Emad Ahmed Mohammed[1] , Hakam Marwan Zaidan[1] , Zaid Ghanim Mohammed[1]

Northern Technical University/ Technical Engineering College/ Mosul (1)

doi:10.15199/48.2023.06.06

Implementation of WSN based Smart Irrigation System

Abstract. *This research paper introduces a real-time, fully automated wireless sensor network (WSN) prototype for irrigation systems in agricultural fields. This automated WSN depends on the soil conditions, like the soil moisture, and takes action accordingly. The WSN is based on the ZigBee protocol represented in the XBee module. The aim is to protect the crops from over/under watering resulting in better crop quality and quantity. Also, this WSN reduces human intervention costs and eliminates or reduces water waste to the minimum acceptable extent. The WSN nodes are classified into three types, the coordinator node, the sensing node, and the relaying node. Sleep mode is used in the sensing node while inactive to achieve the best possible energy savings strategy. Four zones are to be considered in this experimental study. Results showed that the water flows only about 35% of the time of the six observation hours on average in the four zones.*

Streszczenie. *W tym artykule badawczym przedstawiono działający w czasie rzeczywistym, w pełni zautomatyzowany prototyp bezprzewodowej sieci czujników (WSN) dla systemów nawadniających na polach rolniczych. Ten zautomatyzowany WSN jest zależny od warunków glebowych, takich jak wilgotność gleby, i podejmuje odpowiednie działania. WSN jest oparty na protokole ZigBee reprezentowanym w module XBee. Celem jest ochrona upraw przed nadmiernym/niedostatecznym podlewaniem, co skutkuje lepszą jakością i ilością plonów. Ponadto ten WSN zmniejsza koszty interwencji człowieka i eliminuje lub zmniejsza marnotrawstwo wody w minimalnym akceptowalnym stopniu. Węzły WSN dzielą się na trzy typy: węzeł koordynujący, węzeł wykrywający i węzeł przekazujący. Tryb uśpienia jest używany w węźle czujnikowym, gdy jest nieaktywny, aby osiągnąć najlepszą możliwą strategię oszczędzania energii. W tym badaniu eksperymentalnym należy wziąć pod uwagę cztery strefy. Wyniki pokazały, że woda przepływa średnio tylko przez około 35% czasu z sześciu godzin obserwacji w czterech strefach.* (***Wdrożenie inteligentnego systemu nawadniania opartego na WSN***)

Keywords: WSN, ZigBee, XBee, irrigation
Słowa kluczowe: WSN – wireless sensor network, ZigBee

Introduction

Nowadays, the aspect of global warming constitutes a dilemma in every part of our daily life. This aspect leads to temperature rise almost everywhere in the world and short ages in water supplies, leading to agricultural challenges. Therefore, many researchers devote their efforts to trying to contribute to innovative solutions to reduce the effects of this problem. One topic of research regarding this matter is the irrigation system in agriculture. Conventional irrigation sys tems pump water into the farming land at different intervals without any information about the water levels in the soil. Such an irrigation system harms the yield and may cause crop diseases.

op diseases. In the meanwhile, there are many techniques available that can be used to contribute to the solution and supports better quality of life [1, 2, 3, 4, 5, 6]. One of these techniques is the wireless sensor networks (WSNs), which are based on deploying multiple low energy consumption sensors over the area of interest to measure certain type of data. WSNs can be configured to allow sensor nodes to be connected to a central node forming a star network, or can be config ured to allow all the nodes in the network to be connected together forming a mesh network. In both cases, WSNs uti lize a wireless communication links to send sensors' readings to a central node known as the coordinator. Figure 1 shows the WSNs configuration, where 'a' is the star configuration, and 'b' is the mesh configuration.

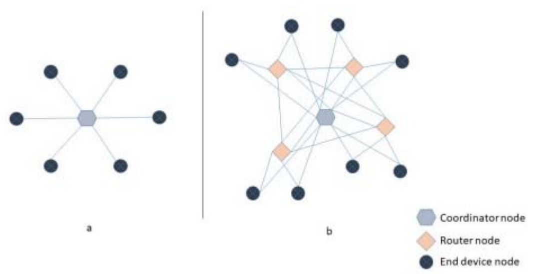

Fig. 1. WSNs topologies, where 'a' is the star topology, and 'b' is the mesh topology.

