SMART GLASSHOUSE SYSTEM SUPPORTED BY GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS AND INTERNET OF THINGS: CASE STUDY: TOMATO PLANT

Article *in* Journal of Engineering Science and Technology · October 2020

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Journal of Engineering Science and Technology
Vol. 15, No. 5 (2020) 3067 - 3081

SMART GLASSHOUSE SYSTEM SUPPORTED BY GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS AND INTERNET OF THINGS: CASE STUDY: TOMATO PLANT

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Abstract

This paper proposes a new system for remotely monitoring and automatically controlling the temperature, humidity levels, and soil moisture content in glasshouses to help increase crop yields in Iraq. The main hardware of the system comprises microcontroller units, sensors, fans, air exchangers, irrigation devices, and transceivers. Further, the LABVIEW software is used to visualize the data obtained on the computer screen of a monitoring station. In addition, plant growth parameters are maintained by controlling the irrigation devices, air exchangers, and fans. The proposed system utilizes the ZigBee protocol implemented in wireless sensor networks to monitor glasshouses in real time and the Global System for Mobile Communications and Internet of Things technologies for the remote operation of glasshouses. A prototype of the new smart glasshouse system is successfully tested, and its functionality and effectiveness are verified. The new system comprises several useful features that are not present in other similar systems, and therefore, it can potentially improve the quality of life of Iraqi farmers.

Keywords: Glasshouse, Global system for mobile communications, Internet of Things, Wireless sensor network, ZigBee protocol.

1. Introduction

The Food and Agricultural Organization of the United Nations suggests that the global population will be more than nine billion by 2050. As a result, there is a requirement to increase food production by 70 % before 2050 to meet the demands of the growing population [1]. However, the natural resources that support agriculture have been decreasing owing to climatic factors. One of the most effective methods of producing quality foods by solving the problems associated with natural resources is precision agriculture. This strategy can be effective for solving the problems of pollution and climate change because it can adjust the measures used during cultivation according to the specific requirements of each crop. In addition, it can maximize the use of the agricultural tools that can yield the maximum produce. In this regard, precision agriculture will be responsible for the economic growth and protection of the environment and agricultural resources.

Further, it is important to consider the use of controlled environment technology other than open field agriculture to attain sustainable agricultural development. In controlled environment agriculture, greenhouses are ideal locations for growing vegetables and fruits. A greenhouse separates crops from the environment, thus protecting them from harsh external conditions. The climate inside a greenhouse allows for the production of all crops without targeting special crops that are only produced under specific conditions.

Plant growth is affected by environmental parameters such as soil moisture, temperature, and humidity. These variables directly influence crop productivity and health, particularly in extremely harsh climatic regions [2]. This problem may be solved by glasshouse cultivation, which shields crops from harsh external conditions. Hence, glasshouse technology is used to achieve optimal plant growth, improve crop quality, protect plants from diseases, and enable farmers to select suitable plants to grow at any location or time [3]. The glasshouses that are manually controlled by farmers are inefficient because it is not possible to grow a few types of plants [4].

Wireless sensor networks (WSNs) exhibit several useful features such as low cost and power consumption. Hence, they are widely utilized in numerous fields including agriculture, in which they have attracted significant interest from academia and industry [5, 6]. The IEEE 802.15.4 standard, referred to as the ZigBee protocol, is a low-power, low-data, and simple protocol that comprises Open Systems Interconnection (OSI) model layers [7]. Here, the Media Access Control (MAC) and physical layers are standardized by the Institute of Electrical and Electronics Engineers (IEEE) 802.15 protocol, and the higher layers represent a ZigBee alliance [8]. The combination of the Global System for Mobile Communications (GSM) and WSNs provides various advantages including increased reliability in emergency cases [9]. Currently, the Internet technology can be integrated with monitoring systems to use them in remote areas [10, 11]. The Internet of Things (IoT) is the next 5th generation technology that will be widely utilized in e-health, industrial, and environmental monitoring (IoT services primarily deal with the big data analysed by cloud services) [12-14]. In this work, we propose a smart system to monitor and control the conditions in glasshouses in Iraq and compare its parameters with those of previously built devices. The main hardware of this system includes microcontroller units, sensors, fans, air exchangers, irrigation devices, and transceivers. Further, the LABVIEW software is used to visualize the data obtained on the computer screen of a monitoring station. The system utilizes the ZigBee protocol implemented in WSNs to monitor glasshouses in real time and the GSM and IoT technologies for the remote operation of glasshouses.

2. Related work

The IoT technology utilized in this study incorporates information management technology and neural network image processing to create a monitoring and warning system for collecting field information. The latter facilitates the development of individual monitoring sites by combining internet-connected networks, interconnected wireless communication, and obtained field data to establish an agricultural hazard monitoring system that includes a decision support program [15].

