NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Design of a Smart Custom Sensor Node Architecture for Wireless Sensor Network (WSN)

Ehizuenlen, P.E, Apeh, S.T

Department of Computer Engineering, Faculty of Engineering, University of Benin, Edo State.

Article Info

Keywords:
Wireless Sensor Network, Sensor Node, Custom, Smart, Power Supply Unit

Received 18 April 2023
Revised 04 May 2023
Accepted 07 May 2023
Available online 07 June 2023

https://doi.org/10.5281/zenodo.8014261

ISSN-2682-5821/

Abstract

A wireless sensor network (WSN) typically employs the use of sensor nodes for the collection of analog data from its physical environment. Most of these sensor nodes are available off-the-shelf with standard functionalities to carry out specified tasks. However, some of these off-the-shelf sensor nodes may not be most suitable to perform additional tasks that may be required during their implementation. Hence, the need to design a smart custom sensor node whose architecture includes a smart power unit that is embedded with an advanced feature that provides information about the node's current available battery energy for appropriate adaptation of the sampling frequency for energy-efficient data acquisition activity. This paper focuses on the design of smart custom sensor node architecture for wireless sensor networks. The custom sensor node architecture includes a sensor(s), MSP430 microcontroller, ZigBee communication module, and a smart power unit., whose smartness is due to its ability to provide information about the amount of energy available in the battery (advanced feature) along with its basic functionality of controlling and optimizing its operating parameters such as current, voltage and energy during its deployment. The smart custom sensor node was first designed using Proteus Professional and later modeled using MATLAB Simulink. The execution proved that the designed custom sensor node provided the available battery energy information as well as detected the gases being monitored which aids reconfiguration decisions for an extended node lifetime.

1.0. Introduction

A wireless sensor network (WSN) is a distributed interconnected network of multiple low-power sensor nodes, which communicates with each other to create a smart sensor network capable of accomplishing several functions. Its applications range from environmental surveillance, military, industrial, agriculture, health, smart home, power grids, and many more [1]. These various applications have become quite popular because the nodes deployed are low cost, communicate wirelessly, have a compact size, and most importantly can operate unattended to, particularly in remote environments that are inaccessible to humans. Also notable is its ability to operate in a self-organized manner [2] especially in the absence of human assistance when deployed in a harsh environment.

A typical WSN consists of two key components which are the sensor node(s) and the base station (BS) [3]. The sensor node converts physical quantities such as temperature, atmospheric pressure, and so on in the sensing environment into electric signals. These signals are then transmitted through the entire network in a way that makes communication possible between sensors, with the data transmitted as signals being centrally collated by a sink node/gateway and analyzed by the BS [3]. A sensor node is a tiny device comprised of four basic sub-units; the power supply unit, sensing unit, processing unit, and communication unit as clearly shown in Figure 1.