IEEE 802.15.4 ZigBee protocol represented in the XBee module made by Digi Mesh is considered one of the best platforms dedicated to WSNs applications. The XBee module is low energy consumption, a low data rate of 250 Kbps, low latency, low cost, and easy to configure WSNs platform that functions in the 2.4 GHz frequency band. Furthermore, two AA batteries last six months to two years, depending on the role in which the XBee module operates [7]. Also, the XBee module takes up to 15ms to wake up from sleep mode.

The network consists of three key nodes, the coordina tor node, the sensing node, and the relaying node. The coor dinator node consists of a microcontroller represented by an Arduino, a sensor, an XBee module configured as a coordina tor, and an output device to control a specific action accord ing to the sensor readings. On the other hand, the sensing nodes consist of an XBee and a sensor without any micro controller. Also, the role of the sensing nodes is only to read the sensor value and sends it to the coordinator node. In ad dition, the XBee in the sensing node is configured as an end device, in which the node can be set to sleep mode while in active. During sleep mode, the node stays inactive until there is available data to be sent, and it takes up to 15ms to wake up and synchronize itself to the network, sends the data, and back to sleep mode again. Therefore, sleep mode plays a fundamental role in energy savings. A third node, the signal relaying node, can be added to the WSN. The relaying node is an XBee configured as a router and can be supported by a sensor to add more sensor readings to the system. This re laying node is advantageous in large fields where the sensing nodes are far from the coordinator node. Therefore, the re laying node is used to relay the sensing nodes signals to the coordinator. Thus, the coordinator node receives the read ings from the sensing and relaying nodes and takes a spe cific required action. Consequently, the coordinator node is the mastermind of the WSNs because it processes its sensor readings, receives the sensors' readings from other nodes, process them as well, and takes the required action accord ingly.

In this research, a low energy consumption, fully au tomated WSN system for irrigation purposes in agricultural fields is developed. The developed WSN provides the nec essary data for the whole irrigation system of the agricultural field of interest. The system can be used by farmers to fully control the irrigation of crops to protect them from over and under-watering and to decrease the waste of water efficiently. Thus, the system results in better crop quality and quantity, with minimum waste for irrigation water besides low energy consumption system

Related work

In [8], the researchers proposed an automated WSN irri gation system to control the irrigation of different crop fields. This system is fully automatic; there is no need for human intervention in the irrigation process. The system deploys sensors in the farm to sense required data and send it to a central node for analysis and decision-making of control ling water pumps. The wireless technology used to build the WSN in this research is the XBee S2 based on the IEEE 802.15.4/ZigBee protocol with a resistive moisture sensor to determine if the soil needs water. Although the used resis tive moisture sensor is susceptible to environmental elements because the sensor electrodes are in direct contact with the farming land, and the used XBee S2 module covers only 40m in non-line of sight transmission, the researchers achieved 50% of savings in water.

In the same context as the previous research, the au thors in [9] used XBee S2 as the bases for their proposed WSN and used the Watermark 200SS moisture sensor. This type of gypsum sensor dissolves in soil over time. In addi tion, the researchers used an Arduino board microcontroller in each sensor node. Thus, an enormous number of Arduino boards will be needed if the irrigation system is set up in a large farming field. In this case, the cost of the irrigation sys tem will increase substantially. This problem can be avoided if the researchers configured the XBees to work as a stan dalone system.

The authors in [10] proposed a dripping irrigation sys tem that contains a Raspberry pi and Arduino board with an XBee module as a wireless communication technology be tween them. The Arduino board controls the irrigation water tank level via an ultrasound sensor. On the other hand, the Raspberry pi receives user emails that contain information about the period in which the irrigation system works. An other Arduino board controls the working of the water pump that releases water to the plants. This type of irrigation sys tem is not fully automatic as it needs the user to send an email to define the time interval in which the system works. Also, using multiple microcontroller platforms increases the cost of the proposed irrigation system. On the other hand, the XBee module is limited only to performing the communication between the Raspberry pi and Arduino board. Furthermore, the irrigation system performs the irrigation process without any feedback about the current state of the soil, which may cause over or under-watering of the plants.

ause over or under-watering of the plants. In [11], the authors proposed an embedded irrigation system that works automatically in cardamom fields using the XBee module. The system works in four cases depending on the infield sensor data. The first case starts the irriga tion process if the temperature is between the maximum and minimum values. The irrigation process stops in case2 when the moisture level exceeds the maximum values regardless of the temperature and humidity conditions. In case3, the ir rigation process stops again if the water level in the irrigation tank falls below a specified point and a motor is turned on to refill the tank. In the last case, the motor stops working when the tank is filled, and the irrigation process restarts again. No sleep mode is implemented in this work.

