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Research Paper

IOT and XBee triggered based adaptive intrusion detection using geophone and quick response by UAV

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Abstract

Monitoring of remote areas needs a lot of man power, in this contrast an important additional layer to perimeter protection for home land security application is Seismic footstep detection based systems. This paper mainly concerns with the detection of any human intrusion by the detection of the footsteps from a person from few tens of meters away using an underground seismic sensor, Geophone and placing the intrusion data over the cloud by using IOT. Presence of footstep is indicated by the impulses in the geophone signal. Kurtosis, a statistical measure is used to identify the impulses, can apply for a short duration of time for which a footstep exists. Present method is less complex and computationally efficient, all the input data stored in memory, which are read through microcontroller through ADC and stored in memory is subjected to kurtosis using microcontroller. Many such nodes are connected in a topology to build a Sensor Network. Indication of the intrusion will occur when microcontroller of sensor node calculates higher kurtosis value and will send this value to control room and data is uploaded to cloud at the same time.

Keywords: *Geophone; Kurtosis Analysis; IOT; GPS; Wireless Communication; UAV Introduction.*

1. Introduction

In order to detect the person or detect vehicles, mostly uses three-component seismic velocity transducer. The principle behind the detection is generation of the succession of impacts when the Person or vehicle move over the ground and this disturbance which generate from the soil disturbance propagates away from the source as seismic waves [1]. These seismic waves are useful in detecting the footsteps which are difficult to be detected acoustically. Footsteps signal having impulsive nature and can be distinguished from the other seismic sources such as vehicles or wind noise [2]. The approach in this system is consist of a matched filter based detection system in which the arrival time of the detected footsteps is associated and localization using a hyperbolic location estimator [3]. For surveillance of a wide area the distributed networks have been used and the purpose of the sensor network is to monitor an area, detecting, identifying, localizing and tracking of one or more object of desired interest [4]. During the detection of seismic waves various additional environmental noises come along with the seismic signal and it is more difficult to filter out these noises from the sum of the seismic signal spectrum [5]. In this case the noise and signal spectra having a greater overlap for seismic signal rather than if taken for a single sensor node [6]. If target move away from these seismic signals or sources, the spectra of the spectra of noise changes rapidly [7]. Vertical ground vibration generated by walker and these vibration are recorded by using standard omnidirectional 4.5 Hz peak resonance geophones [8], [9]. The walker position and speed are measured using the portable GPS device. The data that is collected from the seismic wave is processed and the hypothetical sensor prediction performance prediction is made using an algorithm developed or the classification and detection of the intruder [10]. This data is processed through five layered structure (i.e. resource layer, perception layer, network layer, service layer, and application layer) resource intelligent perception and accessed system is based on IoT [11]. In the proposed system the seismic data from various sensor nodes is transmitted through wireless sensor network which include the Radio frequency Module to transmit the data [12]. This transmitted is received through synchronize protocols between the transmitter and receiver [13]. The sampled signal received at the receiving unit is stored in .wav file [14] and the data is processed through MATLAB. The geophone data is band limited between the 10 Hz to 100 Hz using a band pass filter [15]. Peak amplitude of the band limited geophone is detected and is subjected to kurtosis operation and this kurtosis value is evaluated [16] and Intrusion occurs if this value is greater than three and location information like latitude and longitude of sensor node collected by the GPS system interfaced with the microcontroller of sensor node [17].

2. System description

Intrusion detecting system mainly has three sub systems. They are sensor network for detecting human intrusion, control room and unmanned vehicle to take action against intrusion. Wireless Communication system to communicate between sensor nodes, control room and unmanned vehicle.

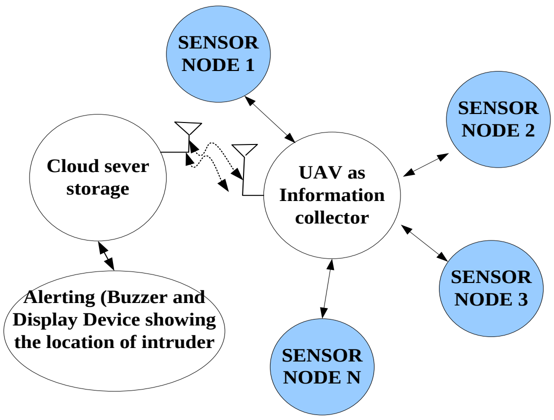

Fig. 1: (A) Generalized Block Diagram.

