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Prototyping a RF signal-based lightning warning device using with Internet of Things (IOT) integration

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Abstract: Lightning had caused at least 25,000 deaths worldwide each year. The study aims to investigate the induced voltage generated by lightning strikes using a lightning detector. Proteus software was employed to simulate the main board of the lightning detector before fabrication. The lightning detector was designed as a radio frequencies receiver and it was tuned to the level (300 kHz to 500 kHz) which enabled it to receive signals from lightning strikes. A lightning simulator was designed using various resistance (100 Ω to 200 Ω) to test the functionality of a lightning detector in order to validate the accuracy of the proposed model. This lightning detector could be activated whenever a small induced voltage (0.2 V and above) were generated by lightning events occurred within 10 km from the detector. This detector captures both the induced voltage and the time difference detected lightning discharge and its sound for further analysis. The time to thunder method was employed to find the estimated lightning discharges distances in parallel to this system in order to validate the current lightning detector. The accuracy of the lightning detector was found to be 88.03%. The analysed data were delivered to the user's smartphone using cloud system

1. Introduction

A lightning strike is a powerful natural phenomenon that can cause various issues[1]. Each lightning strike can discharge an average of 30 kA of current. Depending on the strength of storms, the current in a lightning strike can be ranged from 5 kA to 50 kA [2,3]. Lightning can be a threat to buildings, human beings, and even animals if no proper protection against it[4]. There is an average of 50 lightning strikes occur on earth every second, but not all leads to fatalities. There are about 10% of victims on lightning annually, where approximately 20% to 25% of them were killed[5]. While most of the victims were poorly injured, the injured are mainly from heat, shockwave, intense brightness, radio waves, and secondary slip or fall mechanisms [4]. Unlike common electric shock injured, lightning injured involves transient flashover. Lightning strikes fall randomly between humans, animals, building, Light Rail Transit (LRT) and even power station like wind turbines. All the tall towers, wind turbines, aeroplanes are potential victims of lightning strikes. An aircraft is often exposed to the threat of lightning strikes, which all the aircrafts are facing more than one lightning incidence per year, though they are well protected to endure lightning strikes[6–8]. According to the data, there are around 36% of wind turbines worldwide damaged by lightning strikes every year. LRT services suffered heavy damaged because of the lightning in Malaysia, Japan, and the Philippines [9]. Lightning also occurs on powerhouses, electric grids, transmission lines, higher level towers like Twin tower in Malaysia. All these lightning damages can cost up to billion dollars of losses, life thread, and property losses. Optical ground wires also one of the victims toward lightning strike [10]. Therefore, this project proposes to design a lightning warning device with Internet of Things (IoT)

integration to give approaching thunderstorm warning to nearby publics.

2. Methodology

This project is separated into simulation and fabrication part. The Proteus was used to simulate the circuit before fabrication. The device being simulated consists of two items, which is a lightning simulator and a lightning detector. The electromagnetic waveform needs to be observed and analysed as the lightning simulator works. By using an oscilloscope in Proteus, frequency and signal waveform can be observed during the simulation process. Fabrication of the circuits were made after the simulations. Several components such as antenna, resistor, capacitor, and inductor were used. After performing the fundamental tests, IOT integration was included in the study. IoT involved NodeMCU, Thingspeak, Arduino IDE, and apps development software. The output data shows that whenever lightning detector detected the nearby occurring lightning.

Circuit Simulation

The circuit shown in figure 1 is lightning simulator. It was used to simulate the transient radio frequency that may be generated by actual lightning flash. Waveforms and frequencies which similar to lightning will be produced in this lightning simulator. In this circuit, short pulses at a few Hz will be generated. The pulses generated are useful to test the lightning detector designed in this project. Circuit shown in figure 2 shows the connection of lightning detector. The device used 5 V supply, and the resonant tank was tuned to around 300 kHz. The LED shown will blink for a few milliseconds every time lightning simulator was switched on and connected to lightning detector. The LED will stop blinking after the first signal received and wait for the next signal to come in. Both circuits shown in figure 1 and figure 2 were simulated using Proteus Software.