The research work in [12] proposed an irrigation system that performs automatic irrigation and water level monitoring. The irrigation process takes place based on the infield sensor data. Although this irrigation system is energy-independent, sleep mode is not considered in the used XBee module.

The contributions of our work can be summarized as the following:

• Low-cost, fully automatic irrigation system that requires no farmer intervention depending on the infield sensor data.

• Controlling the water level in the irrigation tanks ensures a smooth irrigation process.

• Energy-efficient design as the sleep mode is considered the basis of our proposed work.

Methodolog

The IEEE 802.15.4/ZigBee wireless Personal Area Net work (WPAN) standards represented by the XBee module has been utilized as the backbone of the proposed WSN due to low cost, low energy consumption, and low latency communication with an outdoor line of sight range of 1200m [13]. In addition, XBee modules can be configured in AT and API modes. In API mode, the sensing nodes can work au tonomously without the need of a microcontroller. Thus, our proposed Irrigation system needs only one microcontroller in the coordinator node to make data analysis and taking re quired actions. Also, we used the low cost Arduino board that comes with ATmega168 that can be easily interfaced with the XBee module. In addition, a low-cost capacitive soil moisture sensor is used to measure the moistness of the soil.

Numerous WSN applications have been studied in lit erature over the past decade, such as traffic control systems [14], estimating building performance [15], water quality mon itoring [16], temperature monitoring [17], and other applica tions. In agriculture, conventional irrigation carried out by farmers leads to waste in water, an increase in labor cost, and low crop production. Exploiting automation in agricul ture, such as WSNs applications, yields enormous crop pro duce and improves the ecological system by saving water that goes to waste by conventional irrigation [18].

The implemented prototype irrigation system is based on the IEEE 802.15.4/ZigBee protocol represented by the XBee module. The XBee module is low energy consumption, a low data rate of 250 Kbps, low latency, low cost, and an easy to-configure WSNs platform that functions in the 2.4GHz fre quency band [13]. The XBee S2 module that covers a dis tance of up to 60m in a non-line-of-sight environment has been considered. As mentioned earlier, the WSN network can be configured as a star or mesh topology. Mesh topology is implemented in large fields where an enormous amount of sensor nodes is required to cover the entire farming field. In this case, the distance between a sensor and the coordinator nodes does not meet the distance requirements. To over come the problem of distance coverage, a router(s) node is required between the sensor and the coordinator nodes to bridge the signals between those nodes. Star topology im plementation is considered in this work because the testing and experimentation took place in a relatively small farming field where the sensor an

The proposed irrigation system is tested in an approxi mately 400m2 farming field divided into four zones labeled Z1 through Z4. The sensing nodes are distributed to three zones, and the coordinator node is in the last zone.

There is no need for a sensing node in Z4 because the coordinator node already contains a moisture sensor connected to the Arduino board. Figure 2 shows the testing farming field.

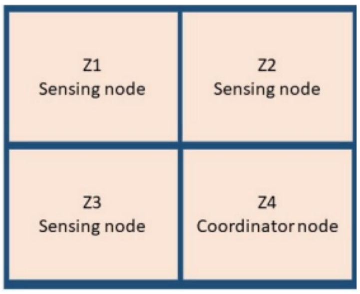

Fig. 2. The testing farming field.

Figure 3 shows the proposed sensing node. The node includes an XBee S2 module that is configured as an end de vice, battery, and capacitive moisture sensor to measure the soil moisture. A voltage divider circuit is required in the sens ing node because that the moisture sensor output is between 1.9V-3V while the internal XBee ADC sensitivity is 1.2V. The working principle of the sensing node is as follows:

• The XBee initializes and sends the moisture sensor reading to the coordinator.
• Enter in sleep mode for five minutes.
• Wake up and sends the sensor reading again.
• Back to sleep mode.