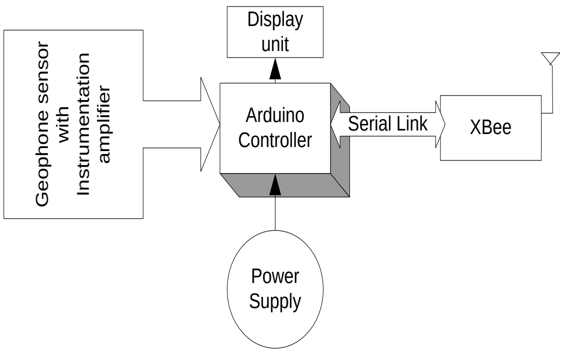

Fig. 1: (B) Single Sensor Node Architecture.

Fig. 1(a, b) are the generalized block diagram and Single Sensor node architecture in which the process of data flow between the different nodes and how a single node communicate with the rest of nodes is shown.

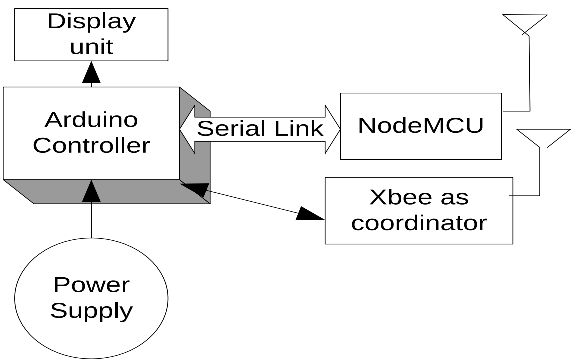

Fig. 1: (C) Information Collector from Sensor Node + Wi-Fi Link Architecture.

Fig. 1(c) is the schematic architecture of the control room that receive the intrusion data through serially link and upload this data to the cloud through NodeMCU.
Fig. 1(d) is the schematic architecture of the UAV that respond the intrusion data. The UAV consist of multiple telemetry system to communicate through various wireless protocols. The three different protocols for GPS, Camera Module and UAV control. UAV responds to the sensor node that detect the intrusion and sends its GPS location to the control room from where UAV activated to supervise the detected node

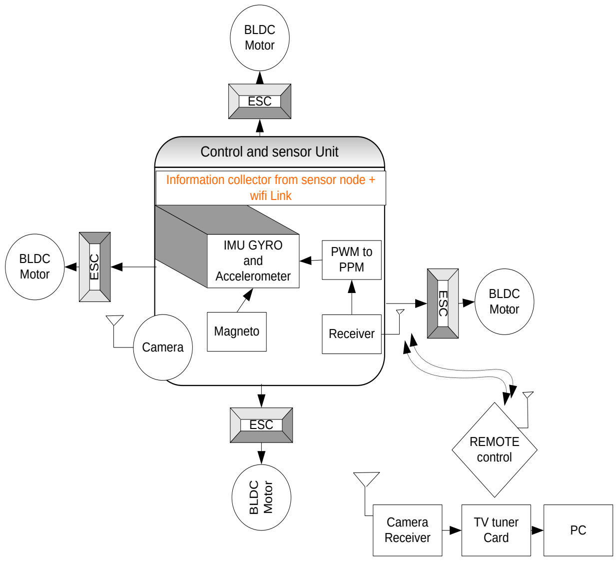

Fig. 1: (d) UAV Architecture.

2.1. Sensor network

Sensor network is a cluster of several sensor nodes arranged in a topology, best suited for the system. Before designing the sensor network, sensor node has to be designed. The more effort will be put on to design a sensor node by implementing the theoretical concepts shown in Fig 1 which is altered and shown below to suit the hardware implementation as in Fig 2.

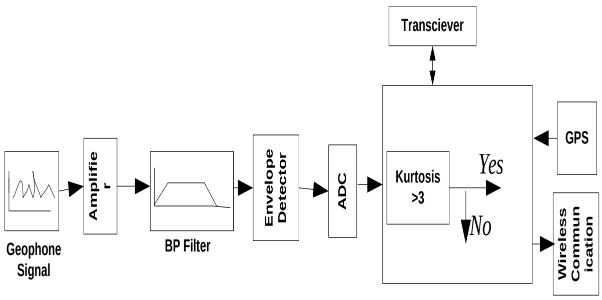

Fig. 2: Actual Sensor Node Setup.

