Jewel Beetle-Batteryless WSN Eco Monitoring System

Rajiv Iyer and Aarti Bakshi

Abstract This paper presents a system for monitoring forest fire using wireless sensor networks (WSN) and the Internet of Things (IoT). Forest fire is an important and unsolved ecological problem. Although many solutions are available in the literature and practice they have not been able to solve the problem effectively. Also, they have problems in terms of cost and ease of implementation. This paper deals with the design and development of a batteryless eco monitoring system and it is used on readily available energy sources. However, improvement of the performance is needed, therefore methods of harvesting energy around these sensors are implemented to extend the life of the battery or ideally provide an endless supply of energy to the sensor. To achieve this, we have designed 3 nodes working on the energy that will be provided from readily available energy from harvesting systems. These nodes with attached sensors are been used to collect the environmental data. The system is optimized in terms of reliability and sensitivity as compared to existing systems.

Keywords Arduino · Eco monitoring · Energy harvesting · Forest fire · IoT · Temperature sensor

1 Introduction

Forest fire is a problem that is yet not solved which is leading to major environmental changes all over the world. It is irreparably affecting the flora and fauna. Although a lot of techniques to detect forest fire are available in literature each has its own challenges in terms of cost, ease of implementation, complexity, and availability. Further battery-based systems require replacements which are difficult in forest environments and are not easily accessible to humans Thus there is a growing interest to harvest ambient energy for the operation of solutions designed for forest fire detection such as low-power wireless sensors. RF energy harvesting can be used to partially/fully

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supply the energy required for the operation of portable electronic devices such as wireless sensors, cell phones, Bluetooth devices, medical implants, and hearing aid devices. The work in this paper presents two energy harvesting techniques that can be deployed for forest fire detection systems. This paper also shows the three nodes developed using processors which are low energy, low cost, and have low processing power suitable for forest fire detection applications. In this paper, we will first review the work done previously in Sect. 2. Section 3 describes the proposed methodology and discussed the results obtained in Sect. 4. We conclude in Sect. 5.

2 Related Work

Zigbee-based methods are used in forest fire detection systems [1] to monitor temperature and humidity in the forest more promptly and accurately. The authors have highlighted the special benefits of data transmission security, network flexibility, and low cost and energy requirements for a forest fire monitoring system based on a Zigbee wireless sensor technology that they designed. The system's topological structure is a cluster tree adaption. A cluster tree structure is simpler to build than a reticular one, because the information flow requires less memory. The maximum range of Zigbee places restrictions on the system.

Also, problems of energy consumption, node location, and clock synchronization need to be addressed. As described in [2], a mechatronic evaluation of forest fire monitoring systems based on UAV is implemented. Drone-based systems are also used for these systems. The requirements are mapped to the mechatronic capabilities that these systems should possess. The supporting technology for these skills are succinctly described. The discrete Choquet integral is used to assess the architectural designs of these systems. Using drones, however, is not cost-effective in scale and faces regulatory issues in many countries.

In [3] a robotics-based mechanism is used. The authors created a drone-based unmanned aerial vehicle (UAV) and employed it for various robot mechanism applications. Magnetometer, temperature, and night vision cameras are all present. To detect the Earth's magnetic field, spot magnetic anomalies, and calculate the dipole moment of magnetic materials, magnetometers are frequently employed in geophysical surveys. A magnetic sensor can assist in the detection of landmines. In order to record or communicate temperature changes, a temperature detector detects the ambient temperature and turns the input line into electrical data. The image or tape-hung night vision camera uses both electrical and graphic camera detectors to permit moving objects within the monitored environment. Based on this module, the Unmanned Aerial Vehicle (UAV) will fly throughout the day, at night, in smoky areas, over uncharted territory, and in search of unknown activities in order to identify the forest fire for emergency purposes. The temperature will be detected, the forest fire will be located, and a response notification will be sent to the controller using a temperature sensor. However, using drones also has issues with the sensors that are mounted on them, especially magnetometers. In [4], a drone-enabled wireless sensor network (WSN) was used.