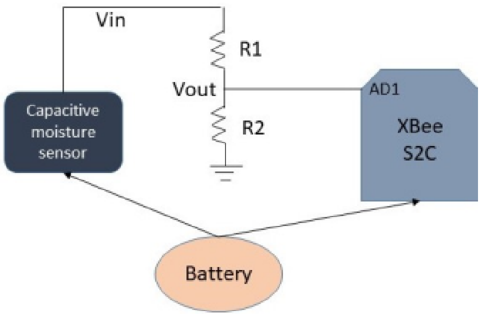

Fig. 3. The proposed sensing node. The node includes an XBee S2 module that configured as an end device, battery, and capacitive moisture sensor to measure the soil moisture.

On the other hand, the proposed coordinator node com prised of an Arduino board, XBee configured as a coordina tor, moisture sensor, charging motor, and Solenoid valves as shown in figure 4. The working principle of this node is as follows:

• The Arduino board checks the irrigation tank water level via an ultrasonic sensor mounted inside the tank.
• Turn on or off the charging motor according to prede fined threshold value (20% of the tank capacity).
• After initialization, the coordinator listens for remote sen sor nodes data and relays them to the Arduino board.
• The Arduino Board controls the working of the Solenoid valves according to the previously received sensor data.

Figures 5 and 6 shows the flowcharts of the proposed irrigation system nodes. The sensing node (figure 6) sends the moisture sensor reading to the coordinator node every five minutes. Otherwise, the XBee module is in sleep mode. In the coordinator node (figure 5), the Arduino board checks the water level in the water tank; if it is below 20% of the capacity, it turns the charging motor on, otherwise it turns the charging motor off. The XBee module is configured as a coordinator. Thus it is always listening to sensor nodes' data and relaying them to the Arduino board. Consequently, the Arduino board controls the Solenoid valves. The sleep mode is implemented only in the sensing nodes while the coordinator node is permanently up and listening to remote sensing nodes.

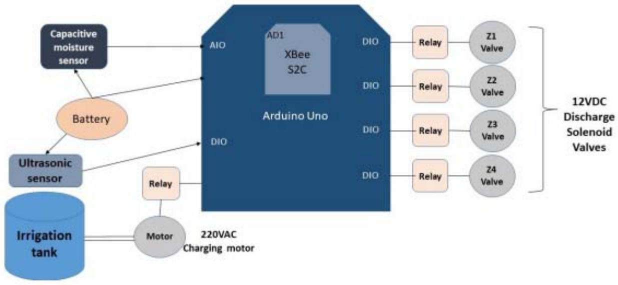

Fig. 4. The proposed coordinator node. It is comprised of an Arduino board, XBee configured as a coordinator, moisture sensor, charging motor, and Solenoid valves.