Simulation of sensor node constructed in MATLAB software. Here, geophone data is recorded using data acquisition device and processed using MATLAB simulation software. Whereas for hardware implementation, geophone signal is band limited between 10 Hz and 100 Hz using a band pass filter. Envelope Detector tracks the peak amplitude of the band limited geophone signal. This signal is subjected to kurtosis operation by Microcontroller by reading Envelope Detector output through Analog To Digital Converter. Intrusion is detected when kurtosis value is evaluated to be greater than 3 by Microcontroller. When intrusion is detected, Microcontroller informs the intrusion information to control room wirelessly. Information consists of time of intrusion and location information like latitude and longitude of sensor node collected by the GPS system interfaced with the microcontroller of sensor node. Otherwise, it keeps looking for intrusion.

2.2. Control room and unmanned vehicle

Any intrusion detected by sensor node is communicated to control room wirelessly. Control room can initiate action against intrusion. Initiation could be taken by sending a unmanned vehicle to the sensor node with special features like camera recording, automatic weapon firing or it could be like turning on the camera installed at the intrusion detected sensor node. Later, initiation will help in monitoring a specific camera, which needs more attention than many other cameras in the vast field. However, in this prototype system model, only unmanned Aerial Vehicle is build, which navigates near sensor node after detection of intrusion. Detection of intrusion is informed by sensor node to unmanned Aerial vehicle using 433 MHz Transceiver in this prototype model. However, higher range wireless communication can be utilized based on the area of the field under supervision.

2.3. Wireless communication system

In this system, wireless communication can be implemented mainly between three points. Firstly, it is implemented between sensor node and control room. Secondly, it is used between control room and unmanned Aerial vehicle. Lastly, wireless communication is required between sensor nodes for future optimization of the sensor network.In this prototype hardware model, sensor node communicates using 2.4 GHz Transceiver, with unmanned Aerial vehicle bypassing control room. Also, wireless communication devices with higher range are preferred over 2.4 GHz in real world.Bottom = 1.5cm

2.4. IoT application gateway

The transformation of the data between the Base monitoring station and the IPv6 is executed by the program which is placed at the IoT application gateway because the sensor nodes are not capable to communicate with the Internet Protocols [19]. The IoT application gateway transforms the RF unit address and encapsulating the data payloads in an internet protocol. The data is encapsulated in an UDP packet by server and converted to IoT application gateway.

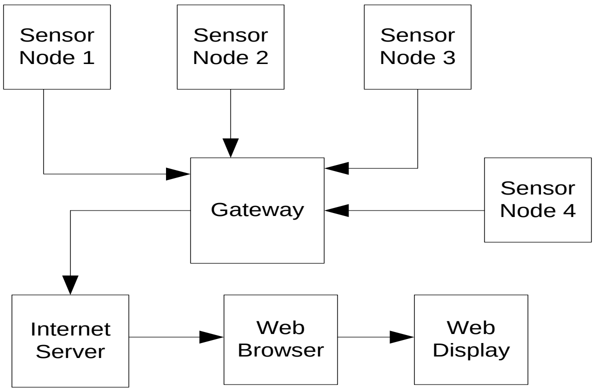

Fig. 3: Data Flow in Hardware Using XBee And IoT.

3. Analysis

3.1. Amplification

Geophone outputs the voltage signal in few millivolts which is very small to supply into band pass filter, envelope detector and microcontroller. Sample geophone signal is as shown in the Figure 4.

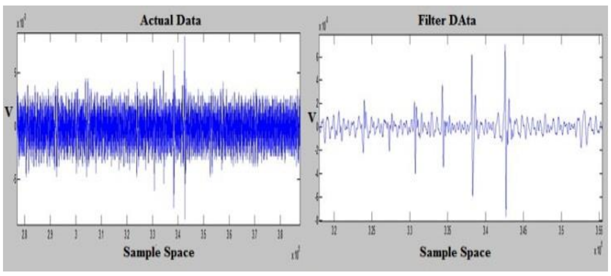

Fig. 4: Geophone Signal and Band Pass Filtered Geophone Signal.