This article proposes the optimal weighted probability function, taking into account the remaining node energy, node spacing, and average energy of the network by the author. This feature helps optimize the clustering process for three levels of heterogeneity by minimizing the energy of the proposed network. The proposed method achieves a 29.45% and 52.48% increase in network life compared to existing algorithms. The reason for this significant increase in network life is to use the proposed features to select the most powerful node as the cluster head. However, the system is limited by flight time and complex mathematical modeling of the drone. In [5] authors establish a geostationary satellite-based forest fire monitoring system that can monitor areas of the Korean Peninsula 24 h a day for forest fire monitoring, and describe how to establish a forest fire monitoring system and use it in various ways. In order to establish a satellite-utilized forest fire monitoring system, they have concluded literature research, technical principles, forest fire monitoring means, and a satellite forest fire monitoring system. The satellite-utilized forest fire monitoring system can consist of one geostationary satellite equipped with infrared detection optical sensors and a ground processing station that processes data received from satellites to spread surveillance information. Forest fire monitoring satellites are located in the country's geostationary orbit and should be operated 24 h a day, 365 days a day. Forest fire monitoring technology is an infrared detection technology that can be used in national public interests such as forest fire monitoring and national security. It should be operated 24 h a day, and to satisfy this, it is efficient to establish a geostationary satellite-based forest fire monitoring satellite system. The satellite-based classical system lags continuous monitoring, requires complex processing and the information does not reach the ground in real-time though. In [6], the author reports on a new tag-based WSN that does not use chips and batteries, which fundamentally breaks all previous paradigms. Consisting of off-the-shelf components on a printed board, this WSN can acquire and transmit information without injecting or collecting DC power, while polling the node with a full-duplex transceiver design, thus the node itself. Not affected by self-interference. The WSN described does not require advanced and expensive manufacturing, but its unique parametric dynamic operation allows for superior sensitivity and dynamic range beyond what is achieved with on-chip sensors. Batteryless systems for forest fire detection are at a very nascent stage and are not available widely.

Thus there is a need for a low-cost solution for forest fire detection with a device that can harvest energy available through renewable sources which can be easily deployed in harsh conditions. This paper addresses the problems in existing systems and is easily deployable and cost-effective.

3 Proposed Methodology

In order to prove the concept of the proposed system, we implemented a processing unit with a temperature and humidity sensor on the main circuit board. We investigated the characteristics of the environmental monitoring applications and clarify the requirements for designing the batteryless WSN system. The Jewel Beetle (JB) system is placed in the forest area where it covers the maximum possible area for monitoring the changes in different physical parameters such as temperature, humidity, etc. When a sufficient amount of energy is charged in the energy storage unit, the Jewel Beetle node gets activated. In an event of an emergency, i.e. when the sensors detect an abnormal situation, the active node informs its control station. The JB node charges energy obtained from an energy conversion device to a storage unit. Since light sources will be found in nearly every place, we are using solar cells for the energy supply of the JB node to support a good variety of monitoring applications. Additionally, we are using the RF energy within the current implementation. The solar cell or RF unit is provided with an energy storage unit in order to store the obtained electrical power temporarily. Further, the energy kept within the energy storage unit is connected to the processing unit that is integrated with sensors to observe the environmental parameters. We are using IoT as a communication model. We have implemented three different nodes with reducing the size as well as cost.

3.1 RF Harvester

The energy harvester will be used by all three nodes being discussed in next section. Firstly we designed an antenna for harvesting RF energy as shown in Fig. 1. This circuit is further given to the doublers circuit shown in Fig. 2. To design an antenna we took a one-sided copper cladding PCB. Then the photoresist mask of that shape that we want to implement is applied to the PCB. For this photoresist, we used a permanent marker here. We applied a double coat of photoresist and let it dry. Then we took FeCl3 (ferric chloride) solution n dipped PCB in it. Shake it well for 10-20 min. By doing this the part without photo resists on PCB goes off. To remove the photoresist acetone solution is rubbed on it. In simple words, the marker part is removed and only the copper substrate remains. Now for the feed line, we need center feed. For this PCB is drilled at the center and from that, a copper wire is mounted and soldered. From this, we get to feed, and hence we got our desired antenna. The RF energy from this is passed through a doublers circuit and then given to the other devices of the system. To store this energy, we have used an electrolytic capacitor.