Several IoT applications have been proposed to integrate the supply chain management of fresh agricultural products with IoT. They include an IoT-based information management system that allows for the enhancement of supply chain integration, cost reduction owing to higher efficiency, the better observation of agricultural produce, and better food quality control [16]. An agricultural irrigation system including a network and hardware architecture based on IoT precision has been designed, and its various software process control parameters have been analysed [17]. An additional IoT-based agricultural system has been proposed to stabilize the demand and supply of agricultural products and project their future growth by employing specially developed sensors for environmental monitoring. Lee et al. [18] have reviewed the IoT-integrated wireless networks and sensors applied to actual agricultural fields. An innovative remote monitoring system model that incorporates wireless communications and the Internet has been proposed. Its main goal is to collect environmental data related to agricultural production in real time while providing seamless access to agricultural facilities by issuing alerts regarding weather patterns, crops, and other parameters and providing advice via the short message service (SMS) [19].

An embedded soil-monitoring and irrigation system that is capable of transmitting information via mobile applications has been proposed to reduce the dependence on the manual monitoring of fields and increase their productivity [20]. An easy-to-install technique has been utilized for soil moisture monitoring because it allows for the maximum plant growth while supplementing scarce irrigation resources. The project also involved processing the information obtained from input sensors using neural network algorithms and soil monitoring correction factors [21].

A system has been proposed for the automatic monitoring of the environmental parameters of agricultural fields while directly sending live videos from a server using a Raspberry Pi camera [22]. The system allows for irrigation based on specified the levels of soil moisture, humidity, and temperature. IoT has been fundamentally integrated with smart agriculture owing to the ability of designed systems to provide information on agricultural fields [23]. The latter has been achieved using a CC3200 chip connected to sensors for monitoring various parameters of agricultural fields including temperature and humidity levels, which have significant effects on agricultural products.

Further, a glasshouse management IoT-based smart system comprising a software control centre and sensor networks has been developed. It incorporates a master control centre and multiple sensors that transmit information via ZigBee protocols. A top web system provides a user interface that can observe and manage hardware facilities, making it possible to notify administrators about the glasshouse status while remotely controlling related environmental factors and irrigation frequencies by issuing commands to the sensors [24].

An IoT-based device has been utilized to collect agricultural information. In this case, the resultant data are stored in a cloud database, and a cloud-based big data analysis model is applied to determine various parameters including stock and market-related, fertilizer-related, and crop-related requirements. Additionally, a data mining technique is utilized to send the resultant information to farmers through mobile applications. This increases the production level and farming efficiency while reducing agricultural costs [25].

It is possible to improve the conventional farming methods employed by rural farmers using the wireless sensor network technology. The IoT-based AGRO-TECH application has been developed to record, store, and update various sensor parameters utilized by farmers during the tracking of field activities related to crop and soil characteristics [26]. The contents of soil macronutrients are measured via wireless sensors, and the obtained data are transmitted to the cloud by the developed system, which facilitates continuous soil fertility monitoring through mobile applications. This technology can help farmers gather real-time information on various soil-related aspects while making suggestions on appropriate crops and fertilizers [27].

Recent technological advancements have allowed for the construction of an automated irrigation system that has made farming more efficient with respect to workload and water use. By employing various sensors, optimal amounts of water are supplied to plants depending on various parameters including temperature, moisture level, and light intensity. In addition, the efficiency of water usage has been significantly increased through the analysis and comparison of the data obtained for the current and previous years [28].

An innovative Raspberry-Pi-based automatic irrigation IoT system has been developed to increase water efficiency and crop productivity. This has been achieved through the combined implementation of precision agriculture technology and cloud computing, which allow for the analysis of field weather conditions and the determination of the optimal water and fertilizer contents [29]. A study has investigated several sensor-based irrigation techniques for the precision irrigation of apple orchards, including evapotranspiration-based, soil-moisture-based, and crop-water-stress-index-based techniques [30].

The above-mentioned studies have certain limitations related to the real-time monitoring and alarm-generation processes, power consumption, cost, applicable software, and the number of agricultural houses that can be monitored and controlled simultaneously. The system developed in this work exhibits better control, monitoring, and power consumption characteristics compared to the systems described above and in [31]. It comprises a portable wireless real-time device supporting alarm and the GSM and Internet services, which can be powered by a solar panel.

3. Overall system description

It is not possible for Iraqi farmers to manually monitor/control several glasshouses. Therefore, in this work, we designed an automatic controlling/remote monitoring real-time system for an unlimited number of glasshouses using the GSM and Internet services. This system monitors soil moisture, humidity, and temperature levels in glasshouses and automatically adjusts their values in real time. Moreover, it sends SMS alarm notifications to the phones of farmers using the GSM service so that the farmers can monitor glasshouses from any location worldwide via the Internet.