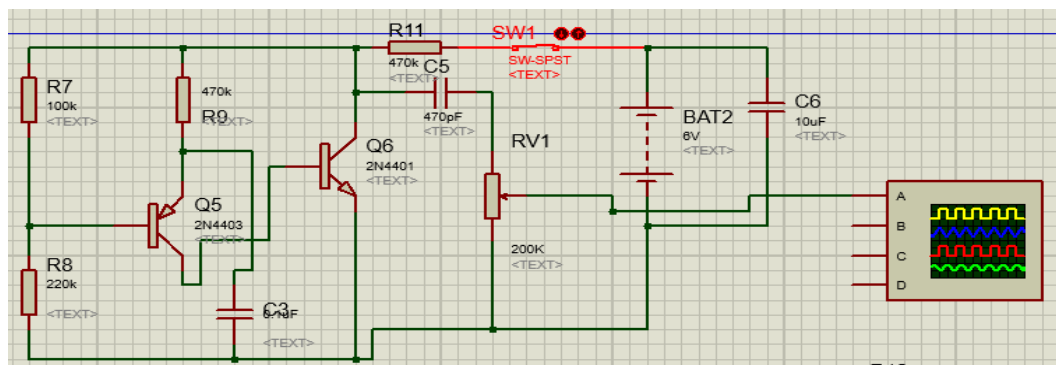


Figure 1. Schematic of the lightning simulator in Proteus.

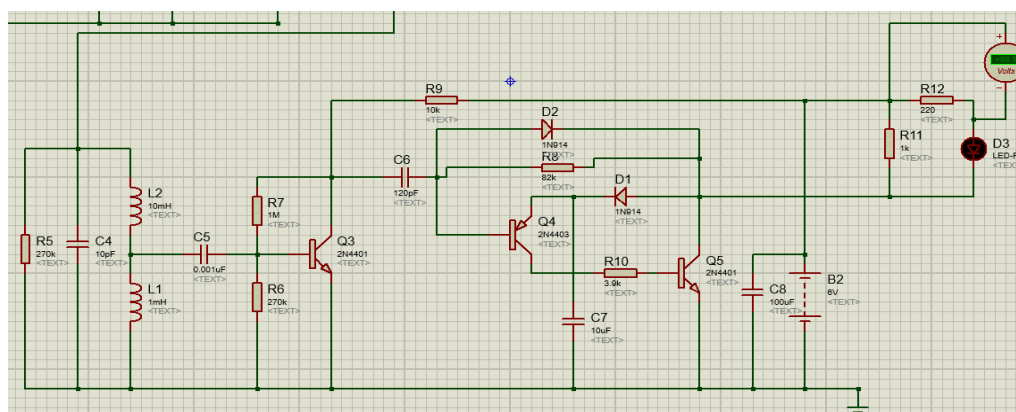


Figure 2. Schematic of the lightning detector in Proteus.

Data Collection

In order to analyse the relationship between the induced voltage and lightning strike distances, a

significant number of data is required. Some simple coding was imported to the lightning detector device to collect the data and measure the induced voltage. Those data were imported into Microsoft Excel during lightning strike occurrences. Figure 3 shows some samples of data collected on 12 April 2019. The data shows the induced voltage detected by lightning detector and time of the induced voltage being detected. The data was used afterwards to analyse the relationship between induced voltage and lightning strikes distances. By IoT integration, the result will be sending to the app installed in the mobile phone. The IoT flow was shown in figure 4.