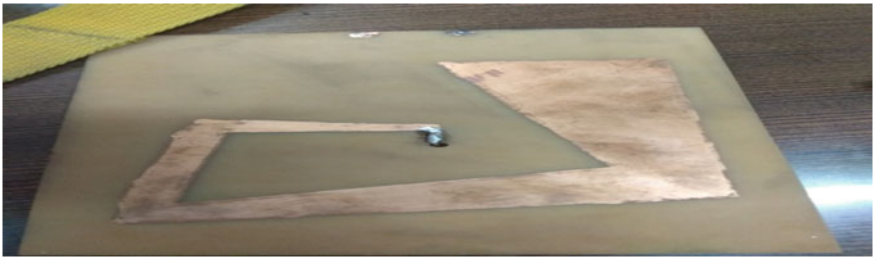

Fig. 1 RF Antenna developed for energy harvesting

Fig. 2 Doublers circuit for RF energy harvesting

3.2 Proposed Models for Forest Fire Detection and Working

We have proposed three different nodes for forest fire detection (FFD); FFD 1, FFD2, and FFD3. Each model has a different hardware.

Node implementation using Arduino (FFD1).

In the above block diagram (see Fig. 3), the solar energy is extracted and converted into dc energy. This energy is stored in a rechargeable battery which charges through the battery charging rectifier circuit that gets the input energy through the solar. This battery charger is used to provide the power supply to the system. A voltage sensor is used to measure the battery voltage. Arduino UNO is used as a processor. Arduino controls the temperature and humidity sensor which is a DTH11 SENSOR and the Wi-Fi module which is ESP8266P. The program for processing is burnt in the Arduino using software ARDUINO IDE. Initially, Arduino is connected to the PC side web application using a Wi-Fi module. DTH11 sensor is used to measure the temperature and humidity of the environment. It will detect the temperature and humidity of the environment and Sensor data will be sent to the controller. If the temperature and humidity increase above a threshold then the controller will send the alert notification as fire is detected on the web application on the PC side through the Wi-Fi module. Here the database is created with date and time. This all is processed through a XAMP SERVER. As shown in Fig. 4, LCD (16×2) is used to display battery voltage status, temperature, and humidity. This node basically uses the RF energy as the resource. This energy is extracted using an antenna. The methodology used is explained in the flowchart as shown in Fig. 5.

Node implementation using Node MCU (FFD2)

As shown in Fig. 6, the Node MCU works as a processing unit as well as a Wi-Fi module. Moreover, it has an inbuilt web application so there is no need to use the XAMP server for the webpage. Figure 7 shows the hardware implementation of the FFD 2 node which has the Node MCU module with an inbuilt Wi-Fi module.

