FoFi: The Development of a Handheld Monitoring Device in Predicting Naturally Occurring Forest Fires

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Abstract: Forest fires, which are natural or artificial burning of woodlands, negatively affect people and the environment. In the Philippines, Cordillera is one of the hotspots for forest fires, with approximately 122 forest fire incidents. Thus, developing a monitoring device for the early prevention of forest fires would reduce these incidents' frequency. This research aimed to create a handheld prototype device, FoFi, that gathers quantitative data which can be used with the Department of Natural Resources's data science and predictive analytics. Using an Arduino Microcontroller and sensors, the device will collect and send data. Two phases were conducted to create a monitoring prototype device for predicting forest fires. According to the results, the temperature and humidity (DHT-22) sensor showed reliable data since it can detect temperature under normal conditions, having a mean of 30.65°C; also, it precisely recorded the relative humidity with a mean of 7.89%. The Global Positioning System (GPS) module obtained a mean error of 7.251 m, which exhibited accuracy in detecting GPS coordinates. Additionally, the Globe SIM showed efficiency for Global Systems for Mobile (GSM) communication since the mean length of time for sending a message is 5.022 s. On the other hand, the gas sensor (MQ-2) and photoresistor lacks sensitivity when used; thus, a more sensitive sensor is recommended. In conclusion, the handheld device was able to achieve its purpose of monitoring forest fires.

Key Words: forest fires; handheld monitoring device; arduino microcontroller

1. INTRODUCTION

A forest fire is the burning of temperate woodland due to natural or human causes (United Nations, n.d.), which can turn uncontrollable due to environmental factors such as wind or topography. The effects of forest fires include the degradation of fauna and flora, increased carbon dioxide levels, and a compromised natural cycle. The increased carbon dioxide levels also contribute to climate change and soil erosion (Perez, 2017). Particulate matter combined with toxic gases such as carbon monoxide (CO) can cause health problems such as heart disease (Stefanidou et al., 2008). The economy has also been negatively affected by forest fires. This is because the costs to recover from these incidents have exponentially risen. In 2015, Indonesia's cost to suppress forest fires amounted to 14 billion dollars (Hirschberger, 2016) and approximately 63 billion dollars for the United States (Thomas et al., 2017).

Furthermore, the Forest Management Bureau (FMB) Chief under Forest Protection stated that the FMB and the DENR imposed a protection system called 'LAWIN,' which uses open-source technology to provide geospatial data analysis obtained from forests. It provides a data model for identifying forest conditions, including information on practical solutions in response to the data imparted.

Dumlao (2019) reported that from January to March 2019, the Bureau of Fire Prevention in Cordillera reported 90 occurrences of the forest fire that have damaged at least 140,000 hectares of forest in Cordillera alone. Agoot (2019) indicated that Cordillera had approximately 122 forest fire incidents. These incidents implicate Cordillera as a hotspot for forest fires.

In this study, the researchers designed and developed a multi-sensor monitoring device called FoFi (from *forest fires*). It aimed to gather data to aid data science researchers for better prediction of naturally occurring forest fires.

Since studies showed that forest fire incidents had increased annually, immediate prevention is essential. Proper wildfire management is about effective communication of information regarding forest fires and technological advancements aid in optimizing effective forest fire detection systems (Molina-Pico et al., 2016). With this, FoFi, from the word forest fires, will help in monitoring forests. The contribution of LAWIN to forestry is significant; however, it only focuses on managing forests to avoid deforestation and degradation, whereas FoFi aims to collect data to predict forest fires.

This study's findings will benefit society and the academic community since it tackles how citizens can protect the forest environment and avoid such disasters. Also, government agencies such as DENR and FMB may benefit from this because this can aid in gathering quantitative data about the status of forests. The increase of forest fires in the Philippines means that this should be addressed immediately so that society members canface such calamities better or even prevent.