From inspection, the average peak amplitude of the geophone signal is around 5 millivolts. But, Microcontrollers generally reads analog voltages from 0 volts to 5 volts. Therefore, signal from geophone has to be amplified from 5 millivolts to 5 volts. Hence, an amplifier of gain 1000 has to be used and the amplifier must be capable of amplifying the small voltages in range of millivolts. Simple operational amplifier will not be capable to amplify analog signal of very small strength. Also, simple operational amplifier will not have the gain in the range of 1000. However, instrumentation amplifiers like PGA202, PGA203 and AD623 can amplify such low amplitude signal and also give gain up to 1000. Above Figure shows the amplification connection using AD623 instrumentation amplifier. From datasheet of AD623, the value of RG is given by 100 kilo Ohms / (G -1). Where, G is the gain value of AD623. System requires a gain of 1000 to amplify 5 millivolts to 5 volts. Substituting the value of 1000 for G in RG = 100 kilo Ohms / (G - 1), value get RG = 100.1001 Ohms. Signal from geophone is applied across the pins 3 and 2 of AD620 IC. Output signal which is the amplified signal of the input is obtained across the pin 6.

3.2. Band pass filtering

The frequency range, which contains the main part of the footstep signal energy for a distance greater than 6m, is usually lower than 100 Hz. A Band pass filter is implemented as 2 poles Low pass filter with cut off frequency of 100 Hz and 2 pole High pass filter with cut off frequency of 10 Hz. The roll off rates of LPF and HPF are -40 dB/decade and 40 dB/decade respectively.

3.3. Envelope detection

After the signal has been filtered it looks like the signal shown in Figure 5. Notice how the impact from the footsteps generates both positive and negative waves. The frequency of these waves is controlled by the terrain. Performing kurtosis on the entire signal instead of just the peak amplitude of signal might generate wrong kurtosis value. The goal however is to treat this whole block as one impact and then determine the parameters. This is achieved by tracking the peak amplitude of the signal and subjecting it to the kurtosis operation. Tracking of peak amplitude is accomplished by the process of envelope detection. Two methods were considered to implement the process. First method, Hilbert Transform method is more suitable when the envelope detection process is implemented by programming. Second method implements the same using a RC hardware, diode and Op-Amp
In Hilbert Transform method, the concept of analytic signal or pre-envelope of a signal x(n) can be described by the expression shown in Eq. (1) as,

$$y(n) = x(n) + jx(n) \quad (1)$$

The envelope of the signal is given in Eq. (2) as,

$$e(n) = \sqrt{x^2(n) + y^2(n)} \quad (2)$$

The envelope is formed by taking the absolute value of the analytical signal. This generates an envelope for each of the footsteps shown in Figure 5.

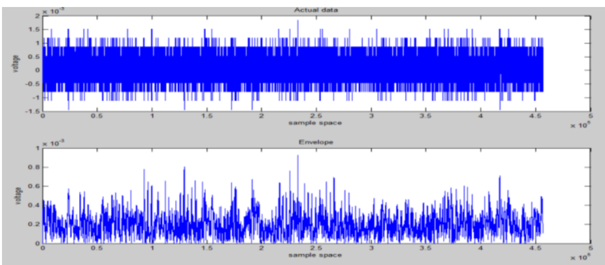

Fig. 5: Envelope Detected Signal of Person Running in 5m Radius.

3.4. Kurtosis-intrusion detection

Footstep signal is characterized with impulsive nature in its seismic signals periodically with each impulsive part of the signal representing a footstep. Such impulsive nature can be used to distinguish the seismic signals generated from footsteps from other seismic signals generated by other events like vehicle movement, wind noise. Measure of impulsiveness is called as kurtosis. Kurtosis calculated on footstep signal is found to be greater than 3 due to its impulsiveness. Whereas, for non-impulsive seismic signal possess kurtosis less than 3. Hence, performing kurtosis on seismic signal will help in distinguishing footstep seismic signal from other seismic signals.

Kurtosis is ratio of the 4th and 2nd moment of the amplitude distribution of the signal. Kurtosis varies only with the shape of the signal but not the amplitude. This concept is very important for the technique to infer that kurtosis performed on walking and running seismic signal do not differ.

For N samples of the seismic signal, the kurtosis is calculated and expressed in Eq. (3) as,

$$Kur = \frac{\sum_k \frac{(x_k-\mu)^4}{N-1}}{\left(\sum_k \frac{(x_k-\mu)^2}{N-1}\right)^2} \tag{3}$$

Where µ is the mean over N samples.

Kurtosis is implemented in sensor node by a microcontroller. For building a prototype sensor node, Arduino Mega 2560 is utilized because arduino microcontrollers provide greater flexibility and ease while coding and has many inbuilt functionalities like analog to digital convertor. Microcontroller reads envelop detected signal through its analog pin, stores in EEPROM of the microcontroller continuously for every few seconds, depending on the sampling rate. Sampling rate is taken as 1000 Hz for this system, which is sufficient enough to sample the envelope detected signal. Simultaneously, while saving the data every 1/Sampling Frequency seconds, by using the concept of interrupt, kurtosis operation is also performed by microcontroller.