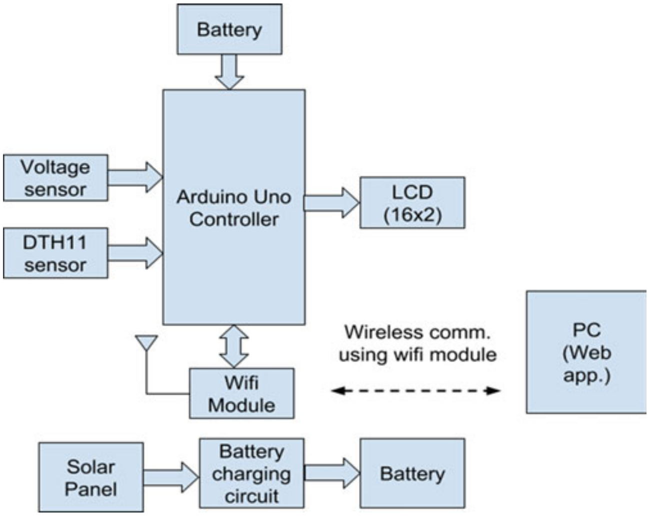

Fig. 3 Block diagram of node1

Fig. 4 LCD display

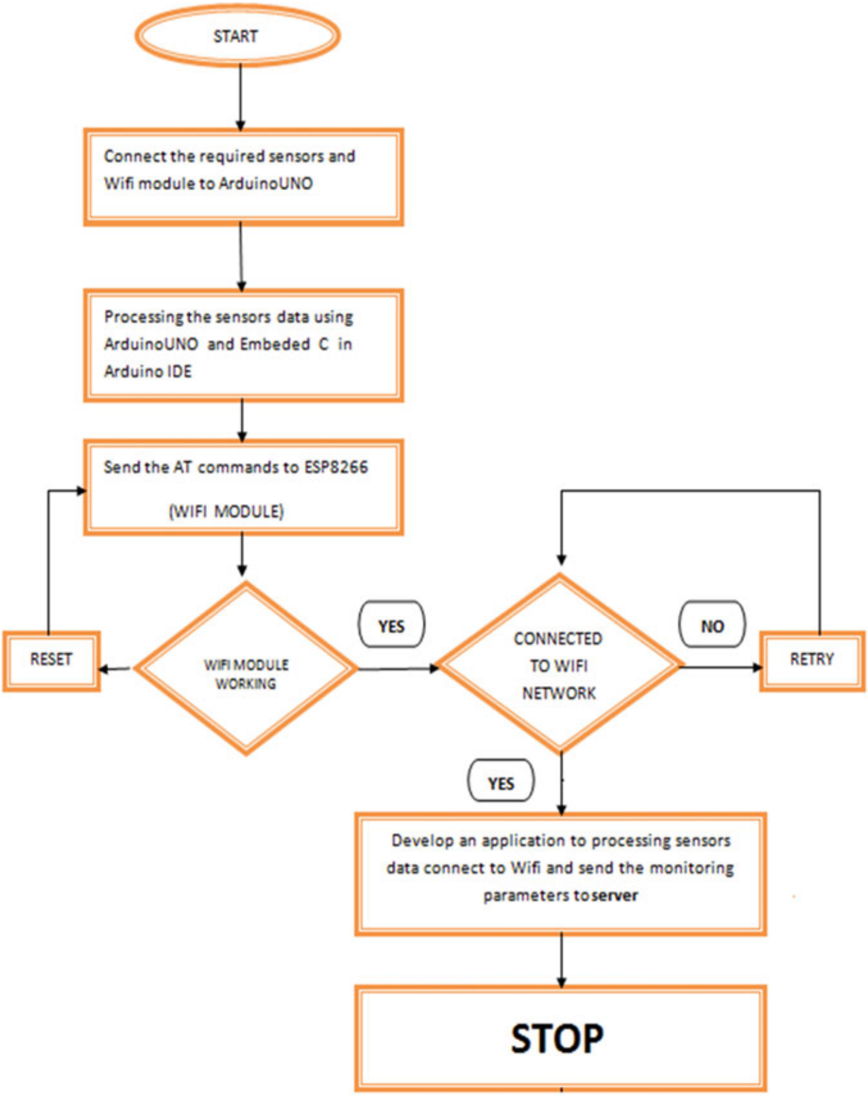

Fig. 5 Methodology of FFD node1

Node implementation using ESP01 (FFD3)

Here again in FFD3, as shown in Fig. 8, in the block diagram the RF energy is extracted using an antenna. The rest working is the same as in FFD2. The only difference is that Node MCU is replaced with the ESP01 as shown in Fig. 10 which works as a processor sending the data to the website as shown in flowchart Fig. 9. This reduces the hardware size as well as the cost much further.