If any change in the humidity or temperature level of a glasshouse is observed, the system starts/stops the air exchangers and fans. Additionally, when the soil moisture content changes, the system increases/decreases the irrigation water ratio and simultaneously sends an SMS alarm to farmers' phones. The system's mode of operation is based on the WSN of the ZigBee protocol that transmits data from glasshouses (nodes) to a monitoring station (PC), thus allowing for the remote monitoring of glasshouses. Overall, the developed system exhibits the following main features:

- High portability
- Ability to remotely monitor glasshouses
- Real-time operation
- Use of Internet and GSM services
- Low power consumption
- Low cost
- Use of universal software that can work on any PC
- Ability to remove the PC without producing a significant effect on the controlling and alarming processes
- High usability

The proposed smart glasshouse system comprises five main parts, i.e., the node, controlling, monitoring, GSM, and Internet subsystems, which are integrated as shown in Fig. 1. Their detailed descriptions are provided below.

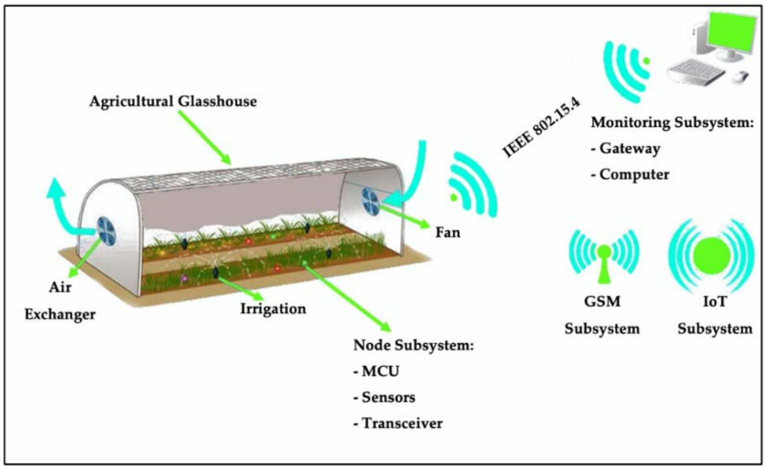


Fig. 1. Schematic of the proposed smart glasshouse system.

3.1. Node subsystem

This subsystem contains four parts: a microcontroller unit (MCU), sensors, a transceiver, and a power supply.

3.1.1. MCU

An ATmega 328 MCU incorporated into the open-source Arduino UNO platform is used in the designed system owing to the ease of implementation.

3.1.2. Sensors

Here, the sensors used are:

- Temperature and humidity sensor

  An RHT03 sensor is used to measure the humidity and temperature of an agricultural glasshouse. It can be calibrated with high accuracy and exhibits excellent precision, a large temperature range, low cost, and low power consumption. Its measurement range spans from 0 to 100 % for humidity and from -40 to 80 °C for temperature [32].

- Soil moisture sensor

  An EC-5 sensor is used to measure the soil moisture content. It is characterized by low cost, low power consumption, and high accuracy, and its operation is not affected by soil salinity or texture. The measurement range of this sensor spans from 0 to 100 % [33].

3.1.3. Transceiver

An XBee series 2 transceiver device is used to connect the monitoring station with the nodes of glasshouses, which are configured using the X-CTU program. The XBees are configured as end devices using the AT command mode in agricultural glasshouses. In this work, a star topology is selected in the WSN because of its small delay time, low power consumption, and ease of synchronization.

In the proposed system, the protocol payload is designed to satisfy the requirements of the two main system operations (searching and sensing). A packet of data contains one sample during the real-time transmission; in other words, a sample is sent by the MCU without waiting for the next sample.

3.1.4. Power supply

The node subsystem is powered by a LiPo rechargeable battery with a capacity of 5000 mAh, which supplies high voltage over a long time. Furthermore, a solar panel is integrated into the implemented system to charge the battery using a LiPo Rider board.

3.2. Controlling subsystem

Automatic processes are controlled in this block. The system changes the parameters of the glasshouses in real time. Thus, when humidity or temperature changes, the system starts/stops the air exchanger or fan to rebalance it. The system decreases/increases the irrigation water amount if the soil moisture content changes. Note that all control processes utilize an MCU-based Power-Switch Tail II device.

3.3. Monitoring subsystem

The monitoring subsystem comprises the gateway (GW) and PC modules.

3.3.1. GW

The GW represents an XBee S2 transceiver that is used to transfer data between the glasshouses and monitoring station, which serves as a coordinator.

3.3.2. PC

The PC performs the monitoring processes using the NI LABVIEW software (SW) because the latter contains a facile graphical user interface (GUI) with an extremely low delay time.