The kurtosis can be calculated on the output of Band Pass Filter. But, this method of calculating might lead to wrong determination of kurtosis as the entire signal is taken into consideration. Therefore, performing kurtosis, after subjecting the band limited signal through envelope detector would give more accurate kurtosis value as envelope detector keep track of the peaks of the band limited signal. Kurtosis value computed on sinusoidal signals and Gaussian noise signals are lesser than 2 and 3 respectively. Hence, our technique is to analyze the envelope signal every 200 ms increments, and compute the kurtosis of the signal in that sample. The reason for choice of 200ms as the window time can be explained as follows. The maximum speed at which a person can run for a short duration is 10 m/s. For covering 10m in a second the person has to take at least 5 footsteps 2 m apart in order to achieve it. Hence there can be 5 footsteps in a second at max and the time interval between two successive impulses is a minimum of 200ms in case of a single source. The cadence frequency of a human is defined as the number of footsteps per second when he is walking normally. The cadence frequency turns out to be 2Hz implying that 2 footsteps can be found 500 ms apart under normal condition.

The duration of the footstep is around 100-150ms. The impulse generated by the heel striking the ground lasts for 50ms with smaller peaks due to the friction of the front part of the ground for the remaining duration of the footstep.

3.5. Variatruion of kurtious with distance

The value of kurtosis varies with distance between source and sensor. When the source is nearer to the sensor the value of kurtosis during the footstep is larger and when the source moves away from the sensor the kurtosis value of the footstep decreases. At a certain distance the kurtosis value falls below the threshold of 3. The range of the sensor is thus limited by the noise in the environment. When the surroundings are calmer then the range of detection is larger than usual. It was observed that the detection range considerably increased during night.

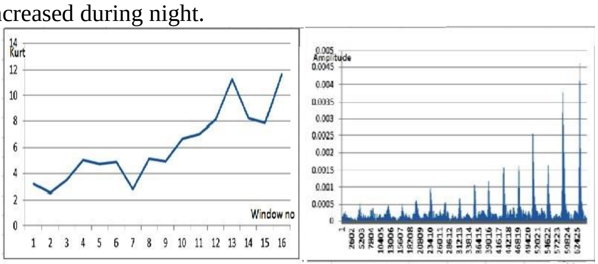

Fig. 6: Variation of Kurtosis as Source Walks Towards the Sensor.

4. Software development

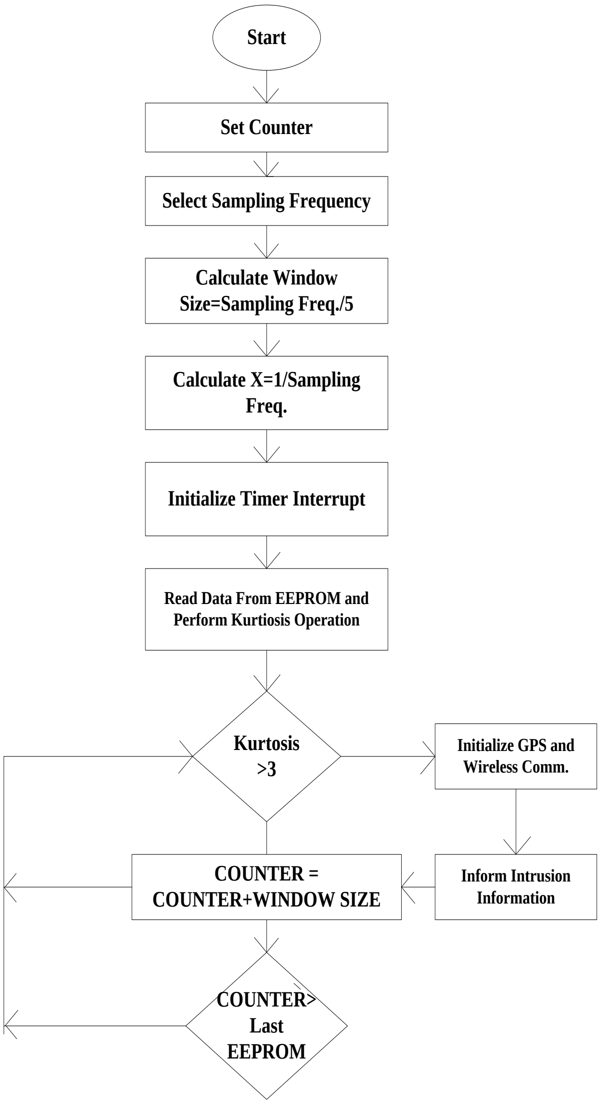

Fig. 7: Flow Chart of Sensor Node.