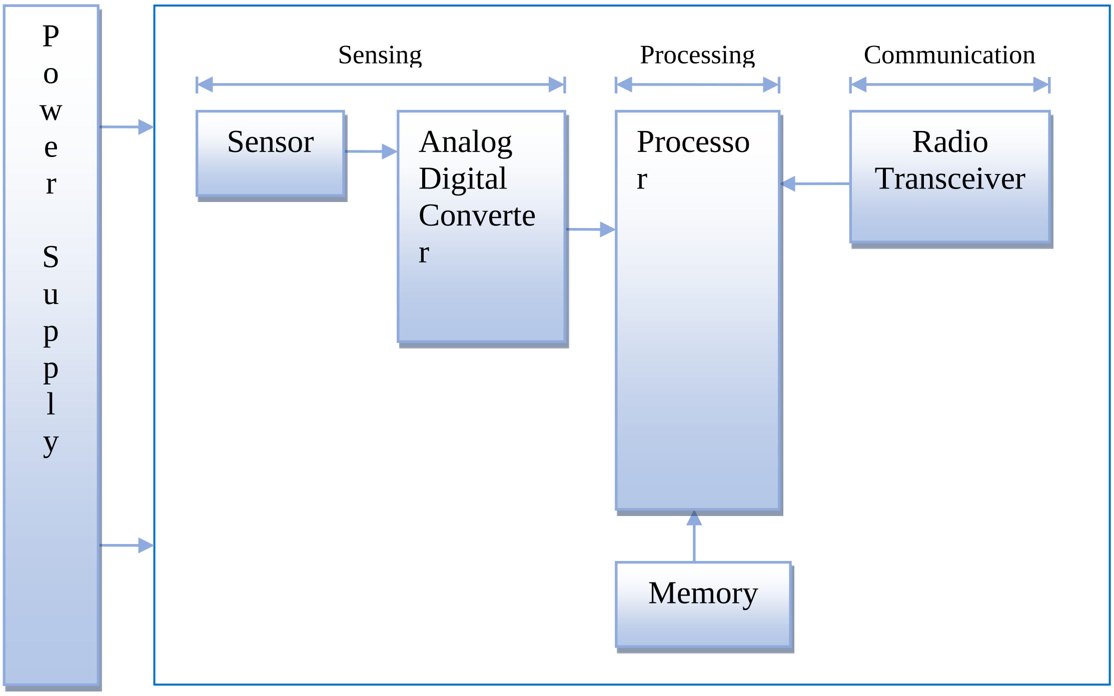

Figure 1: Block Diagram of a Sensor Node

The sensing unit consists of the sensor and an analog-digital converter (ADC) which are used to obtain and convert physical quantities from a monitored environment into its equivalent electrical form. The sensing activities include the sampling of physical signals, conversion of analog signals into their equivalent electrical form, signal conditioning, and conversion from analog to digital signals [4]. The processing unit whose main component is the processor for example a microcontroller is responsible for processing the digital signal fed into it from the sensing unit [5]. The communication unit which has the radio transceiver as its main component is responsible for communicating or transmitting processed data signals to the desired location for example a BS [6]. These communications can be achieved using any of the following wireless communication technology such as infrared, Wi-Fi, Bluetooth, Zigbee, satellite, [7] and so on. Finally, the power supply unit consists of a battery that supplies power to the sensor node [8-9]. It is responsible for supplying direct current (DC) power to the other units to bais the active components such as the crystal oscillator, registers, counters, etc. for the processing, communication, and sensing units [6]. This paper focuses on the design of smart custom sensor node architecture for a wireless sensor network whose power supply unit is capable of providing current node available battery energy in addition to its standard functionalities.

1.1. Literature Review

Due to the vast applications of WSN, several off-the-shelf and custom sensor nodes have been designed to monitor different physical quantities. For example, [10-12] proposed a wireless sensor node design using a DHT 11 a temperature and humidity sensor for environmental data acquisition, LPC2103FBD48 which is an ARM low-power microcontroller for data preprocessing, and a Nordric RF module labeled nRF24L01 for wireless communication between the sensor node and base station (BS). These different components are powered by an AA alkaline battery for environmental monitoring. Based on the result, the designed node functioned properly but lacked a sense of smartness as it was not capable of providing the available battery energy which would aid reconfiguration decisions helpful in minimizing energy consumption.

[2] designed a simple wireless sensor node prototype using chip ATMega32U4 low-power CMOS 8-bit microcontroller with an advanced RISC architecture, an MRF49XA chip from Microchip which is a sub-1 GHz RF transceiver, sensors for sensing physical variables such as temperature, pressure, gases, presence, and light, an antenna made of a single strand of 24 AWG wire for capturing energy from pervasive electromagnetic sources such as radio frequency. The node can also be powered by a super-capacitor which is recharged by energy harvested from mint plants. Simulation results showed that since the system had a means of recharging the node battery, emphasis on providing available battery energy information for the reconfiguration of node behavior to minimize energy consumption was neglected.

[5] built six sensor nodes which comprises of ATMega 328P microcontroller, XBee S2C module to transmit data wirelessly using ZigBee technology, Li-Po 3300-mAh battery to provide electric energy, four sensors to measure temperature, relative humidity, soil moisture, UltraViolet (UV) light, and visible light intensity and custom-size acrylic case. Based on the result, the environmental variables measured were obtained successfully but without any information about the available battery energy which is necessary for reconfiguration of node behavior thus aiding extended node lifetime.