3.4. GSM subsystem

The GSM subsystem is used to send an SMS alarm to farmers. This operation is conducted without using an external GSM modem. Therefore, it is characterized by low cost, small delay time, and low degree of complexity achieved by connecting a phone to the PC through a USB port and using the AT SMS commands.

3.5. Internet subsystem

The Internet subsystem can be used to monitor the glasshouses from any location worldwide. This is achieved by designing a special website by utilizing the VB.NET and ASP.NET software. This website contains an added user login feature for the privacy of farmers. Furthermore, we use the Blynk Cloud software to design a phone application for displaying the glasshouse parameters to simplify the monitoring process for the farmers who do not possess sufficient Internet proficiency skills.

4. System implementation

The components outlined above were integrated during the implementation of the system design. The resultant setup comprised board software for running the devices and a variety of functions. Interconnected circuits controlled by special software were utilized to increase the efficiency of operation. Additionally, the pins of the Arduino Uno board were connected to various components to allow for direct integration and ensure a high degree of functionality and compatibility, which were verified through testing and interactive debugging. The system was programmed using an Arduino-integrated development environment, and its source code written in the C language. GSM and NET functions were employed using the available libraries to ensure the simplicity of coding and implementation. In addition, constant prototype checking was conducted during the development process to enhance the functionality of the system.

The next step involved the selection of a power supply for every integrated component and the designed system controller. For this purpose, a solar panel was employed to increase the power capacity while ensuring the system's availability via a specially designed circuit. The sensors were connected to the microcontroller to retrieve the signals for triggering predetermined events. The sensors were directly powered by a battery to ensure that they remained continuously active. Operation control based on sensor events was achieved by coupling the integral alarms with the microcontroller containing the GSM module. The microcontroller clock was utilized for synchronizing all components.

By optimizing each function, it was possible to achieve relatively low power for operating the microcontroller in a range of 1.8--5.5 V. Furthermore, the LiPo Pro Rider board ensured that the supplied voltage did not exceed the maximum level when additional energy was provided by the solar panel. Sensor events triggered alarms, which served as actuators that consumed the majority of power during short periods. When the sensors failed to trigger an alarm, the battery power consumption increased.

The monitoring, analysis, and recording of data were started when the measured data were sent to the PC through the GW. In the implemented system, the LabVIEW SW was used for this purpose because it contains a GUI window that can handle data rapidly and an easy interface with external hardware. The SW uses serial connection as input and output data, which interface with the XBee serial connection of the GW. The flowchart of the main operations of the SW system is shown in Fig. 2.

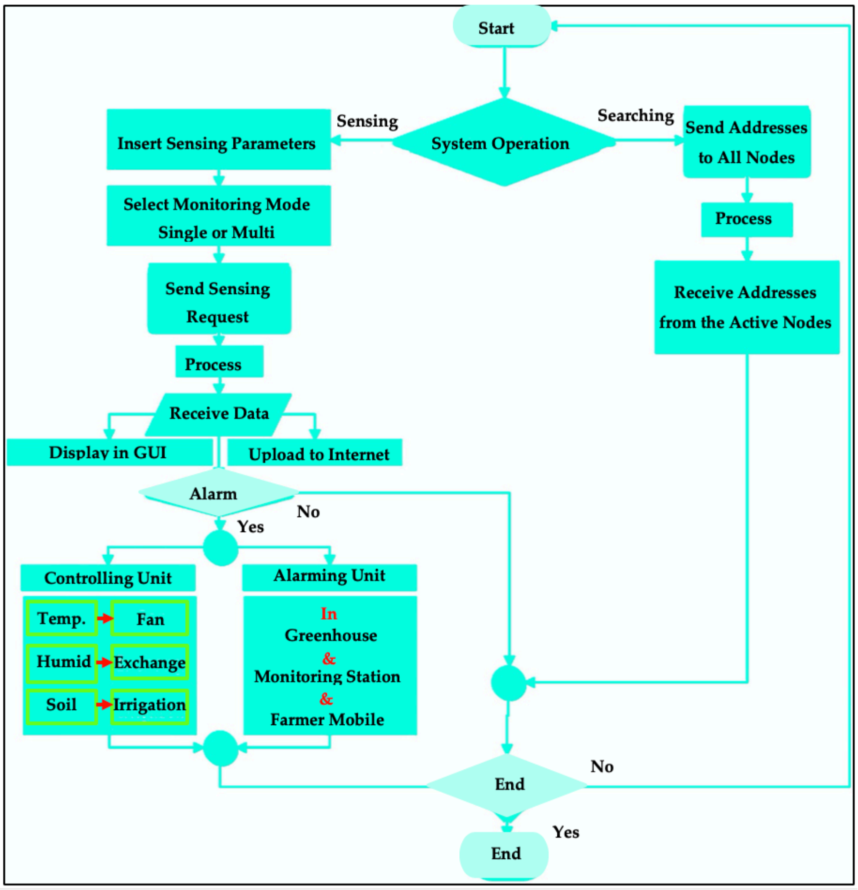


Fig. 2. Basic flowchart describing the glasshouse system operation.