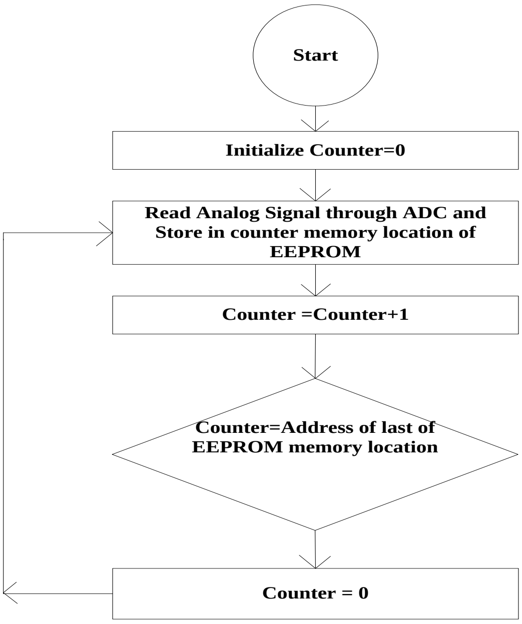

Fig. 8: Flow Chart of Interrupt Subroutine for Reading Sensor Data.

5. Unmanned aerial veichle (UAV)

An Unmanned Aerial vehicle (UAV) is a robot used to augment human capability in both civic and military activities in open terrain. It is used as a human replacement in several military operations such as capturing video, handling explosives, diffusing bombs and front linear reconnaissance. UAV receives command from control room to take action against the intrusion, when sensor node detects intrusion. Sensor node informs its location attributes read from Global Positioning System (GPS) to control room; same is communicated to UAV as well, which helps UAV in navigated to the sensor node, again with the help of GPS.

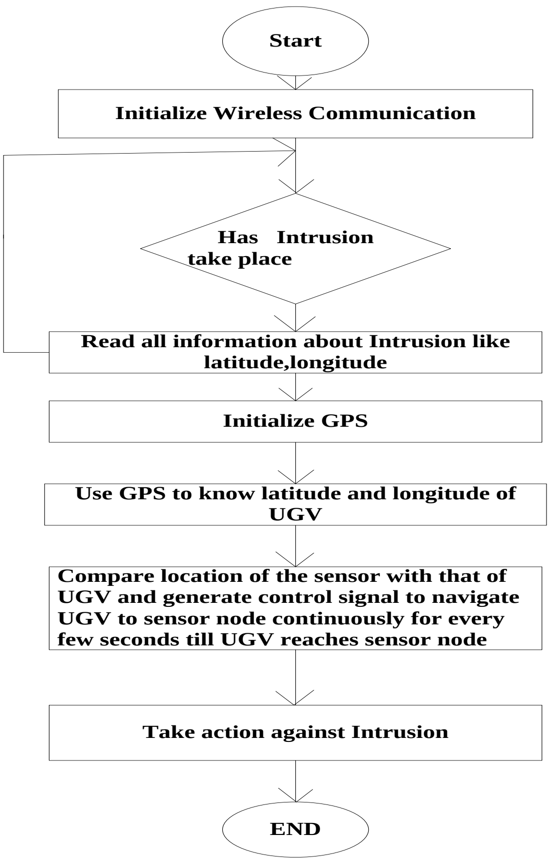

Fig. 9: Flow Chart of UAV.

6. Programmed algorithm of data communication

```
void send_data()
{
  for(int i=0;i<=8;i++)
   {
   LCD_BLYNK.clear();
   Blynk.virtualWrite(V6, GEOValues[i]);
   LCD_BLYNK.print(0,0,"VIR:");
   LCD_BLYNK.print(5,0,GEOValues[i]);
   delay(10);
   //Serial.println(GEOValues[i]);
   }
  }
```

Fig. 10: Function to Send Data to APP.

```
/////////////////////gps

BLYNK_WRITE(V2)
  {
  GpsParam gps(param);
  Serial.print("LAT:");
  Serial.print(gps.getLat());
  Serial.print("LONG:");
  Serial.println(gps.getLon());
 }
```