2. METHODOLOGY

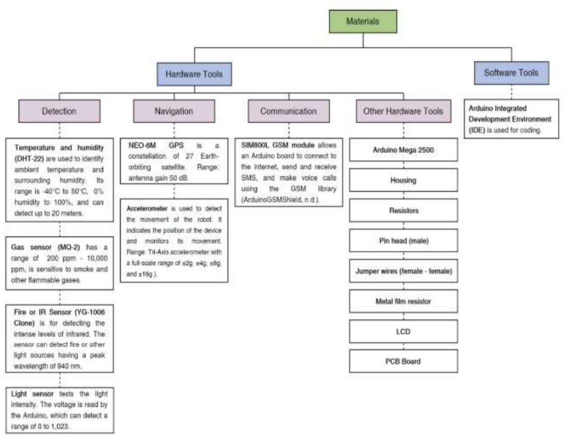

Fig. 1. List of materials needed for the handheld device.

The list of requirements, together with the knowledge gathered about the various devices and sensors, was used to plot out the materials needed for FoFi. Arduino was strictly used for the microcontroller and programming language to create a monitoring system for forest fires. The components used were interfaced together and a GSM module was used as there are cell towers present in the targeted forest areas. Moreover, this research was conducted using a fire and environment simulation and not in an actual forest environment. The intent of this was to test the efficiency of the device in gathering data and not its durability. The sensors were limited to what was listed in Figure 1. Additionally, there were two phases in conducting the study: evaluating the sensors and refining FoFi.

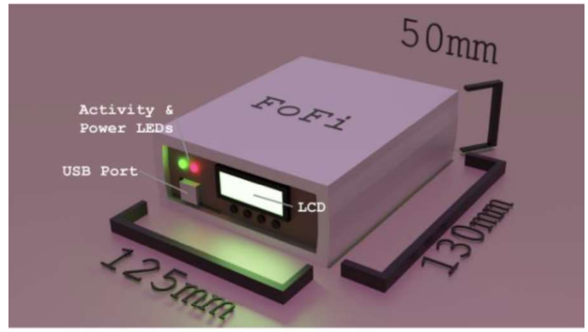

Fig. 2. A 3D draft model of FoFi.

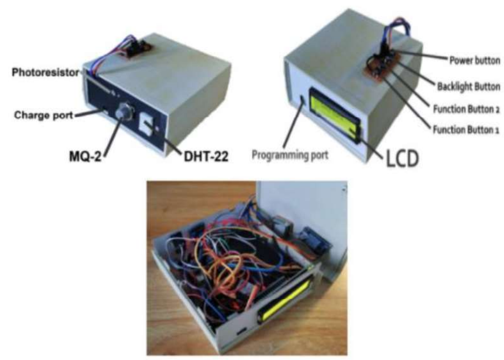

Fig. 3. Final version of FoFi with sensors pieced together.

With a general idea of the housing and hardware, a draft 3D model was made using Blender 2.9. there were some changes in piecing all the components together for the final device. Figure 3 shows the final version of FoFi. Unlike the draft, the buttons were moved on top due to the lack of space caused by the LCD driver board. The rest remain the same with the LCD and USB port being in front while the sensors and charging port are at the back.

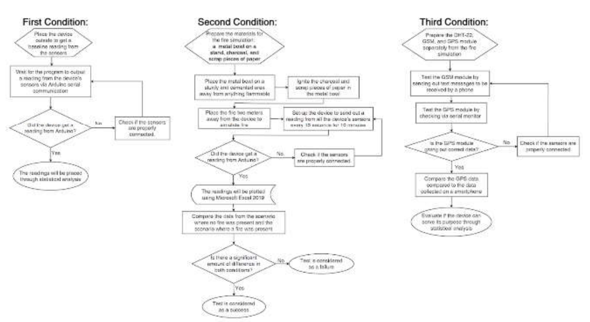

Fig. 4. Evaluation of the handheld device.

According to Figure 4, there were three conditions in evaluating FoFi. In the first condition, the sensors were tested on a normal setting, without fire. The device was then tested in a fire simulation for the second condition. For the third condition, some sensors were tested separately from the fire simulation. The conditions were evaluated using statistical analysis to gather quantitative data. Also, it involved the estimation of parameters to gauge the mean parameters of the data collected and hypothesis testing, which determined the reliability of the data. A quantitative experimental research design was used to test the ability of each sensor to collect data.