The implemented system exhibited sensing and searching capabilities. The latter involved the detection of active nodes (glasshouses) in the network, while the former involved reading the signals passing through a glasshouse during the monitoring of the plant status. The searching and sensing operations occurred between the GW and device nodes using the real-time star WSN. Individual end device nodes utilized an XBee transceiver to receive requests from the GW and passed them to the MCU for processing while performing specified operations.

Sensor information was transmitted to the GW before being passed to the GUI window to be processed and displayed in specific fields. The coordinator (GW) toured between the end devices for 3 s at each node. In the case of an alarm, the GUI window played an alarm tone to alert a user. The buzzer and light emitting diode were simultaneously turned on by the MCU node.

All data were automatically uploaded to the designated website in real time using the VB.NET and ASP.NET platforms to optimize system usability using an internet browser as the sole system-accessing tool. In addition, the user could employ the designed mobile application to monitor the system.

5. Results and discussion

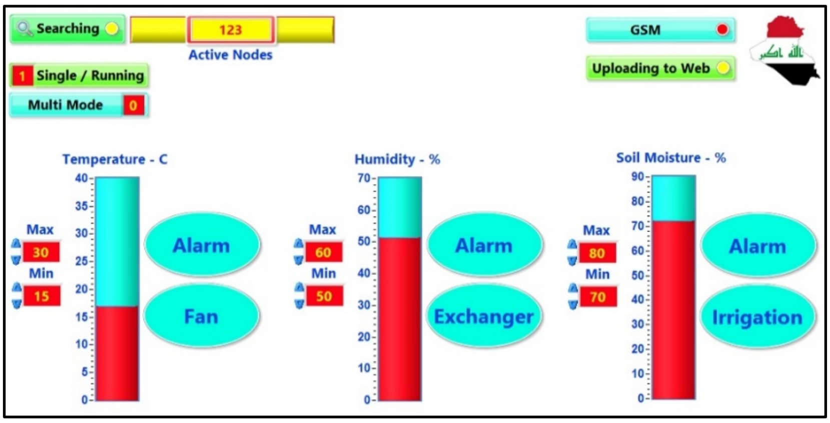
Three glasshouse prototypes were constructed according to the specified procedure. The results presented in this section were obtained for the actual cases of tomato glasshouses in the month of August with the best tomato growing conditions corresponding to a temperature of 15-30°, a relative humidity of 50-60 %, and a soil moisture content of 70-80 % [34].

Figure 3(a) shows the data obtained for the first node. In this case, a user selected a single-mode monitoring regime with no alarms. Figure 3(b) displays the data obtained for the second node. Here, the user selected a multimode monitoring regime with no alarms.

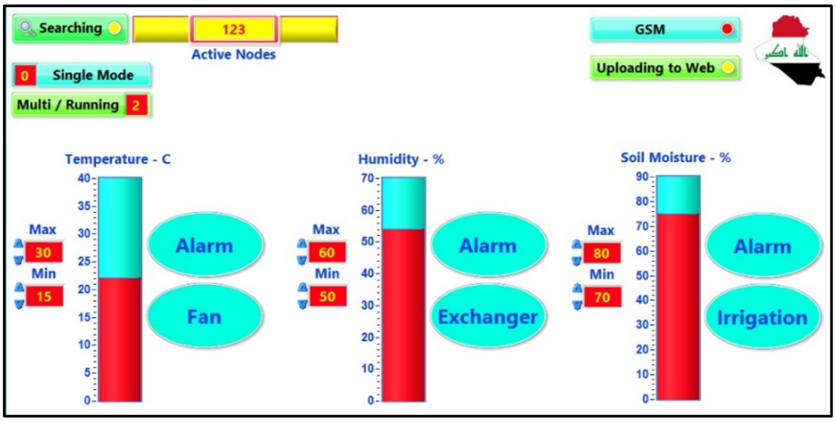
Figure 3(c) shows the data obtained for the third node, which included a temperature alarm. Figure 4(a) depicts the SMS alarm notification message that was received by the farmer in the normal case. Figure 4(b) displays the alarm SMS notification message received by the farmer when a node was shut down (turned off). The actual monitoring data presented on the designed website and the data displayed by the designed phone application are presented in Fig. 5(a) and Fig. 5(b), respectively.