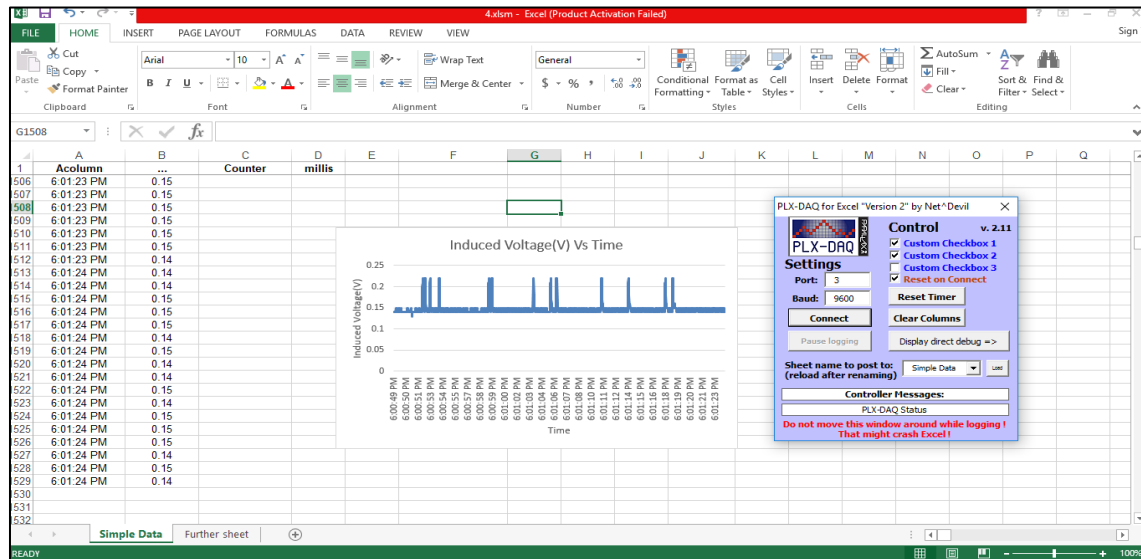


Figure 3. Sample of Data collected on 12 April 2019

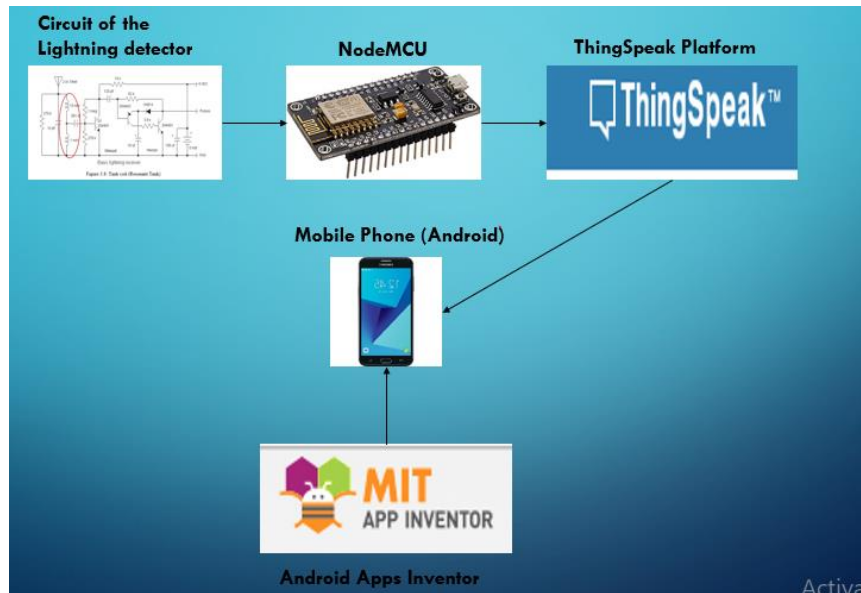


Figure 4. IoT Flows

3. Results and discussion

Data collected

Figure 5 shows the graph of the induced voltage measurement during the lightning strikes occurred on 3 April 2019 at Perlis, Arau. The result showed three peaks induce voltage at 0.61 V during lightning occur at around 2.38 p.m. on 3 April 2019. Three lightning strikes were measured according to figure 5. Others induce voltage measurement that fluctuates below 0.1 V is due to the flux produced in the lightning detector itself or the noise from surrounding and they can be easily identify and can be excluded from our data base.

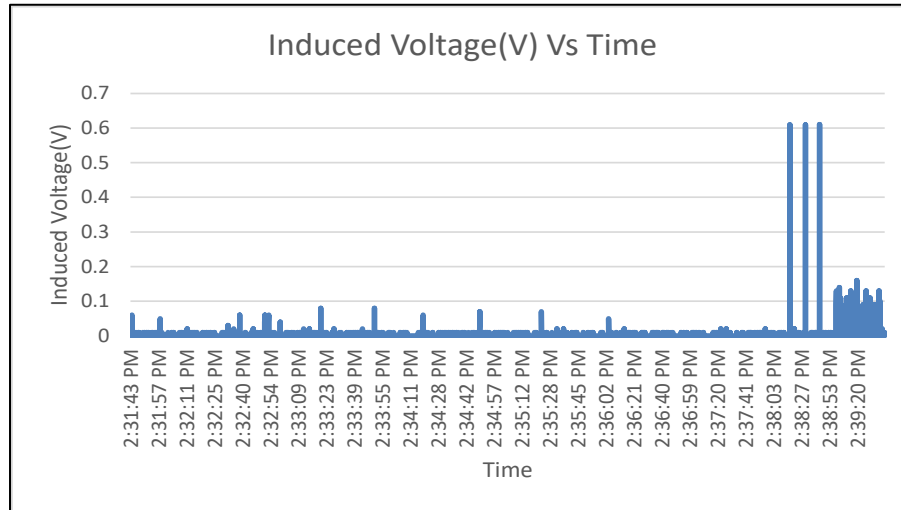


Figure 5. Induced voltage measurement versus time

Relationship between Induced voltage and lightning strike distance

The two data (the distance of lightning strike and induce voltage) are plotted in the scatter chart as shown in figure 6. The relationship between the induced voltage and distance of lightnings strike can be best explained by using equation (1). Based on the scatter chart plotted in figure 6, the R-squared value was added, and the value is 0.8908. Based on this R-squared value, it showed that the trend line relationship is pretty much reliable between two data. From the scatter chart shown in figure 6, it can be observed that there is a strong relation between induced voltage and lightning strike distance. The data indicated that the higher the induced voltage, the nearer the distance of lightning strike.