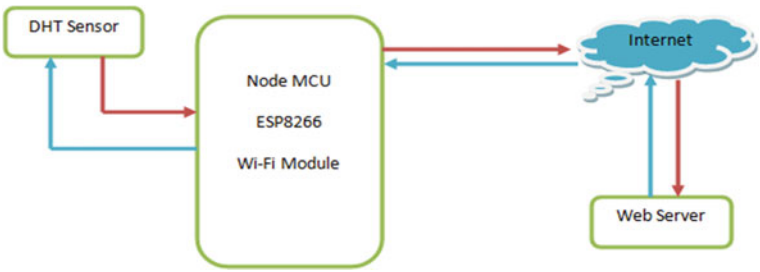

Fig. 6 Block diagram of node2

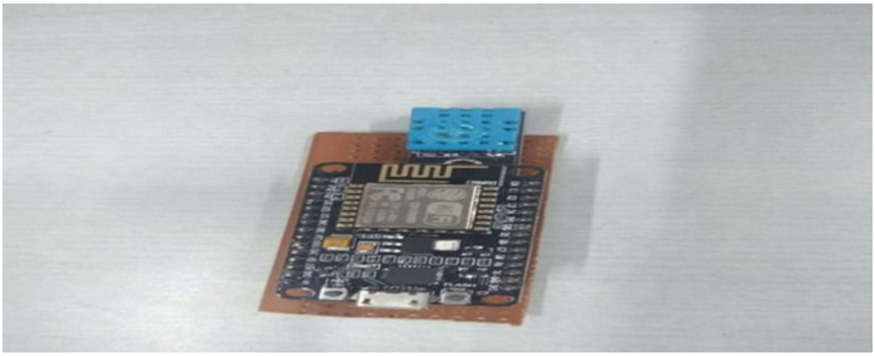

Fig. 7 Hardware implementation of FFD2 node

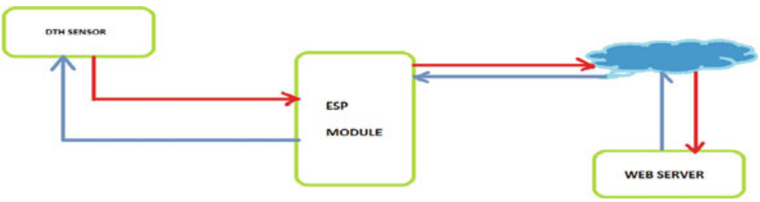

Fig. 8 Block diagram of node3

4 Result Analysis

4.1 Result for Node Implementation Using Arduino (FFD1)

The above figure shows how results will be displayed on the webpage. On the computer side web application, display of the DTH11 sensor status, voltage charging status and data log will be available as shown in Fig. 11.