Before fabricating the system, all components were tested against calibrated instruments. The obtained results indicated that the search process occurred without errors and that all measured data were successfully displayed. The alarm tones and indicators at the monitoring station and inside the glasshouses were activated without any problems, and SMS alarm messages were transmitted to the farmer's phone in real time.

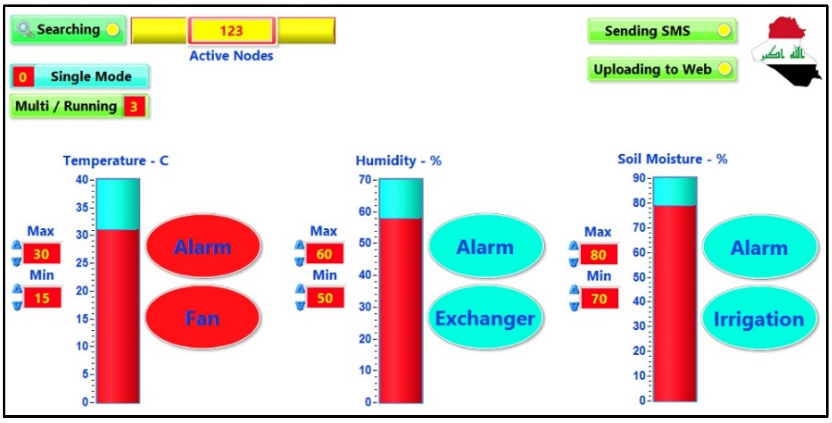
The process of logging into the website was conducted successfully, and all data were uploaded to it correctly. The implemented system was presented to agricultural engineering specialists who confirmed its operational effectiveness.



(a)

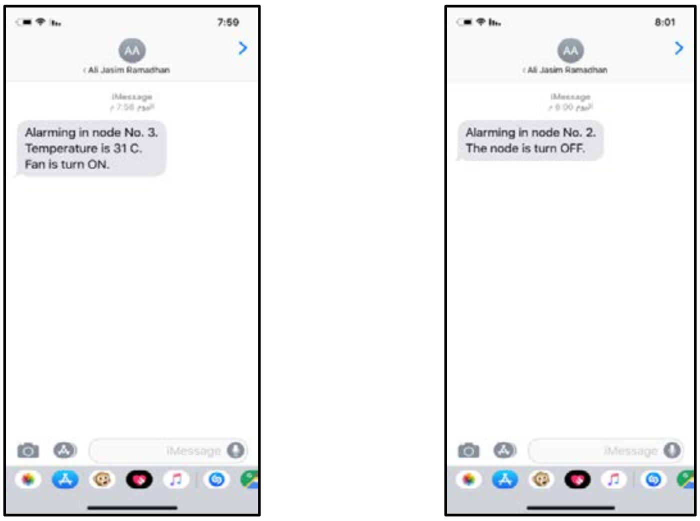


(b)



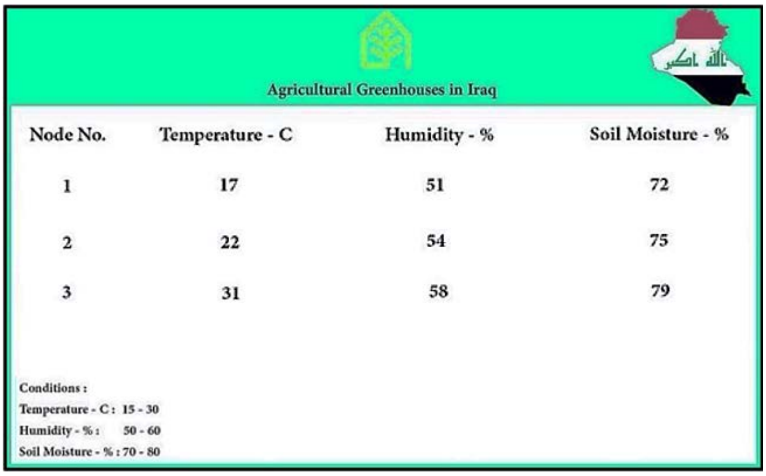
(c)

Fig. 3. Glasshouse monitoring results obtained for the (a) first, (b) second, and (c) third nodes.

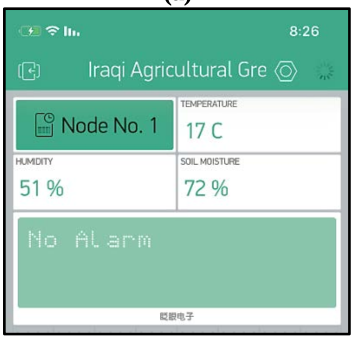


(a) **(b)**

Fig. 4. (a) Temperature and (b) shutdown alarm messages received by the farmers.



(a)



(b)

Fig. 5. Glasshouse monitoring results displayed
(a) on the website and (b) by the designed phone application.