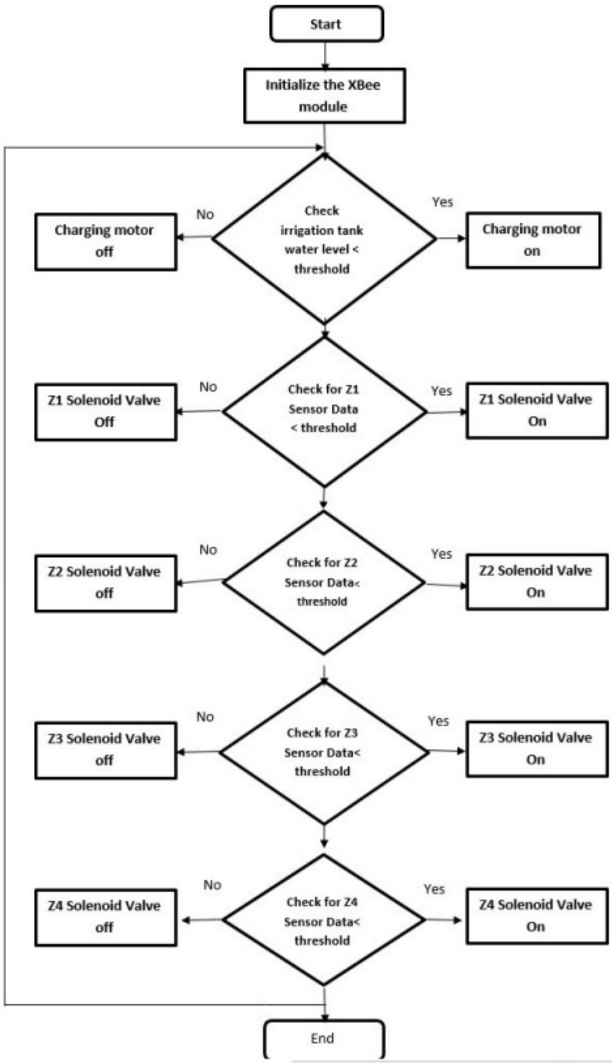

Fig. 5. Flowchart of the proposed irrigation system (coordinator node)

Results

The moisture sensor is tested as the following:

• Wet environment: the sensor is dipped in a glass of wa ter.
• Dry environment: the sensor is in the air. •

Finally, the sensor is in dry soil. Table 1 shows the moisture sensors output value in two cases:

• The first case: the sensor is directly connected to the Arduino microcontroller (without an XBee) as in the co ordinator node.

• The second case: the sensor is connected to an XBee (as in the sensing node). The XBee sends this reading to the coordinator node.

Table 1. Moisture sensor output.

Status	Sensor reading	
	Without XBee	With XBee
Dry	850	1023
Wet	400	600
In dry soil	645	860

The sensor's output is analog. Thus, upon connection to the Arduino or XBee, this analog signal is converted by the analog-to-digital converter (ADC) to 10-bit digital values. These values are mapped to a soil moisture percentage ac cording to equation 1, where 0% means the soil is dry, and 100% indicates it is well irrigated. Although the sensors used.

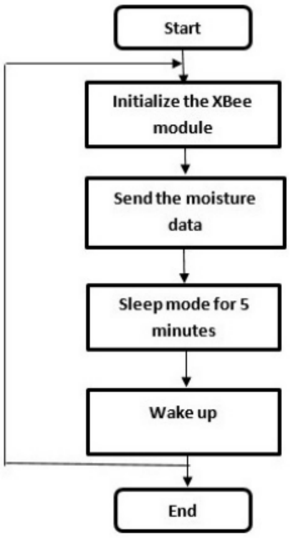

Fig. 6. Flowcharts of the proposed irrigation system (sensing node). are the same, the output values of the sensor connected di rectly to the Arduino are different from the ones of the sensor connected to the XBee, as shown in figure 7. This differ ence is because the ADC reference values in Arduino and the XBee are disparate. The reference value is 5V in the Arduino Uno, while it is 1.2V in the XBee.

(1)

$$SoilMoisture(\%) = \frac{(ADCvalue - Wet) * -100}{(Dry - Wet)} + 100$$

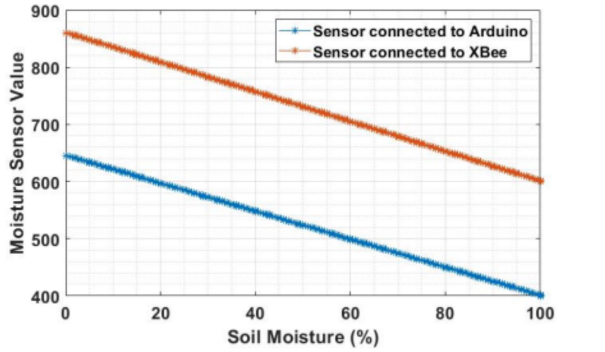

Fig. 7. Soil Moisture Sensor Output Values mapped to a soil mois ture percentage.

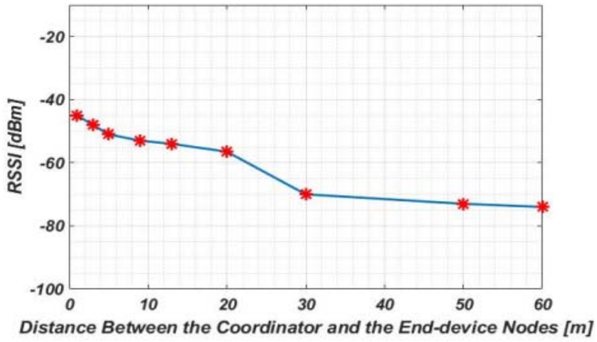

Fig. 8. RSSI Variations as Distance increases between the Coordi nator node and the End-device node.