[4] designed and developed an intelligent sensor node equipped with a multimode sensor for sensing four different environmental parameters such as light, temperature, humidity, and three different types of gases. The node architectural hardware included an ultra-low power PIC18F2550 microcontroller, CC2500 RF transceiver module which operates in the 2.4 GHz Industrial Scientific Medical (ISM) free radio frequency band, DS 18S20 temperature sensor, Resistive type humidity sensor, TSL235R Light to Frequency converter, TGS 2600 air contaminants, MQ-4 methane sensor, MQ-7 carbon monoxide sensor and a 3.7V, 2000 mAh lithium polymer battery, and a solar panel. From several experiments performed, the developed node achieved the desired environmental monitoring for the specified parameters. However, the node intelligence did not include the ability to provide available battery information which is required for the adaptation of the node behavior when reconfiguration becomes necessary.

[10] proposed the design of a wireless sensor node based on a programmable system on chip (PSoC) which is a true and flexible, programmable, and reconfigurable system on radio chip (SoC) of CMOS solution, an application-specific antenna and hardware for the system on chip, CyFi RF transceiver which has a high performance of 2.4 GHz Direct Sequence Spread Spectrum. Based on the results obtained, the developed node achieved flexibility and improved performance compared with other sensor nodes available as convergent technologies operating systems (CTOS) but lacked the smartness required in providing its available battery information required for the reconfiguration of node behavior to minimize energy consumption.

From the various related works reviewed, it was observed that most proposed sensor node architectures did not include any mechanism that will enable the node to provide information about its available battery energy which is necessary for the varying of certain node parameters such as sampling frequency and sampling interval for the reconfiguration of node behavior to ensure minimal energy consumption. However, in this paper, a smart power unit that provides alongside its sensed data, information about the node’s available battery energy was introduced to the sensor node architecture.

2.0.Materials and Methods

2.1 Materials used for the design of the Smart Custom Sensor Node

The materials required for this design include a microcontroller, communication module, and sensors. Since there are several of these components available in the open market, component selection becomes very necessary.

The components selection was achieved through a careful study of several components datasheets and product reviews for various microcontrollers, sensors, and wireless communication modules. The study revealed the specifications, features as well as opinions of researchers who have deployed the different components in the field. At the end of the extensive study, a member of the MSP430 microcontroller family precisely MSP430F2272 was selected as the processor. The choice of MSP430 MCU is because of its low cost, reduced code size, and most importantly, its ultra-low-power capability which makes it suitable for battery-powered measurement applications. ZE51-2.4 was chosen as the wireless communication module due to its ability to support low power modes up to 2.5 mW and also because it has a high-temperature tolerance range from -40^{0}C to 85^{0}C. Gascard NG and Graphene gas sensors are chosen as the sensor which was selected largely because of the nature of the perceived deployment environment (environmental). The gases of interest to be monitored are carbon dioxide (CO_2), methane (CH_4), and nitrogen dioxide (NO_2). It is important to note that the choice of these components to develop the smart custom sensor node architecture was based on their energy efficiency and flexibility of handling. After the selection stage was concluded, a method was followed to implement the design of the smart custom sensor node architecture.

2.2 Method for the Design of the Smart Custom Sensor Node

The method employed for the implementation of the design of the smart custom sensor node is achieved as clearly shown in Figure 1.

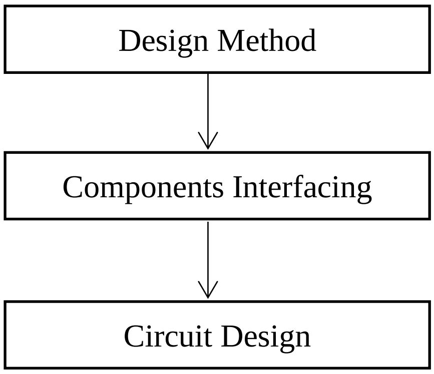

Figure 1: Design Stage Flowchart

Figure 1 shows that the design method involves two stages namely; interfacing the different components and the design of the circuit using the software precisely Proteus.

- **a.** Component Interfacing: The selected components are then interfaced as shown in the block diagram of the smart custom sensor node architecture illustrated in Figure 2.