6. Conclusions

In this work, a new electronic system was proposed to remotely monitor and control Iraqi glasshouses in real time based on the ZigBee protocol in the implemented WSN. This system is suitable for all plant types and can be operated using a portable wireless device. The system generates alarms, incorporates the GSM and Internet technologies, and is powered by a solar panel. All sensors of the designed system were tested against calibrated instruments, and its efficiency was successfully verified in different operation modes. We believe that this system will increase crop yields in Iraq and significantly improve the quality of life of Iraqi farmers.

We experienced various limitations and challenges during our work. The most prominent challenge was the unavailability of certain components required for building the system prototype owing to the current political and economic situation in Iraq. In future, we plan to include additional sensors into the designed smart glasshouse system to increase its capabilities and make it suitable for the detection of gases and light and for monitoring fertilizer contents and seed growth.

Nomenclatures

Abbreviations

GW	Gateway
GUI	Graphical User Interface
IoT	Internet of Things
MCU	Microcontroller Unit
PC	Personal Computer
SW	Software
WSN	Wireless Sensor Network

References

1. Liu, Y.; and Wang, M. (2019). Wireless greenhouse environment monitoring system based on lora network. *Journal of Food Science & Technology*, 4(8), 889-902.
2. Shaker, M.; and Imran, A.A. (2013). Greenhouse micro climate monitoring based on WSN with smart irrigation technique. *International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, 7(12), 1566-1571.
3. Jasim, S.; Shaker, M.; and Imran, A.A. (2013). Greenhouse automation based on wireless sensor network with novel diagnostic subsystem. *European Journal of Scientific Research*, 102(3), 425-440.
4. Nagesh Kumar, D.N. (2015). ARM based remote monitoring and control system for environmental parameters in greenhouse. *Proceedings of the 2015 Institute of Electrical and Electronics Engineers (IEEE) International Conference on Electrical, Computer and Communication Technologies (ICECCT),* Coimbatore, India, 1-6.
5. Ramadhan, A.J. (2018). Wearable smart system for visually impaired people. *Sensors*, 18(3), 843.

6. Zubov, D.; Kose, U.; Ramadhan, A.J.; and Kupin, A. (2018). Mesh network of eHealth intelligent agents in smart city: A case study on assistive devices for visually impaired people. *Proceedings of the 1st International Workshop on Informatics & Data-Driven Medicine*. Lviv, Ukraine, 65-81.
7. Khan, I.; Belqasmi, F.; Glitho, R.; Crespi, N.; Morrow, M.; and Polakos, P. (2015). Wireless sensor network virtualization: A survey. *Institute of Electrical and Electronics Engineers (IEEE) Communications Surveys & Tutorials*, 18(1), 553-576.
8. Karnain, M.A.B.; and Zakaria, Z.B. (2015). A review on ZigBee security enhancement in smart home environment. *Proceedings of the 2015 2nd International Conference on Information Science and Security (ICISS)*, Seoul, South Korea, 1-4.
9. Sahani, M.; Nayak, A.; Agrawal, R.; and Sahu, D. (2015). A GSM, WSN and embedded web server architecture for Internet based kitchen monitoring system. *Proceedings of the 2015 International Conference on Circuits, Power and Computing Technologies (ICCPCT-2015)*, Nagercoil, India, 1-6.
10. Ramadhan, A.J. (2017). Implementation of 5G FBMC PHYDYAS prototype filter. *International Journal of Applied Engineering Research*, 12(23), 13476-13481.
11. Ramadhan, A.J. (in press). Smart water quality monitoring system based on enabled real-time internet of things. *Journal of Engineering Science and Technology* (*JESTEC*).
12. Ramadhan, A.J. (2019). Overview and implementation of the two most important candidate 5G waveforms. *Journal of Theoretical and Applied Information Technology*, 97(9), 2551-2560.
13. Ramadhan, A.J. (2019). Implementation of a 5G filtered-OFDM waveform candidate. *International Journal of Engineering Research and Technology*, 12(4), 500-507.
14. Khare, A.; Sharma, R.; and Ahuja, N.J. (2020). Experimental investigation of integrated ID method to mitigate message loss in IOT control devices. *Journal of Engineering Science and Technology* (*JESTEC*), 15(1), 32-45.
15. Qiang, W.K.; and Ken, C. (2010). Farmland information gathering and monitoring system based on IOT. *Proceedings of the 2010 Second Pacific-Asia Conference on Circuits, Communications and System*, Beijing, China, 253-256.
16. Yu, G.; Gu, Y.; Bao, Y.B.; and Wang, Z.G. (2011). Large scale graph data processing on cloud computing environments. *Jisuanji Xuebao*, 34(10), 1753-1767 (in Chinese).
17. Li, S. (2012). Application of the internet of things technology in precision agriculture irrigation systems. *Proceedings of the 2012 International Conference on Computer Science and Service System*, Nanjing, China, 1009-1013.
18. Lee, M.; Hwang, J.; and Yoe, H. (2013). Agricultural production system based on IoT. *Proceedings of the 2013 Institute of Electrical and Electronics Engineers (IEEE) 16th International Conference on Computational Science and Engineering*, Sydney, NSW, Australia, 833-837.
19. Patil, K.A.; and Kale, N.R. (2016). A model for smart agriculture using IoT. *Proceedings of the 2016 International Conference on Global Trends*

in Signal Processing, Information Computing and Communication, Jalgaon, India, 543-545.

