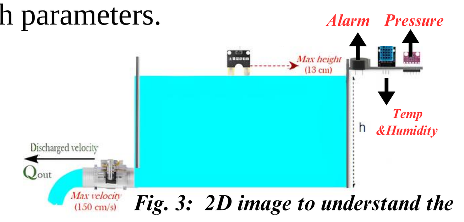


Fig. 3: 2D image to understand the project objective using Photoshop

2-Testing the mobile application's ability to visualize data While exposing each sensor to its respective testing conditions, a team member monitored the values displayed on the application dashboard. These values were then compared to those shown in the serial monitor to ensure accuracy.

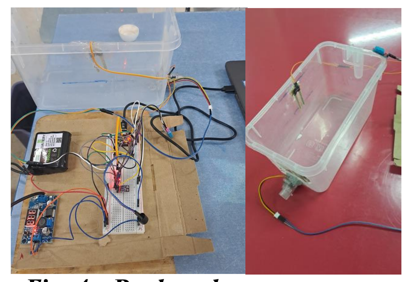


Fig. 4: Real made prototype

Results

The project aims to reduce the effects of sudden floods on communities by a system, that can predict the happening of the flood. A simulation for flood conditions was done to make a test plan and get results. The readings from each sensor are shown in Table (2). We examined the prototype and concluded the positive results of the prototype as shown in table (3).

Table(2)Data of each sensor

Reading	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Temperature (C)	19.4	19.4	20.6	22.6	25.1	28.4	32.8	31.2	31
Humidity(%)	63	63	74	80	98	98	86	77	68
Pressure (hPa)	1015.71	1015.71	1016.54	1016.39	1016.26	1015.16	1016.09	1016.02	1015.7
Velocity cm/s	151	144	131	118	105	91	---	---	---

Table(3): Positive & Negative Results

Status	
Positive	• The system is fully operational and running smoothly. The sensors have precise and accurate readings. • The sensors have the capability to adapt quickly to any changing conditions, ensuring reliable and trusted system performance. • The data is presented in a clear, in different specific colors according to the danger levels to ensure that it's easy for regular users to interpret and stored accurately, allowing users to review the reading history as needed. • Alerts are sent through buzzers or notifications during abnormal conditions.
Negative	Dashboard readings delayed due to: 1. Unstable internet connection with Wi-Fi communication 2. Heavy load on Node-RED server slows data processing. Not perfect reading due to environmental factors, power instability and the errors for each sensor reading: Flow rate (±2%), Temperature (±2 C), Humidity (±4% to ±5%) RH, Pressure (±2% to ±3%)

Analysis

Flooding in Egypt become devastating, especially for those living near the Nile. Heavy rainfall or storms upstream can cause flash floods, overwhelming drainage systems and damaging homes, roads, and crops. Climate change has a main role in flooding occurrences, so we try to adapt to these conditions and make a system to overcome this issue. The system will monitor the possibility of flood occurrence according to specific environmental parameters. These parameters are temperature, humidity, and pressure. These parameters have a standard value for achieving the safety of the region. The system measures temperature, humidity, pressure, water level and discharge velocity, which must stay within specific safety thresholds and reading alerts t abnormality.

Scientific Base

According to **Torricelli's law As shown in Figure (5)**, also known as **Torricelli's theorem**, is a theorem in dynamics relating the speed of fluid flowing from a hole to the height of fluid above the hole. The law states that the speed v of efflux of a fluid through a sharp-edged hole in the wall of the tank filled to a height above the hole is the same as the speed that a body would acquire in falling freely from a height. **Torricelli's Law is considered a special case of Bernoulli's equation with some Assumptions:**

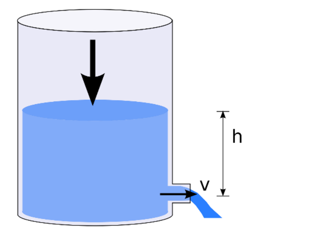
1. The fluid at the surface of the reservoir is nearly stationary, so its velocity (v_1) is approximately zero.
2. The pressure at both the surface and the orifice is atmospheric ($P_1 = P_2$).
3. The potential energy at the orifice is negligible, as the height at the orifice (h_2) is taken as zero.

Torricelli's Law

$$v = \sqrt{2gh}$$

Where:

- v: Speed of the fluid (m/s)
- g: Acceleration due to gravity (9.81 m/s²)
- h: Height of the fluid column (m)



Fig(5): Torricelli's Principle

We use Torricelli's Law to understand the relationship between the water velocity measured by the **YF-S201C Water Flow Sensor** and the water height that are detected manually. In our experiment, we poured water into a container and recorded the velocity readings at different heights. According to the equation, we can rewrite **Torricelli's Law as $v^2 = 2gh$** which shows a direct relationship between the square of the velocity and the height of the water column. By squaring the velocity values at each height reading, we can represent this relationship graphically. Additionally, we can calculate the correlation between our readings by statistics concepts by using Pearson correlation formula:

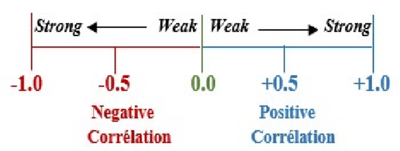
$$r = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \cdot \sum(Y_i - \bar{Y})^2}}$$

H(m)	V²(m²/S²)
0.13	2.2801
0.112	2.0736
0.095	1.7161
0.078	1.3924
0.066	1.1025
0.05	0.82181

Table(4): Reading

Where:

- **-X** represents *height* and Y the *velocity ²*
- X_i and Y_i are the individual data points.
- $\bar{X}$ and $\bar{Y}$ are the means of the X and Y variables, respectively.
- **r** is the Pearson correlation coefficient.