Figure 8 shows the received signal strength indicator (RSSI) of the End-device node against the distance change between the Coordinator and the End-device nodes. The RSSI value is susceptible to variations due to changes in sta tionery and moving objects between the nodes. Thus, the overall effect is that the RSSI signal will suffer from fading. The observed RSSI was in the range of -45dBm to -73dBm in the distance of 1m to 60m. No data loss is observed within this range of distance.

The proposed system performance is evaluated through the agricultural field in real-time, as shown in figure 9. The system evaluation process took place over 6 hours from 09:00 am to 15:00 pm (320 minutes). As mentioned ear lier, the implemented system controls the irrigation process on four zones named Z1:Z4. The system checks the soil moisture of the four zones and controls the irrigation water flow. The water starts flowing in the intended zone if the soil moisture drops below 75%, and the irrigation stops when the moisture is above 90%.

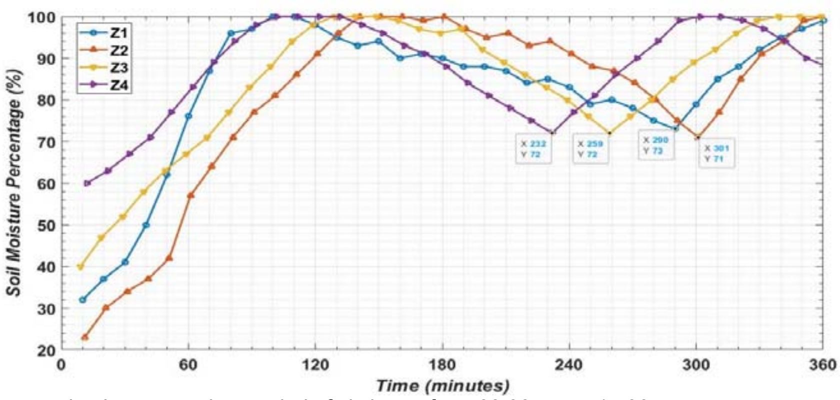

Fig. 9. The proposed system evaluation over a time period of six hours from 09:00 am to 15:00 pm.

When the system started operating, the soil moisture in Z1 was 32%, so the irrigation water started flowing from minute 0 to minute 75. At minute 75, the irrigation process stopped because the soil moisture reached 91%. Then, the irrigation water restarted flowing at minute 290 (soil mois ture is 73%) and stopped at minute 325 (soil moisture is 91%). Therefore, the irrigation water flow in Z1 continued only through 110 minutes out of the six observation hours, about 30%. The same applies to Z2, Z3, and Z4, as shown in Table 2. It is worth mentioning that the six observation hours were during daylight. Therefore, sunlight affects soil moisture and increases the need for irrigation. Nonetheless, the water flows only about 35% of the time of the six observation hours on average in the four zones.

Table 2. Irrigation water flow through the 6 observation hours.

Zones	Water flow (minutes)	Percentage (6 observation hours)
Z1	110	30%
Z2	150	41%
Z3	140	39%
Z4	103	29%
Average		35%

Conclusion

The implemented irrigation system is practical, low cost, low energy consumption, and easy to install in agricultural fields. Also, it reduces labor costs as it needs no human in tervention in the irrigation process. The main goal of this re search is achieved, where the implemented irrigation system maintains the crops' health, protects the plants from over and under-watering, and saves the ecological system by reducing the waste of irrigation water. The implemented WSN showed no data loss in the field. As a future work, a spacious agricul tural field consideration is planned, and more infield metrics are to be incorporated into the system and uploaded to the cloud as an IOT application for further data analysis.