20. Ananthi, N.; Divya, J.; Divya, M.; and Janani, V. (2017). IoT based smart soil monitoring system for agricultural production. *Proceedings of the 2017 Institute of Electrical and Electronics Engineers (IEEE) Technological Innovations in ICT for Agriculture and Rural Development*, Chennai, India, 209-214.
21. Athani, S.; Tejeshwar, C.H.; Patil, M.M.; Patil, P.; and Kulkarni, R. (2017). Soil moisture monitoring using IoT enabled arduino sensors with neural networks for improving soil management for farmers and predict seasonal rainfall for planning future harvest in North Karnataka—India. *Proceedings of the 2017 International Conference on IoT in Social, Mobile, Analytics and Cloud*, Palladam, India, 43-48.
22. Venkatesan, R.; and Tamilvanan, A. (2017). A sustainable agricultural system using IoT. *Proceedings of the 2017 International Conference on Communication and Signal Processing (ICCSP)*, Chennai, India, 763-767.
23. Prathibha, S.R.; Hongal, A.; and Jyothi, M.P. (2017). IOT based monitoring system in smart agriculture. *Proceedings of the 2017 International Conference on Recent Advances in Electronics and Communication Technology*, Bangalore, India, 81-84.
24. Li, Z.; Wang, J.; Higgs. R.; Zhou, L.; and Yuan, W. (2017). Design of an intelligent management system for agricultural greenhouses based on the internet of things. *Proceedings of the 2017 Institute of Electrical and Electronics Engineers (IEEE) International Conference on Computational Science (CSE) and Engineering and Institute of Electrical and Electronics Engineers (IEEE) International Conference on Embedded and Ubiquitous Computing (EUC)*, Guangzhou, China, 154-160.
25. Rajeswari, S.; Suthendran, K.; and Rajakumar, K. (2017). A smart agricultural model by integrating IoT, mobile and cloud-based big data analytics. *Proceedings of the 2017 International Conference on Intelligent Computing and Control (I2C2)*, Coimbatore, India, 1-5.
26. Pandithurai, O.; Aishwarya, S.; Aparna, B.; and Kavitha, K. (2017). Agro-tech: A digital model for monitoring soil and crops using internet of things (IoT). *Proceedings of the 2017 Third International Conference on Science Technology Engineering & Management*, Chennai, India, 342--346.
27. Shylaja, S.N.; and Veena, M.B. (2017). Real-time monitoring of soil nutrient analysis using WSN. *Proceedings of the 2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, Chennai, India, 3059-3062.
28. Monica, M.; Yeshika, B.; Abhishek, G.S.; Sanjay, H.A.; and Dasiga, S. (2017). IoT based control and automation of smart irrigation system. *Proceedings of the 2017 International Conference on Recent Innovations in Signal Processing and Embedded Systems*, Bhopal, India, 601-607.
29. Rao, R.N.; and Sridhar, B. (2018). IoT based smart crop-field monitoring and automation irrigation system. *Proceedings of the 2018 2nd International Conference on Inventive Systems and Control*, Coimbatore, India, 478-483.

30. He, L.; Zeng, L.; and Choi, D. (2019). Investigation of sensor-based irrigation systems for apple orchards. Retrieved March 9, 2020, from https://elibrary.asabe.org/abstract.asp?aid=50194&t=1&redir=aid=50194&redir=[confid=nabec]&redirType=section_meeting.asp&redirType=section_meeting.asp.
31. Ramadhan, A.J. (2016). Automatically maintain climatic conditions inside agricultural greenhouses. *Journal of Engineering*, 22(11), 83-100.
32. RHT03 digital humidity & temperature sensor. (2020). Retrieved March 9, 2020, from https://cdn.sparkfun.com/datasheets/Sensors/Weather/RHT03.pdf.
33. EC-5 soil moisture sensor. (2020). Retrieved March 9, 2020, from http://manuals.decagon.com/Manuals/13876_EC-5_Web.pdf.
34. Duffy, R. (2013). *Agricultural practices for greenhouse vegetable crops.* Rome, Italy: FAO, 532-557.