The prototype was refined to ensure that the device can successfully gather data. This involved fixing the device to resolve any issues that were identified during the testing phase. There were four challenges encountered during building FoFi. First, the MQ-2 and IR sensors were not functioning correctly. Both sensors were then retested at different conditions to double-check their functionality. Second, there was a defect in the ability of the GPS module to provide data. However, after re-examining it, the sensor only needs a few minutes to lock onto satellites before providing the data. Also, reprogramming the Arduino enabled detection regarding whether the GPS module is ready. Third, there was an issue with the Arduino Mega's serial communication. After thorough testing, it was determined that the TX and RX pins were interchanged and the GSM module only works on Serial IO 1 and not on other serial ports due to its need for serial interrupts. Lastly, insufficient current was evident while testing; the Arduino and sensors were not able to run through USB power from a laptop; thus, the rechargeable battery was used during the testing.

3. RESULTS AND DISCUSSION

Statistical analyses were interpreted using Microsoft Excel 2019. The estimation of the true mean parameters of primary data is determined at a 5% level of significance. A two-tailed test at a 5% level of significance tested the null hypothesis of whether the mean parameters of primary data are significantly comparable to the mean parameters of data obtained from the data collection stage or other studies.

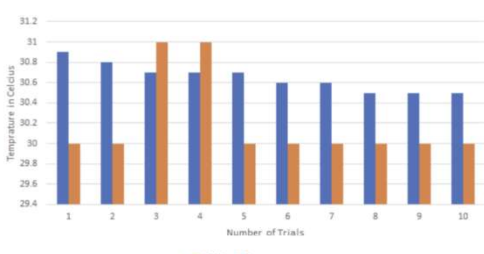

Fig. 5. Temperatures recorded by the DHT-22 sensor and thermometer.

Table 1. Data analysis for ambient temperature recorded using DHT-22 sensor.

Mean (°C)	30.65
Standard Deviation	0.1285
Variance	0.0165
Estimation of Parameters (One Population Mean)[1] at α = 5%	30.65 ± 0.0796
Hypothesis Testing (One Population Mean)[1] at α = 5%, t-test	Ho: μ = 30.20 ; Ha: μ > 30.20 p-value: 1.0000 , t > 1.8331 or p > 0.05, reject Ho.

1 - recorded on 1/18/21 from 4:06 to 4:30 pm; mean temperature noted with thermometer (): 30.20°C

A DHT-22 sensor is used to detect temperature and humidity. Its range is -40°C to 50°C, 0% to 100% humidity, and it can detect up to 20 meters. Given the mean temperature recorded

() by the thermometer, there is proof that the sensor is accurately detecting temperatures in normal conditions. Though Trials 3 and 4 were the only trials wherein the sensor detected lower temperatures than the thermometer, the difference is not significant enough to warrant misinterpretation. However, Obanda (2017) did not compare the sensor readings with a thermometer to test accuracy; the grove temperature sensor used successfully detected temperature changes. Similarly, the DHT-22 was more precise as it had an accuracy of ±0.5°C compared to the grove sensor's which was ±1.5°C. Although the grove sensor can read up to 125°C compared to 80°C from the DHT-22, the device is not aimed to detect extreme temperatures.

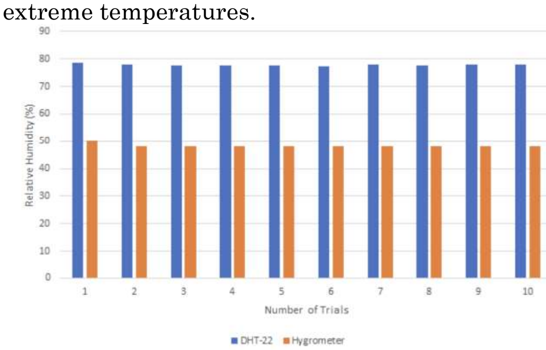

Fig. 6. The data from the DHT-22 sensor when tasked to read the relative humidity.

Table 2. Data analysis for relative humidity using a DHT-22 sensor.

Mean (%)	77.89
Standard Deviation	0.3562
Variance	0.1269
Estimation of Parameters (One Population Mean)[2] at α = 5%	77.89 ± 0.2208
Hypothesis Testing (One Population Mean)[2] at α = 5%, t-test	Ho: μ = 48.20 ; Ha: μ > 48.20 p-value: 1.0000 , t > 1.8331 or p > 0.05, reject Ho.