Fig(6):Correlation strength level

By substituting in the law the correlation (r)= 0.9961

In statistical concepts, this correlation is classified as very strong. The strength of the correlation, as illustrated in the in Figure(6). , serves as a positive indicator of the accuracy of our calculations and the reliability of our data collection.

It is critically important to create a regression line to effectively visualize the trend or relationship between velocity squared and height by a single line. The equation of the regression line is calculated using the following formula: $v^2 = mH + c$

Where :

$$m = \frac{\sum(H_i - \bar{H})(V_i^2 - \bar{V}^2)}{\sum(H_i - \bar{H})^2} \quad \& \quad c = \overline{v^2} - m\bar{H}$$

m =18.8976 & c =-0.108

According to the original equation $v^2 = 2gh$,

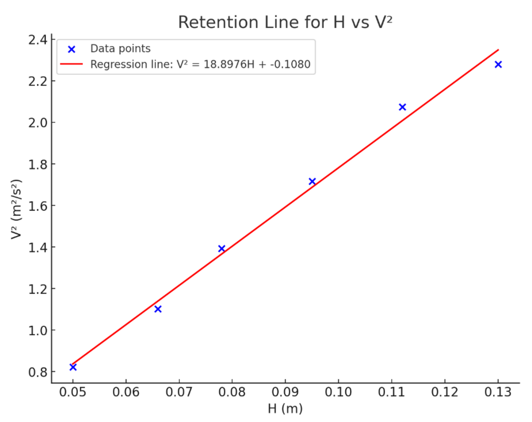
the slope of the line $\frac{dv^2}{dh}$ should equal (2g) which is constant .

By comparing the slope of our regression line to (2g),

we can validate the accuracy and efficiency of our

calculations. In our case the slope represented by (m)then we

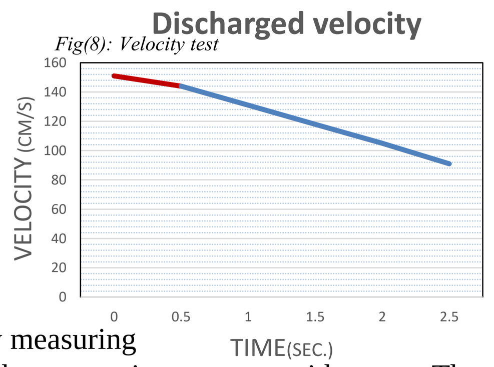
can represent the accuracy by $=\frac{m}{2g}=\frac{18.8976}{2 \times 9.8}=$ $\boxed{96.35\%}$



Fig(7): scattered pattern and regression line

The high accuracy of our reading show that our data and calculation could be reliable and trusted

- The **Water Flow Sensor** contains an internal fan that rotates as water flows through it. This rotation generates pulses, which are translated into the water flow rate, typically measured in L/min,then we converted it to m³/s. Then if we need to get the velocity of the water, we use the continuity equation (Q=Area/velocity)For testing, we filled the container with water and recorded the velocity over time. The system's threshold is set at a water velocity of 150 cm/s, which indicates a danger level.

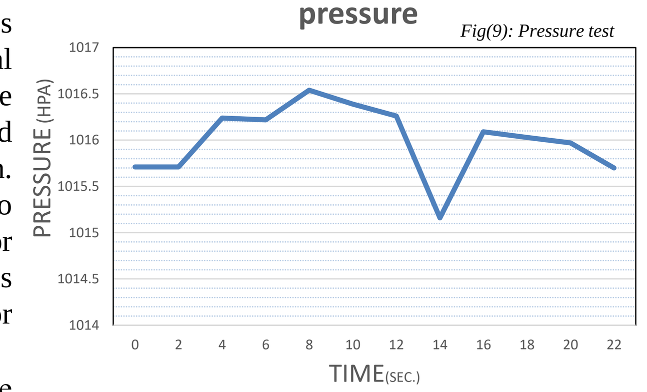


Fig(8): Velocity test

- A soil moisture sensor can function as a water level detector by measuring changes in conductivity or resistance between two probes when they come into contact with water. The sensor is placed vertically at heights between 6 cm and 12 cm in the container. As the water rises, it alters the conductivity, which is expressed as a percentage. A range of 1% to 99% indicates a potential danger, and when it reaches 100%, the water level exceeds 12 cm. At this point, a notification is sent, and the buzzer is triggered