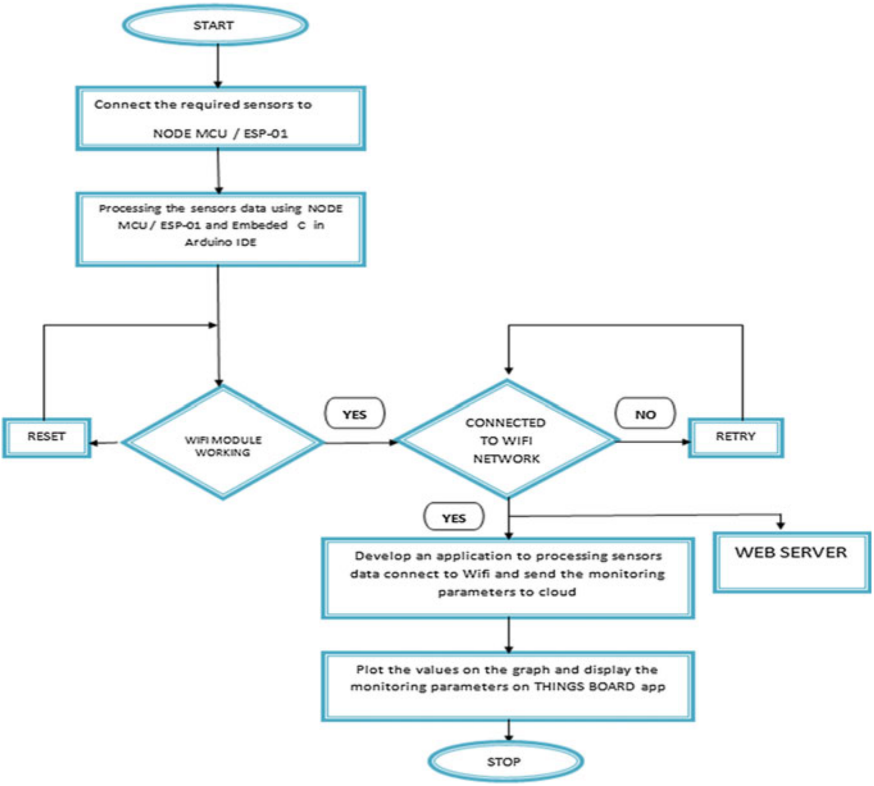

Fig. 9 Methodology of node2 and node3

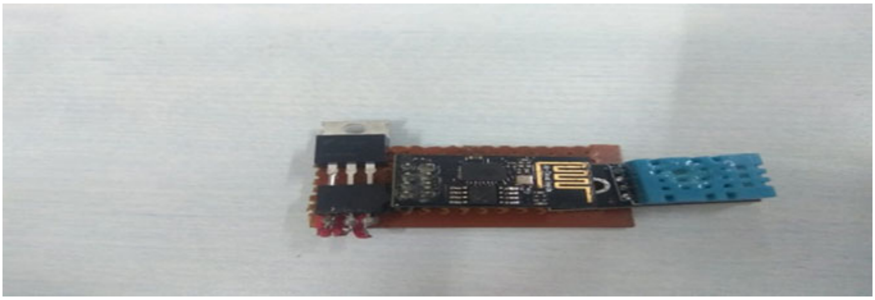

Fig. 10 Hardware implementation of node3

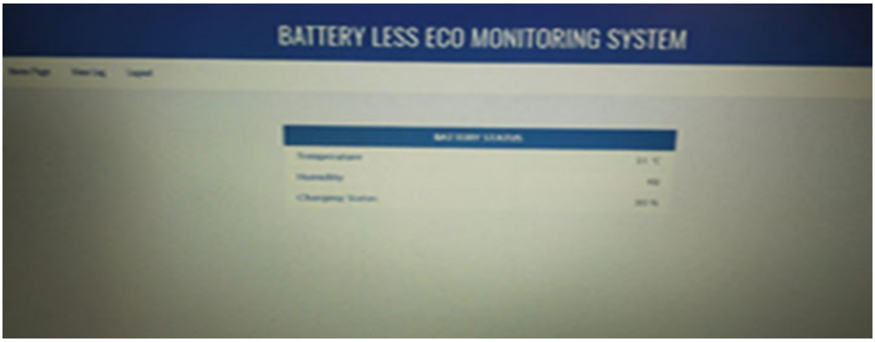

Fig. 11 Web Page displaying the value of temperature, humidity and charging voltage

4.2 Result for Node Implementation Using Node MCU (FFD2)

Using Things-board open source software the data is sent to the web side and monitored for real-time application. The data is not stored but it displays the present time values on the screen and displays the data in graphical form. Using the alarms function in the software, an alarm is created using the threshold value, which then alerts when the temperature exceeds the threshold value set. This system's main advantage is that it reduces programming at a major level. It also has a major reduction in the cost and the size. Figure 12 shows the results in normal conditions when there is no forest fire. Figure 13 shows the scenario when a forest fire is detected. As seen by comparing both the results it can be seen that the temperature and humidity value varies as soon as a forest fire is detected.