2 - Data recorded on 1/18/21 from 4:06 to 4:30 pm; mean temperature noted with thermometer during this period (): 48.20%

Given the mean relative humidity recorded () by the thermometer, there is proof that the sensor recorded relative humidities but inaccurately. The sensor's mean humidity records are significantly higher than the humidity recorded by the thermometer, which may lead to misinterpretation of data. The sensor's data was precise, indicating that further tests can be conducted to compensate for the unusually high readings with software.

The MQ-2 sensor is sensitive to smoke and has a built-in potentiometer to adjust its sensitivity for digital output (Mukherjee, 2016). Across ten trials, only the first trial showed a value of 2 parts per million (ppm) for CO and 0 ppm for the other trials. In detecting LPG, it reported 0 ppm across all trials as no LPG was present during the testing. This was included in the testing to determine a possibility of a trend in LPG readings. Like the CO tests, the first test showed 2 ppm for a smoke while the rest showed 0 ppm. This is similar to Niranjana and HemaLatha's (2018) findings, as they found that the range of raw data given was 45 to 80 ppm without smoke and 100 to 250 ppm with smoke. Conclusively, the sensor did not detect smoke, LPG, or carbon monoxide levels accurately enough to be used in the device.

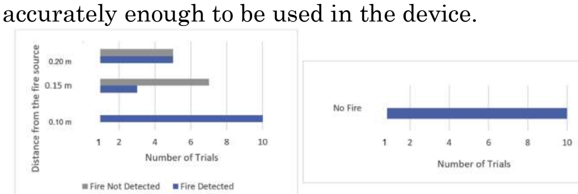

Fig. 7. The YG-1006 sensor's data regarding the detection of infrared levels

The infrared sensor (YG-1006) can detect fire or other light sources having a peak wavelength of 940 nm. According to Figure 7, in the trial without fire, all ten trials reported a fire which are attributed to the presence of sunlight during testing. When placed 0.10 meters away, all ten trials also reported fire. Furthermore, when placed 0.15 meters away, 30% of the trials detected fire, and when placed 0.20 meters away, half of the trials detected fire. This indicates that a YG-1006 sensor would be impractical as it may detect sunlight as infrared. Although Obanda (2017) recommended to use a YG-1006 sensor instead of a light sensor, the results still reported inconsistencies due to the presence of sunlight.

The light sensor (photoresistor) can be used together with a 10k ohm resistor connected to the ground to give various voltage outputs. This is then read by the Arduino's analog input which could provide a range of values from 0 to 1023. The device was subject to three scenarios (10 trials per scenario):

- A scenario with no light
- A scenario where a light source is placed 5cm away
- A scenario with the light source directly on the sensor

The values obtained from this sensor were consistent across all 10 trials for all 3 scenarios; however, due to the sensor only giving various voltages and depending on the analog read pins of the Arduino, the values do not have any standardized unit of measurement such as lux. This is a problem as it could lead to inconsistencies across multiple devices and potentially negatively affect the effectiveness of data science research.

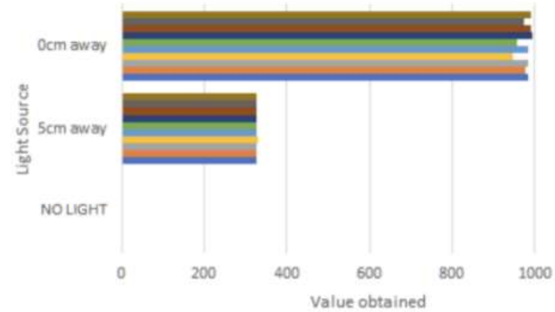

Fig. 8. The photoresistor's data in varying lighting conditions

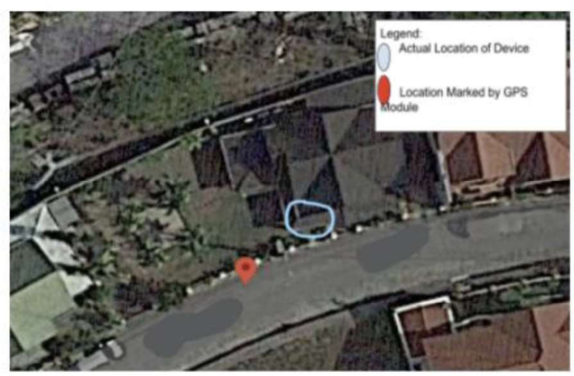

Fig. 9. The GPS module's data regarding the GPS coordinates on Trial 1

Furthermore, the GPS is a navigation system that has a range of antenna gain 50 dB. By obtaining the coordinates and inputting it in Google Maps, the GPS data, highlighted by the red pin is seen to be relatively close to the actual location of the device.