Fig. 11: Function to Read GPS Coordinate from APP.

```
//////////////////////////////RTC
void clockDisplay()
{
  String currentTime = String(hour()) + ":" + minute() + ":" + second();
  String currentDate = String(day()) + " " + month() + " " + year();  //
  Serial.print("Current time: ");
  Serial.print(currentTime);
  Serial.print(" ");
  Serial.print(currentDate);
  Serial.println();

  // Send time to the App
  Blynk.virtualWrite(V4, currentTime);
  // Send date to the App
  Blynk.virtualWrite(V5, currentDate);
  delay(20);
 }
```

Fig. 12: Function to Read RTC from APP.

```
Current time: 10:12:39 7 11 2017
Current time: 10:12:51 7 11 2017
[601464] Connecting to blynk-cloud.com:8
[601996] Ready (ping: 93ms).
Current time: 10:13:0 7 11 2017
Current time: 10:13:14 7 11 2017
[624391] Connecting to blynk-cloud.com:8
[625219] Ready (ping: 93ms).
Current time: 10:13:19 7 11 2017
Current time: 10:13:29 7 11 2017
Current time: 10:13:39 7 11 2017
Current time: 10:13:49 7 11 2017
Current time: 10:13:59 7 11 2017
LAT:30.42LONG:77.97
Current time: 10:14:10 7 11 2017
```

Fig. 13: Serial Data of RTC and GPS on NodeMCU from APP.

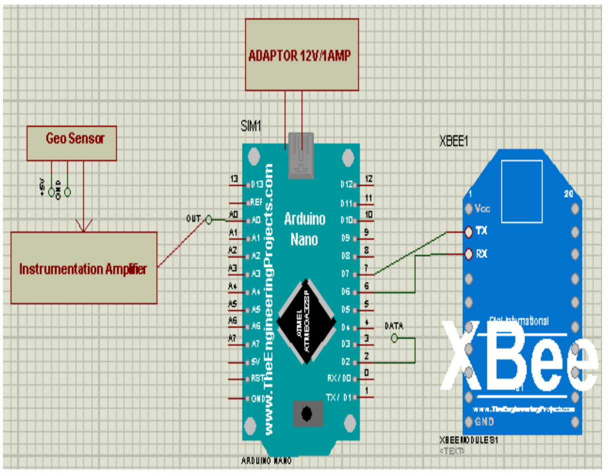

Fig. 14: Schematics of Sensor Node.

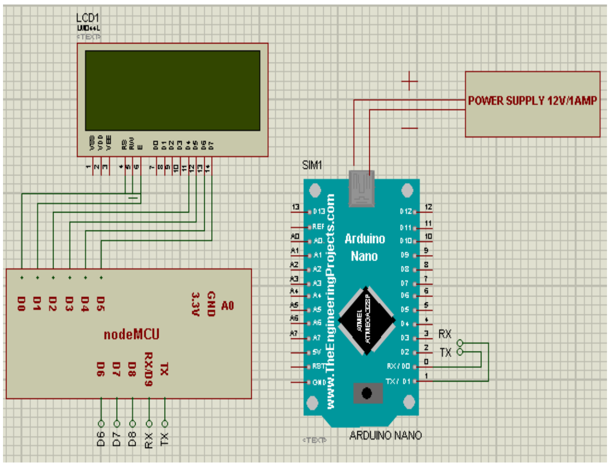

Fig. 15: Schematics of XBee Coordinator and Wi-Fi Link to cloud.

Fig. 14 and 15 shows the schematics of sensor node and XBee coordinator to collect the information send to cloud using Wi-Fi link. The main elements of system are Arduino Nano, XBee, Geo phone and NodeMCU.

7. Result and discussion

Geophone available with us is not sensitive enough to capture the seismic signals generated by human footstep. Hence, the project is demonstrated using Signal Generator and DAC in Arduino Due microcontroller board.

A sinusoidal signal of 5 millivolt amplitude is generated using Signal Generator. This signal is corresponds to the non-footstep signal captured by geophone. If the frequency of the signal is not in between 10 Hz and 100 Hz, then the signal is attenuated at band pass filter of sensor node, hence no signal is available to process further in sensor node. This is due to the reason that the sensor node is designed to work only with footstep signal, which can have frequency between 10 Hz to 100 Hz. If the signal is confined between 10 Hz and 100 Hz, then the signal is amplified, band limited and subjected to envelope detector circuits before subjecting to microcontroller for performing kurtosis operation. The signal generated is sinusoidal in nature, which is different from the footstep signal generated in geophone. Kurtosis calculated by microcontroller is always less than 3. This demonstrates that the intrusion has not occurred. Hence Unmanned aerial Vehicle remains in its place.