The interfaced components are powered by a smart power supply unit which has a 3/AA alkaline battery connected in series to produce a voltage level between 4.5 and 5.0 V, with 2500 mAh; the choice of the alkaline battery is due to its ability to operate for a long time due to its low self-discharging rate.

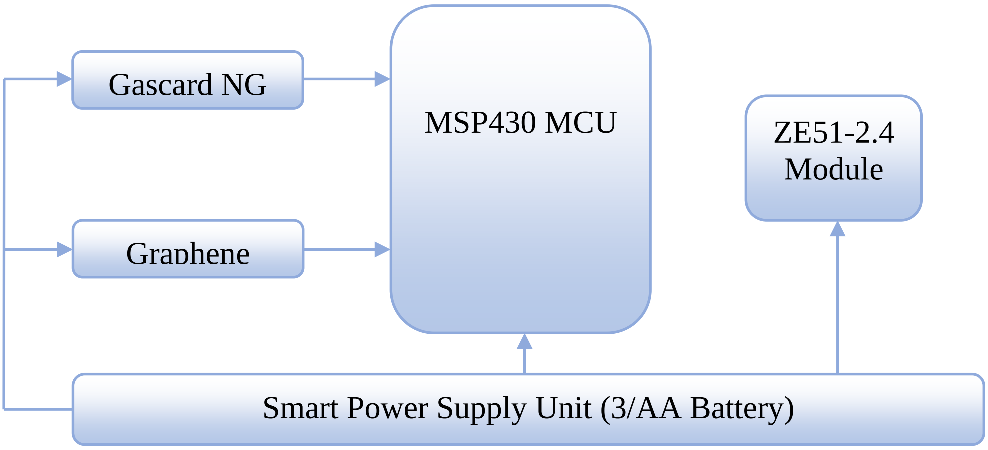

Figure 2: Block Diagram of the Smart Custom Sensor Node Architecture

b. Circuit Design: The smart custom sensor node architecture circuit was designed using Proteus 8 Professional as shown in Figure 3.