$$y = 0.8557x^{-1.396} \quad (1)$$

Where y = distances of lightning strikes in km
 x = induced voltage in V

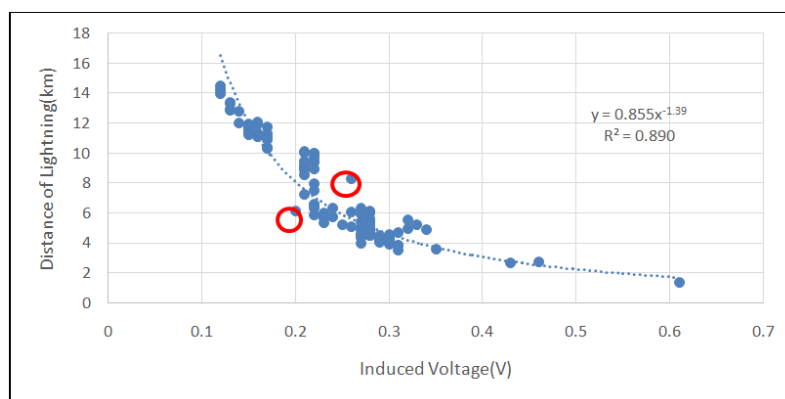


Figure 6. Scatter chart of induced voltage against the distance of lightning strike.

Accuracy of lightning detector

The distance of lightning strike was measured by using equation (1), which obtained in figure 6. Equation (2) was proposed made by time to thunder method, which was using the concept of sound speed (1 mile every 5 second). Accuracy of each data was calculated by using equation (2). Comparing the calculated distance and distance estimated from time to thunder, the average accuracy was found to be 88.03%. Figure 7 shows the scatter chart of the distance of lightning strike against the accuracy of the lightning detector. Base on figure 7, it is clearly shown that the accuracy of the lightning detector does not affected by the distances of lightning strikes.

$$\frac{t}{5} \times 1.60934 \text{ km} \quad (2)$$

Where t = time differences in second (s)

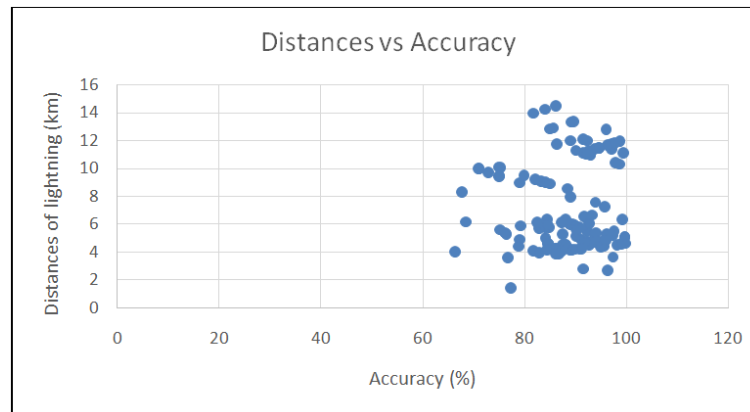


Figure 7. Scatter chart of distances of lightning strikes and accuracy of designed lightning detector.

IOT integration

The output (induced voltage) collected by lightning detector was sent via the microcontroller (NodeMCU) and stored in Thing Speak's platform as shown in figure 8. The mobile apps that created using MIT software will extract the data from Thing speak and the result will appears as shown in figure 9.