Generation of footstep signal, captured by geophone using signal generator alone is difficult. However, Generation of the signal which is similar to the output signal of Envelope Detector, when sensor node is subjected to footstep signal is easy. This signal is generated using DAC of Arduino Due microcontroller board. This signal is applied to microcontroller of sensor node for performing kurtosis on signal. Microcontroller of sensor node finds that the kurtosis value is greater than 3, which indicates intrusion. This information is informed to UAV wirelessly and at the same time is uploaded to cloud by IoT NodeMCU device. Unmanned Aerial Vehicle navigates towards sensor node and stops. Hence, all the scenarios are demonstrated using Signal Generator and DAC of Arduino Nano.

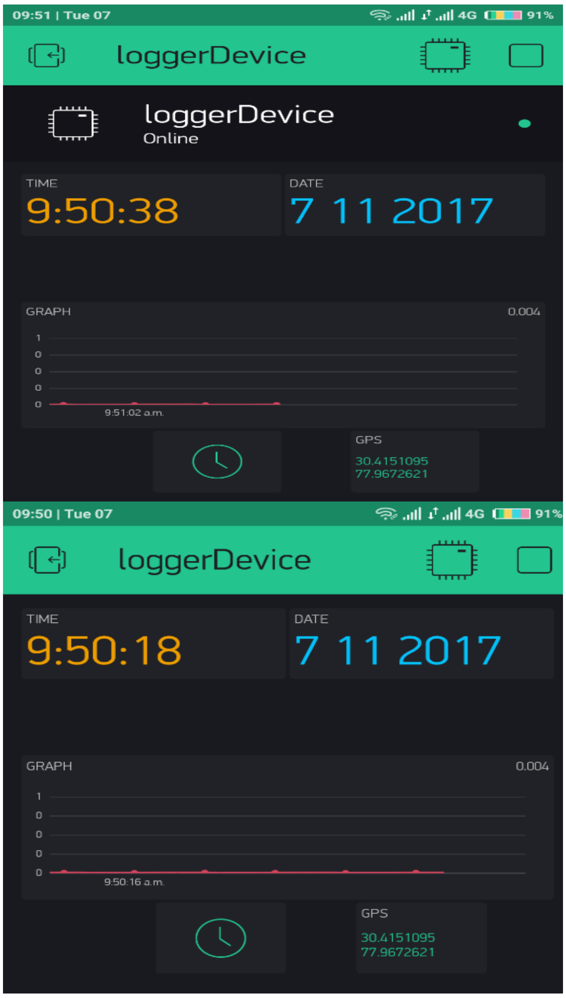

Fig. 16: Snap Shot of APP as Data Logger.

8. Conclusion and future scope

Result demonstrated by generating signal similar to geophone signal using signal generator and DAC of Arduino Due microcontroller board shows that the geophone with sufficient sensitivity can be used to develop sensor node that can detect human footstep, thereby detecting intrusion. However, the results of the project is demonstrated by generating the signal similar to the geophone signals using Signal Generator and DAC of Arduino Due microcontroller board which hold true with results that can be produced using geophone with sufficient sensitivity too.2.4 GHz transmitter and receiver are used to communicate between sensor node and UAV, bypassing control room. As only one sensor node is developed, control room has been bypassed. Using 2.4 GHz transmitter and receiver, maximum distance of communication between sensor node and UGV is few meters. This distance can be increased by using better form of wireless communication. Topology of the sensor network can be altered according to the requirements of the area of security. In this project one to one topology is used between sensor node and UAV bypassing control room. Navigation of UAV from control room to sensor node and vice versa has to be updated with better technology. Obstacle avoidance of the UAV is also a concern.

- This paper has huge scope for updating. Following are few updates that can be considered as updates.

- The Band pass filter used for filtering of footstep is fixed for this project. The filter has to be made adaptive so that the filter can be modified based on the site and incoming data.
- Envelope Detection, Amplification processes has also need to be adaptive.
- Unmanned All-Terrain vehicle, Quad copter can be used instead of simple UAV with better technologies like obstacle avoidance, transmitting video wirelessly and better algorithm to reach destination or intrusion detected sensor node with shortest distance from control room Range of wireless transmission can be increased using better wireless technologies like Wi-Fi, NRF, LoRA etc.

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