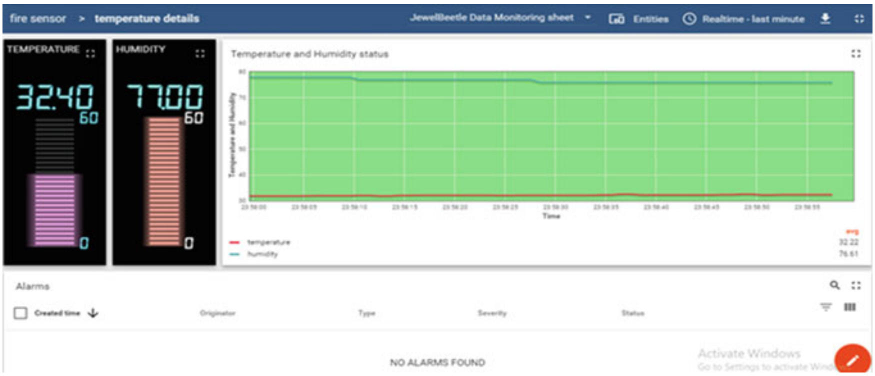

Fig. 12 Normal conditions

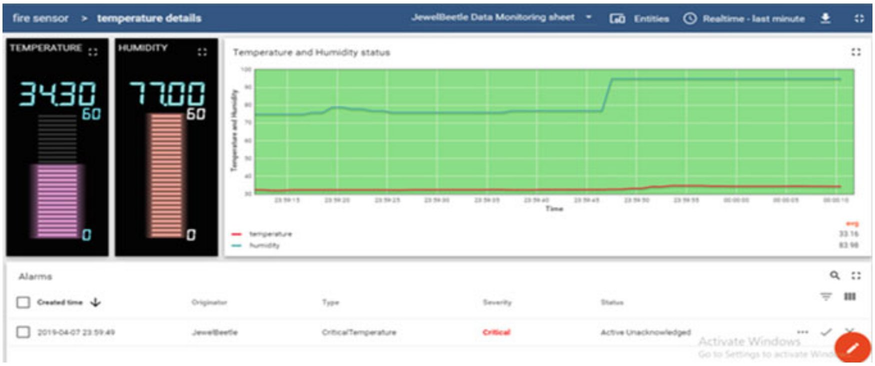

Fig. 13 Fire detection

4.3 Result for Node Implementation Using ESP01 (FFD3)

Using Things-board open source software the data is sent to the web side and monitored for real-time application. The data is not stored but it displays the present time values on the screen and displays the data in graphical form. Using the alarms function in the software, an alarm is created using the threshold value, which then alerts when the temperature exceeds the threshold value set. This system's main advantage is that it reduces programming at a major level. It also has a major reduction in the cost and the size. Figure 14 shows the results in normal conditions when there is no forest fire whereas Fig. 15 shows the scenario when a forest fire is detected. As seen by comparing both the results it can be seen that the temperature and humidity value varies as soon as a forest fire is detected. It is showing the ADC voltage change as well as compared to node 2 where only temperature and humidity were displayed.

The comparative analysis yields that our proposed Jewel Beetle system's sensitivity and resolution are improved compared to satellite and drone-based systems [2–6]. As our proposed system is an on-site system and it can be deployed in the forest permanently.

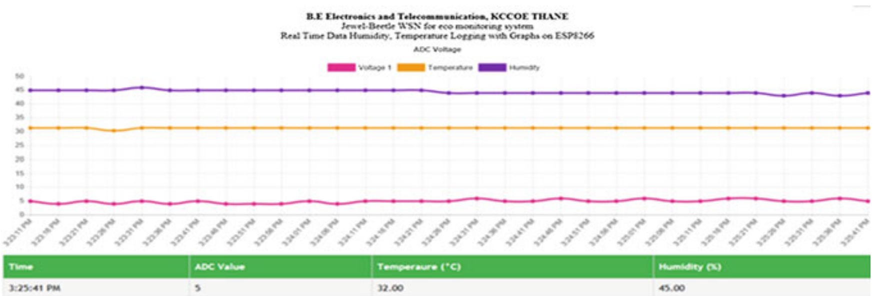

Fig. 14 Normal conditions

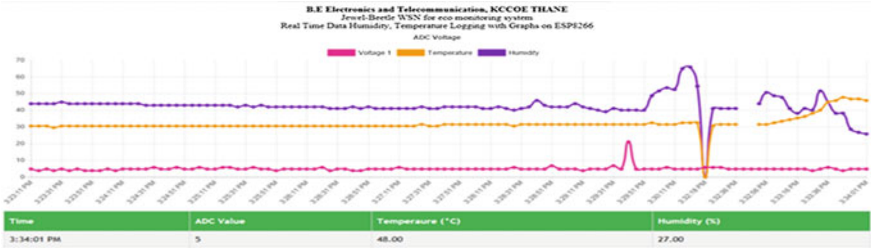

Fig. 15 Fire detection

5 Conclusion

The Batteryless eco monitoring system is a specialized system for supporting typical scenarios of environmental monitoring applications. For environmental monitoring the IoT-based solutions were designed, developed, and analyzed. The analysis of the implementations revealed the fact that Wi-Fi technologies are suited for monitoring applications. As expected, Wi-Fi consumes more energy but enables the development of solutions with a reduced total cost of ownership through the use of the existing infrastructure. It is a system that can monitor the temperature and humidity level using Arduino controller that helps to analyze the various patterns in the environmental parameters while IoT is proposed which can help in data sending on web application side on PC and accordingly notifies. By the use of DTH11 sensors, the temperature and humidity can be sensed and according to the sensor status, a fire alert can be given. The Arduino controller serves as the heart of this module which controls the entire process. The Wi-Fi module connects the whole process to the internet. The proposed solution in this paper is low-cost and easily deployable in a forest environment.

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