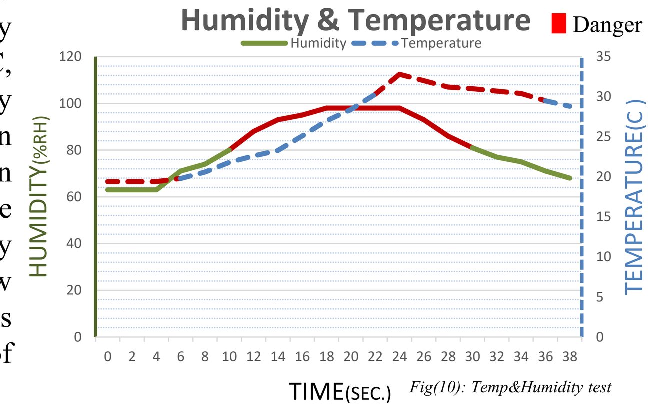
Analysis

- The **BMP280 Barometric Pressure** Sensor is used to monitor external pressure. the normal pressure should stay above 1010 hPa because anything lower can encourage cloud formation and increase humidity, which often leads to heavy rain. To test the sensor, we tried blowing on it to simulate a sudden increase in pressure. The sensor responded perfectly, as shown in the graph. This test proves that it's accurate and reliable for detecting changes in pressure in real life.



Fig(9): Pressure test

- The **DHT 11** is used to measure the temperature and humidity. The temperature should stay between 20°C and 30°C. If it drops below 20°C, condensation increases and this leads to heavy rainfall and potential flash floods, especially in poorly drained areas. On the other hand, when temperatures rise above 30°C, the atmosphere becomes unstable, which can also trigger heavy rain.in terms of humidity, it should remain below 80%. When it exceeds this threshold, the air holds more moisture which increases the possibility of making heavy rain quickly



Fig(10): Temp&Humidity test

We boiled water in a glass and placed it beside the system. The sensor demonstrated its ability to adapt to environmental changes and the readings clearly indicated whether the conditions were normal or not, proving that the sensors are reliable and effective.

Power and Memory Calculations

DHT11 :2 values (temp and humidity) × 2 bytes each = **4 bytes**, **Soil Moisture:** 1 value × 2 bytes = **2 bytes**, **Flow Rate:** 1 value × 4 bytes (float) = **4 bytes**, **BMP280** :2 values (pressure and temperature) × 4 bytes each = **8 bytes**, **Timestamp:**1 value × 4 bytes = **4 bytes. Pre- record size =22 bytes/record**

Total records in one year: 2 records/minute×525,600 minutes/year=1,051,200 records

Total storage=22 bytes/record×1,051,200 records/year=23,126,400 bytes/year≈22.05 MB

First, total sensors power= ∑ (I x V) = 1.6846 Watt. Second, E battery=V battery×C battery, to calculate it Runtime(hours)= E battery / P total, E battery = 4380 hours x 1.6846 Watt= 7378.548 W. h, the battery desired must be 12V, 614.879 ampere-hours.

Code	Learning Transfer
ST.3.02	We used to calculate the correlation between velocity squared, draw the regression line, and determine its equation.
PH.1.09	We studied the equation of continuity to calculate the water flow rate and applied Torricelli's Law to understand the relationship between the height of water and the velocity in the dam of discharged water
CH.3.01	applying scientific methodology by identifying flood risks, designing and testing a solution, collecting data, and analyzing results to confirm the system works.
PH.3.04 & PH.3.05	The communication methods learnt in these learning outcomes helped us in controlling communication between the components of the system.
ES.2.05	understanding river systems and drainage basins by showing how water interacts with landforms and the hydrologic cycle.

Conclusion & Recommendations

The project has showed its success as the sensors and modules work together with efficiency and the data processing by the algorithms of looping, if statements, and calculation function is done correctly to give a real-time output for the users. The microcontroller ESP32 makes communication with mobile via Wi-Fi to be able to get data everywhere. The DHT11 sensor measures the humidity and the BMP280 measures the atmospheric pressure, which are two different weather parameters. The soil moisture sensor has proved its ability to measure the water level in the tank, that classified as an important parameter we measure. The flow rate sensor measures the velocity of water in the water stream. Both flow rate sensor and water level sensor if they reach the dangerous conditions notify the user by the mobile application.

The project faces challenges due to limited time and budget, and we propose recommendations for teams to adopt and continue developing our work:

1-**Using real-time** data to create models that simulate how floods might spread, helping to predict their impact and provide more accurate early warnings.

2-**Using of better sensors and modules** to collect more fast and accurate data for more precise calculations and outputs such as GFS131-WC2 as a Flow Sensor or SHT35 (Sensirion) as temperate and humidity sensor

3-**Using GIS tools** to generate detailed flood maps, to make it easier for authorities to plan and coordinate their responses effectively.

4-**Using the high discharged velocity** to move turbine for generating a clean renewable energy

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