Authors: *Ph.D. Emad Ahmed Mohammed, email: e.a.mohammed@ntu.edu.iq, M. Sc. Hakam Marwan Zaidan, email: hakam_m_zaidan@ntu.edu.iq, M. Sc. Zaid Ghanim Mohammed, email: zaid_gh@ntu.edu.iq, Technical Engineering College/ Mosul, Faculty of Computer Tech niques Engineering, Northern Technical University, Mosul, Iraq.*

REFERENCES

[1] T. Rymarczyk, K. Niderla, K. Kania, M. Maj, and P. Nita, "Wear able sensor for biopotential measurements of patients' health monitoring," Przegl ˛ad Elektrotechniczny, vol. 96, 2020.
[2] S. Bhushan, S. G. Antoshchuk, P. O. Teslenko, V. V. Kuzmenko, W. Wójcik, O. Mamyrbaev, and U. Zhunissova, "Hybrid ap proach to energy efficient clustering for heterogeneous wireless sensor network using biogeography based optimization and k means. przegl ˛ad elektrotechniczny, 95," Przegl ˛ad Elektrotech niczny, vol. 95, 2019.
[3] M. A. Ragab, "Iot based smart irrigation system," International Journal of Industry and Sustainable Development, vol. 3, no. 1, pp. 76–86, 2022.
[4] L. García, L. Parra, J. M. Jimenez, J. Lloret, and P. Lorenz, "Iot-based smart irrigation systems: An overview on the recent trends on sensors and iot systems for irrigation in precision agri culture," Sensors, vol. 20, no. 4, p. 1042, 2020.
[5] R. Liao, S. Zhang, X. Zhang, M. Wang, H. Wu, and L. Zhangzhong, "Development of smart irrigation systems based on real-time soil moisture data in a greenhouse: Proof of concept," Agricultural Water Management, vol. 245, p. 106632, 2021.
[6] O. SZCZEPANIAK, D. SAWICKI, G. W ˛EGRZYN, and R. SZCZYGIEŁ, "Przegl ˛ad elektrotechniczny vol 2021, no 10."
[7] A. Kumar, K. Kamal, M. O. Arshad, S. Mathavan, and T. Vadamala, "Smart irrigation using low-cost moisture sensors and xbee-based communication," in IEEE Global Humanitarian Technology Conference (GHTC 2014), 2014, pp. 333–337.
[8] C. Z. Zulkifli, N. M. Noor, and N. H. A. Hassan, "Performance evaluation of integrated moisture with zigbee mesh network for automated irrigation system."
[9] T. Savic and M. Radonji ´ c, "Wsn architecture for smart irrigation ´ system," in 2018 23rd International Scientific-Professional Con ference on Information Technology (IT). IEEE, 2018, pp. 1–4.
[10] J. Anghan and H. Parveen Sultana, "Smart irrigation system using raspberry pi," International Journal of Scientific & Engi neering Research, vol. 9, no. 6, pp. 197–210, 2018.
[11] V. M. Ramya, B. Palaniappan, and B. George, "Embedded system for automatic irrigation of cardamom field using xbee pro technology," International Journal of Computer Applications, vol. 53, pp. 36–43, 2012.
[12] G. I. Hapsari, G. A. Mutiara, L. Rohendi, and A. Mulia, "Wireless sensor network for monitoring irrigation using xbee pro s2c," Bulletin of Electrical Engineering and Informatics, vol. 9, no. 4, pp. 1345–1356, 2020.
[13] Digi XBee S2C Zigbee, Digi International Inc., 11 2022. [On line]. Available: https://www.digi.com/resources/library/data sheets/ds_xbee_zigbee
[14] R. Hussian, S. Sharma, and V. K. Sharma, "Wsn applica tions: Automated intelligent traffic control system using sen sors," 2013.
[15] M. Frei, C. Deb, R. Stadler, Z. Nagy, and A. Schlueter, "Wireless sensor network for estimat ing building performance," Automation in Construc tion, vol. 111, p. 103043, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0926580519307472
[16] A. T. Demetillo, M. V. Japitana, and E. B. Taboada, "A system for monitoring water quality in a large aquatic area using wire less sensor network technology," Sustainable Environment Re search, vol. 29, no. 1, pp. 1–9, 2019.
[17] V. Boonsawat, J. Ekchamanonta, and K. Bumrungkhet, "Xbee wireless sensor networks for temperature monitoring," 2010.
[18] N. Gondchawar and R. S. Kawitkar., "Iot based smart agricul ture," International Journal of Advanced Research in Computer and Communication Engineering, vol. 5, no. 6, pp. 838–842, 2016.