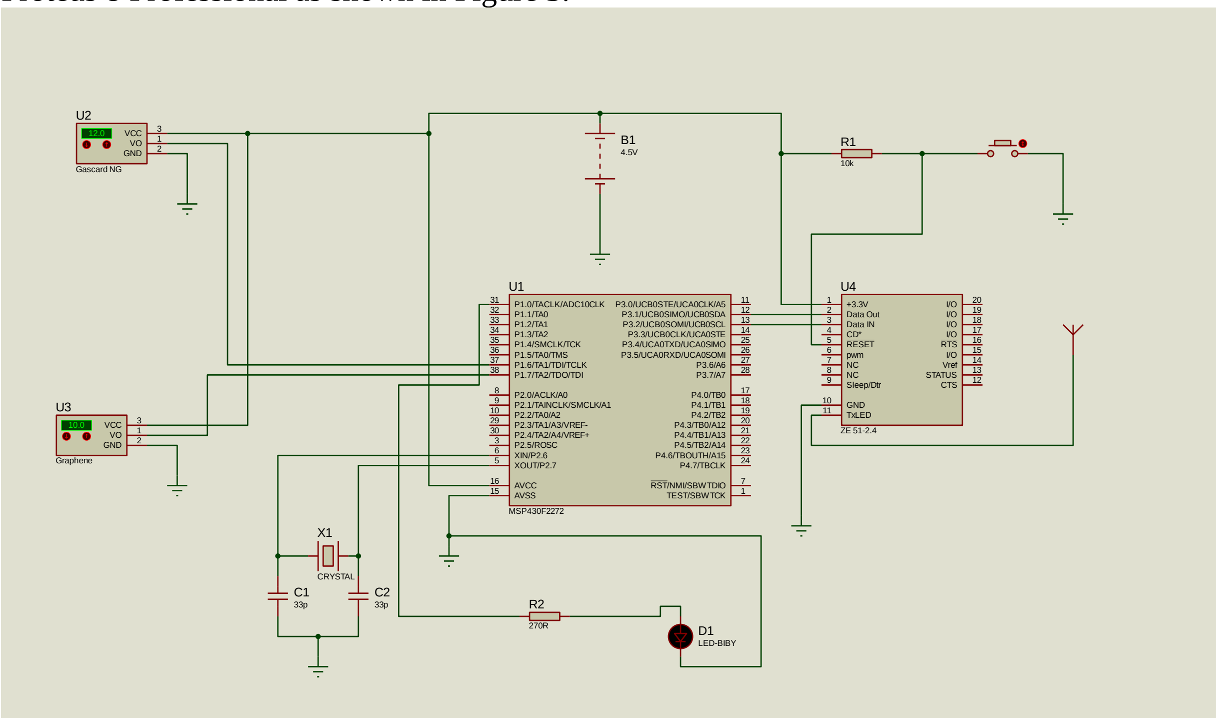

Figure 3: Smart Custom Sensor Node Architecture Circuit Diagram

The circuit diagram in Figure 3 shows the interfaced electronic components which comprise the pull-up resistors (R1 and R2), crystal oscillators (C1 and C2), diode (D1) as well as the microcontroller (U1), communication module (U4), and the sensor module (U2 and U3). The design calculations for the pull-up resistor and the crystal oscillator are presented as follows:

i. Pull-up resistor: based on the input voltage specification presented in the microcontroller datasheet (MSP430 SLAS504B, July 2006), the typical input voltage supplied to any normal pin is given as Vcc - 0.25, where V_{cc} is 4.5 Volts. The maximum input current (I_{max}) as obtained from the datasheet (MSP430 Datasheet, July 2006), is specified to be 1.5 mA. However, for the safe operation of the device, 50% of the I_{max} is been employed as it is usually not advisable in design for the input current to be fully utilized, hence, the typical input current I_{in} = 0.75 mA (0.00075 A). From Ohm's law, Equation 1 was obtained as:

$$V = I \times R \qquad (1)$$

So that the value of Vcc can be evaluated using Equation 2:

$$Vcc = (\text{current through resistor } R) \times R \qquad (2)$$

Equation 2 may be rearranged as:

$$R = \frac{Vcc}{\text{current through } R} \qquad (3)$$

$$R = \frac{4.5 - 0.25}{0.75 \times 10^{-3}} = 5667\ \Omega$$

ii. Crystal oscillator: there are two capacitors labeled C1 and C2, with each of the capacitor loads given as 12.5 pF while the crystal oscillator is given as 32.768 kHz (MSP430 Datasheet, July 2006).

3.0.Results and Discussion

The smart custom sensor node was designed to detect three gases precisely carbon dioxide (CO_2), methane (CH_4), and nitrogen dioxide (NO_2) within the following sensitivity range of values as presented in Table 1.

Table 1: Gas Sensitivity Range

S/N	Gas	Sensitivity Range
1.	Carbon dioxide	0 – 3000 ppm
2.	Methane	0 – 100%
3.	Nitrogen dioxide	10 – 38 ppb

The designed smart custom sensor node architecture was modeled using MATLAB 2018b Simulink. The initial startup values supplied as inputs to the MSP430 microcontroller to test the operation of the designed smart custom sensor node architecture are presented in Figure 4.