Table 3. Data analysis for GPS module

Accuracy of GPS Module in Documenting Coordinates	
Mean	7.2510
Standard Deviation	4.5876
Variance	21.046
Estimation of Parameters (One Population Mean)³ at α = 5%	7.2510 ± 2.8434
Hypothesis Testing (One Population Mean)³ at α = 5%, t-test	Ho: μ = 12.5 ; Ha: μ < 12.5 p-value: 0.0001, t < 1.8331 or p < 0.05, reject Ho.

3 - Reference parameters of error readings of GPS coordinates obtained from Islam and Kim (2014); μ : 12.5 m

Table 3 shows that the GPS module accurately identified the GPS coordinates, with a mean error reading of 7.251 meters from the device's actual location. The mean error distance of the GPS readings is also significantly lower than the error readings obtained by Islam and Kim (2014). Conclusively, the GPS module is more accurate and precise in recording data.

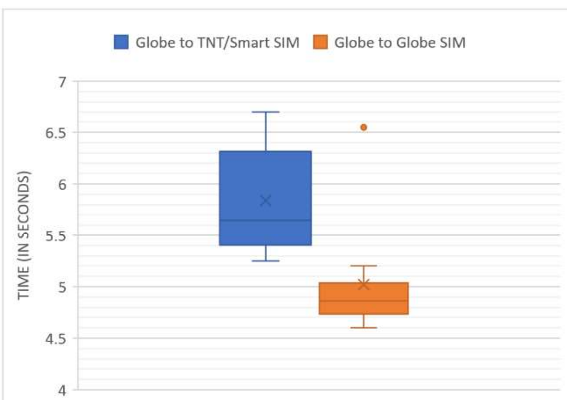

Fig. 9. The data of the GSM regarding communication through text messaging.

Table 4. Data analysis for GSM text messaging.

Length of time for messaging to be sent using GSM Module	SMART/TNT SIM	GLOBE SIM
Mean (s)	5.842	5.022
Standard Deviation	0.4988	0.5330
Variance	0.2488	0.2841
Estimation of Parameters (Difference of Two Population Means) at α = 5%	0.8200 ± 0.4525	
Hypothesis Testing (Difference of Two Population Means) at α = 5%, t-test	Ho: Smart = Globe Ha: Smart > Globe p-value: 0.9998, t > 1.645 or p > 0.05, reject Ho.	

Meanwhile, the GSM module allows the Arduino board to send and receive SMS and make voice calls using the GSM library. The mean length of time for sending a message to TNT or Smart SIM is 5.842 s, while Globe SIM is 5.022 s. The time difference between the SIMs is significant since the device must send out information quickly. Thus, the Globe SIM is more efficient for GSM text messaging. Moreover, Mr. Nahial stated that cell towers are available in Cordillera since it is used by the people living near the forest. Obanda (2017), who used a SIM900 module, found that text messages took as little as 45 seconds and as long as 80 seconds, which is longer than FoFi's data. However, this could be due to the different carriers they used and other factors.

4. CONCLUSIONS

Forest fires are natural disasters that endanger natural and human resources. In the Cordillera region in the Philippines, data science is being used to predict the subsequent forest fires, prompting the researchers to create a handheld device that forest rangers can use to gather quantitative data to support the LAWIN system's qualitative data.

Readily available electronic components were interfaced with the Arduino microcontroller and were tested to gauge their performance in the context of forest monitoring. The results showed that the YG-1006 IR sensor is too inconsistent to be used in recreating a similar device. The MQ-2 sensor and photoresistor should be replaced with more capable alternatives. On the other hand, the DHT-22 accurately gathered data for ambient temperature. However, it would require tuning for reading relative humidity. Also, the GPS and GSM modules were effective in identifying coordinates and sending information. Overall, FoFi can significantly contribute to the prediction of forest fires.

5. ACKNOWLEDGMENTS

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