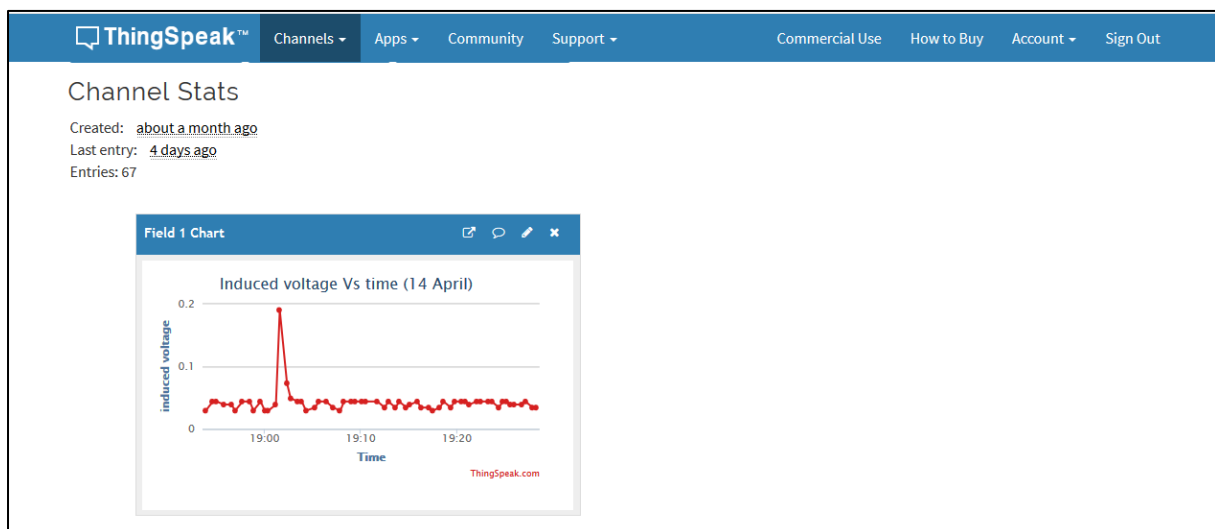


Figure 8. ThinkSpeak's Platform

Discussion

According to the data collected during lightning strikes, the relationship between induced voltage and lightning strike distance can be best explained using equation 1. Induce voltage with 0.2 V and above will able to trigger the lightning detector and activate the LED build on the detector. The red circle in figure 5 shows "abnormal" data recorded due to the disturbance on surrounding during data collection. For example, if there is an additional radio frequency (can be caused by some electronic devices such as walkie-talkie) nearby to the detector, it may cause the impulse detected by the detector higher than its actual value. The time difference is employed in the time to thunder method to estimate the lightning strike distance which is greatly affected by the time difference between the lightning strike and the thunder sound. Hence error on measuring the time difference may cause abnormal data. The estimated distances by the time to thunder method was slightly different compared with equation 1. Assuming that the time to thunder method was reliable in measuring the lightning strike distance, then the accuracy of using equation 1 to measure lightning strike distance was around 88.03%.



Figure 9. User Interface (UI) of the mobile app

Hence, equation 1 is legible to relate between lightning strike distance and induced voltage. It is suggested that the data can be sent to Malaysia Meteorological Department (MMD) centre to further improve the lightning locating system in MMD and can be included in a smartphone or smart watch for lightning threatening warning. Due to the coverage limitations of the device which mainly measures the lightning strikes within a radius of 10 km, it is recommended to install several lightning detector on the radius of 10 km. In that case, further research could be done in order to improve the detector coverage area.

4. Conclusion and Future work

Lightning causes many problems for human beings, and it is a deadly and extremely hazardous natural phenomenon. However, these dangers can be avoided by raising the awareness among public. This shows the importance of a lightning warning system in reducing the risk of injury or fatal case. Lightning can strike anywhere, so it is essential to building a mature lightning warning system to benefit others. Throughout the project, it can be concluded that lightning strikes produce electromagnetic pulses and radio frequency. These signals can be received via an antenna and create a lightning warning system. The results also prove that there is a relationship between the induced voltage and the distances of the lightning strike. Based on the analysis, it is concluded that the nearer the lightning strikes occur, the higher the induced voltage will be detected by the device. The lightning simulator is built to test and demonstrate the unit in action when no lightning is occurring around the area. It is a low frequency, and low-level oscillator. The lightning warning device was designed with a combination of IoT integration to enhance the convenience of using it. The simulations of the circuit help to prevent unnecessary mistakes when prototyping the real device. Based on the results and a few mV of the induced voltage. The small induce voltage signal produced by the lightning simulator is successfully triggered the lightning detector and produce a warning signal (LED flashes). According to the captured data from the real-time lightning strikes, it can be concluded that the lightning warning system coordination with IoT is successful. The lightning detector can capture the real-time lightning strikes and measures the distance of lightning strike within 10 km with the accuracy of 88.03%. The obtained results can be available at the mobile applications by coordination with IoT devices.

Acknowledgement

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