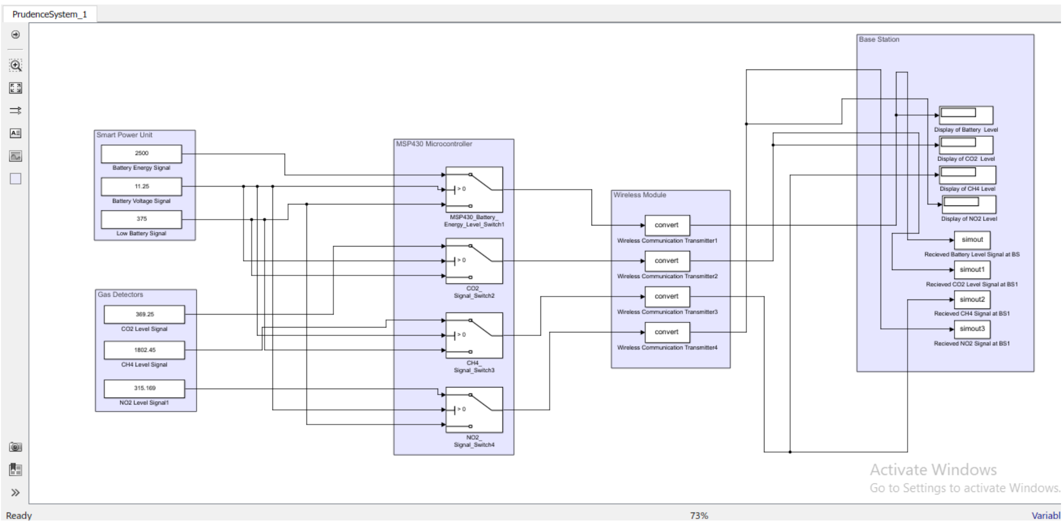

Figure 4: Smart Custom Sensor Node Model

The model was then executed to generate the corresponding values as the output on a BS terminal. The results for the smart custom sensor node design model after its execution are presented in Figure 5.

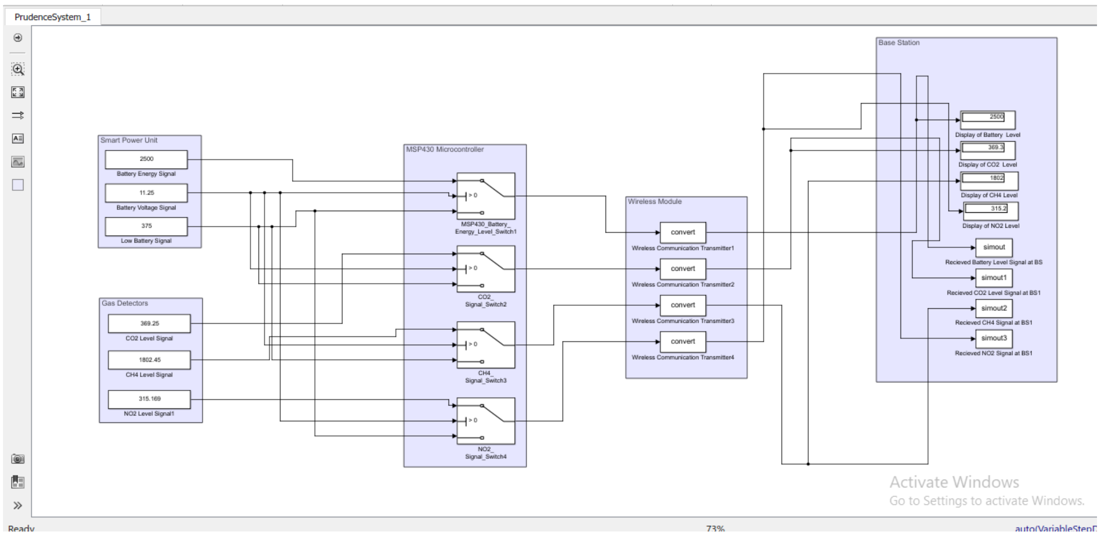

Figure 5: Smart Custom Sensor Node Model Outputting Signals

Figure 5 showed that the smart custom sensor node modeled provided the sampled data of the three gases namely; carbon dioxide, methane, and nitrogen dioxide been monitored along with their current available battery energy after each round of sampling. The performance of this model was validated with the work of [4] which also designed and developed a wireless sensor node that successfully provided information about the environmental parameters being monitored, but lacked smartness, particularly concerning information about its current battery energy. The introduction of this feature in the proposed model allows for the adaptation of the sampling frequency and sampling interval to ensure an extended node lifetime through the reconfiguration of the node behavior particularly when there is no significant change in sampled data. This feature is unique as is absent in most off-the-shelf and custom sensor nodes.

4.0.Conclusion

This paper has introduced an advanced feature to the standard functionality of a sensor node employed in a WSN. It describes the design and operation of smart custom sensor node architecture which include the power unit's ability to forward to the BS the information about its available battery energy. This feature enables appropriate adaptation and reconfiguration of the node behavior by varying the sampling frequency based on its available battery energy to effectively manage its limited energy and prolong its lifetime. The designed smart custom sensor node architecture was specific to the environmental monitoring of CO_2, CH_4, and NO_2 for climate change monitoring and was modeled using MATLAB Simulink. The model result proved that the designed smart custom sensor node provided information about the available battery energy along with its standard functionality. Future research will focus on the hardware implementation of the designed custom sensor node.

Acknowledgment

The authors wish to acknowledge the assistance and contributions of the co-author Engr. academic staff of the Department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City toward the success of this work.

References

[1] Abdulwahid, A.H and Salih, M.J. (2021). Wireless Sensor Networks Applications, Challenges, and Security Requirements. *IMDC-IST 2021*, September 07 – 09, Sakarya, Turkey, 1 - 11.

[2] Alcalia-Garrido, H. A., Barrera-Figueroa, V., Rivero-Angelos, M.E., Garcia-Tajeda, Y.V and Perez, H.R. (2021). Analysis and Design of a Wireless Sensor Network Based on Residual Energy of the Nodes and the Harvested Energy from Mint Plants. *Journal of Sensors*, 2021, 1 – 26.
[3] Bhardwaj, S. (2013). Artificial Neural Network for Node Localization in Wireless Sensor Network. International Journal of Advanced Research in Electrical, Electronics and Electrical and Instrumentation Engineering. 2(5), May 2013,
[4] Bhattachrjee, D., Kumar, S., Kumar, A. and Choudhury, S. (2010). Design and Development of Wireless Sensor Node. *International Journal on Computer Science and Engineering*, 2 (7), 2010, 2431 – 2438.
[5] Celis-Penaranda, J. M., Escobar-Amado, C.D., Sepulveda-Mora, S.B., Castro-Casadiego, S.A., Medina-Degado, B and Guevara-Ibarra, D. (2020). Design of a Wireless Sensor Network for Optimal Deployment of Sensor Nodes in a Cocoa Crop. *TecnoLogicas*, 23(47), 121 -136.
[6] Dargie, W and Christain Poellabauser, C. (2011). Fundamentals of Wireless Sensor Networks: Theory and Practice. *Wiley Series on Wireless Communications and Mobile Computing*.
[7] Karapistoli, E., Economides, A.A and Mampentzidou, I. (2014). Environmental Monitoring based on the Wireless Sensor Network Technology: A Survey of Real-world Applications. *International Journal of Agricultural and Environmental Information Systems.* 5(4) pp. 1 – 39.
[8] Khalid, W., Sattar, A., Qureshi, M.A., Amin, A., Malik, M.A and Memon, K.H. (2019). A Smart Wireless Sensor Network Node for Fire Detection. *Turkish Journal of Electrical Engineering & Computer Science*. 27, 2541 – 2556.
[9] Matin, M.A and Islam, M.M. (2012) Overview of Wireless Sensor Network. Wireless Sensor Networks - Technology and Protocols.1 – 23.
[10]Nayse, S.P and Atique, M (2014). A Design of Application Based Wireless Sensor Node. *Federated Conference on Computer Science and Information Systems*. 3, 177 – 181.
[11]Patel, H and Shah, V.A. (2018). Sensor Node Design with Dynamic Remote Reconfiguration and Analysis. *International Journal of Applied Engineering Research.* 13(6), 3415 – 3424.
[12]Rahmen, N.A.A., Jambek, A.B., Rahmen, N.A.A and Jambek, A.B (2016). Wireless Sensor Node Design. *3rd International Conference Electronic Design (ICED),* August 2016.
[13]Ruiz, L.B., Braja, T.R.M., Siliva, F.A., Assuncao, H.P., Marcos, J., Nogueira, S and Loureiro, A.A.F. (2005). On the Design of a Self-managed Wireless Sensor Network. *IEEE Communication Magazine*.
[14]Tarannum, S. (2010). Energy Conservation Challenges in Wireless Sensor Networks: A Comprehensive Study. *Wireless Sensor Network*, 2, 483 – 491.
[15]Wu, J and Ding. X. (2021). Using Wireless Sensor Network to Remote Real-Time Monitoring and Tracking of Logistics Status Based on Difference Transmission Algorithm. *Journal of Sensors*, 1 – 10.