Vol. 5, No. 2 | July – December 2022

Wireless Sensor Networks-based Smart Agriculture: Sensing Technologies, Application and Future Directions

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Abstract:

With the advent of the latest sensing technologies and Wireless Sensor Networks (WSN), agricultural tasks can be performed quickly, adequately and precisely. These practices are termed Smart agriculture. In this paper, we discuss various sensing technologies that enable smart agriculture. Later, a system based on WSN has been designed to monitor agricultural parameters. The proposed system has been deployed in a Wheat field. This work aims to increase the quality and productivity of the Wheat crops and minimize the extensive field visits of the farmers. This system enables precision agriculture by periodically measuring the three most key parameters (temperature, light, and water level) for achieving a remarkable increase in quality, productivity and growth of the Wheat crops. Thus, this system helps the agriculturists, landowners and research experts to monitor these parameters at the base station without going to the field site. A GUI tool is also designed to display the measured data and stored it in the database accordingly. While designing this system; IRIS mote, MDA100 data acquisition board, and MIB520 USB interface board are employed. We use TinyOS operating system for the development of codes for wireless nodes and the GUI tool is designed in Microsoft Visual Studio. ZigBee IEEE 802.15.4 protocol and direct topology are used for the communication of nodes with the base station. In last, we also discuss future research directions.

Keywords: *Wireless sensor networks, smart agriculture, precision agriculture, sensing technologies, Wheat crops.*

Pakistan, being an agricultural country stabilizes its economy through agricultural projects. The economy of most of the population depends on the outputs gained from the agriculture sector. It fulfils the major ingredient of food for mankind and other living organisms on earth. Modern technology can bring a remarkable increase in the production and quality rate of crops. Through modern techniques and technologies not only the human efforts can be reduced but agricultural expenditures from sowing to harvesting can also be minimized. Two basic needs of humans can only be fulfilled from

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agricultural resources, which are food and clothes. Hence, modern techniques and technologies always do come up with the best solution for higher productivity and quality of cash crops like wheat, rice, cotton, sugar-cane and vegetables [1]. For enhanced productivity with low cost, a Wireless Sensor Network (WSN) provides a variety of solutions for real-world challenges. WSN has proved its significance very effectively in various other applications like structural and health monitoring of highways and buildings, habitats and irrigation [2]. Meanwhile, WSN can also be equally beneficial in precision agriculture for monitoring the quality parameters of the crops and helping the farmers and landowners in cultivation procedures as well [3].

A management framework in which suitable strategies and plans based on information and communication technologies (ICT) are made to handle the agricultural practices is called precision agriculture or precision farming [4], [5]. The impacts of precision agriculture on improving crop profitability are addressed in [6]. The principle aim of precision agriculture is to increase crop productivity and quality and reduce the efforts of the farmers using ICT systems and algorithms [7]. Precision agriculture is somehow related to data monitoring of an agricultural field [8]. Typical attributes of precision agriculture are [7], [9]:

- Monitoring of agricultural environmental parameters.
- Appropriate set point for data collection.
- Data transmission from source (field) to destination (sink).
- Control actions and decision-making as per sensed data.

In this paper, we portray novel deployment architecture of smart agriculture, which depicts the shape of future digital agriculture. The architecture is comprised of various key technologies, for example, renewable energy sources, sensor classifications, and other emerging technologies. We also provide a detailed discussion on different sensors and sensing technologies is carried out. Later, we perform a case study on the wheat crop. In which, we design a WSN-based system to monitor the three most key parameters (temperature, light, and water level). In last, we discuss the research gaps in this study, which can be implemented in the forthcoming paper. The readers and researchers can also integrate our suggested research gaps in their work.

The remaining sections of the paper are described as follows: Section 2 describes the previous research work based on WSN that had been carried out by different researchers. Section 3 gives the details about the term smart agriculture followed by different sensors and sensing technologies. In section 4, we describe the general block diagram of the system followed by the complete picture of the sensor node with IRIS mote and deployment scenario. Section 5 gives the software implementation description, which is also divided into two sub-sections: implantation in TinyOS and implementation in MS Visual Studio. The deployment results are discussed in section 6. Section 7 is based on general discussions, for example, the requirement of Wheat crops, different users, and future directions. Conclusion is given in section 8.

Exhaust research work on WSN-based precision agriculture has been carried out by different researchers. Most of the research work on precision agriculture is based on various application scenarios like agricultural monitoring, data monitoring, greenhouses, pest detection, soil monitoring and irrigation management [5], [8], [12]–[18] by incorporating different methodologies, techniques, tools and platforms [19]–[21] along with basic guidelines [22]. In [23], a WSN-based system was developed for monitoring the fluoride-affected area. Their system enables the users to access the status of fluoride sensors at the remote station on their cell phones via the Internet. Government organizations and ordinary people can also make use of their systems to monitor the affected areas. Nowadays, mobile devices such as robots and drones are engaged in agricultural monitoring.

In [14], WSN-based aerial robots were employed. Aerial robots were dedicated to vineyards for frost monitoring. The core task of the aerial robot is to provide dynamic mobility to the nodes in vineyards for sensing and creating a communication link between the base station and scrubby clusters sited at disjointed points. Their system is very suitable for such areas where wireless sensor networks have some limitations for such characteristics. By using the dedicated communication channel, data can be routed even at long distances. In [13], an instrumentation setup has been made for monitoring the critical inputs of Wheat crops such as water and Nitrogen. Their system was employed for collecting field data continuously. Besides, agricultural environmental monitoring, a suitable irrigation plan is also needed for precision agriculture [9]. Providing an adequate amount of water in meantime plays a dramatic role in improving crop quality and quantity. In addition, some basic guidelines must be considered before the deployment of WSN in an agricultural field and useful descriptions, such as SOPs (Standard-Operating-Procedures) of a crop must be reviewed for proper crop monitoring and pre-and-post processing actions.

In [22], authors have reviewed different existing components of WSNs for precision agriculture, viz. mote platforms, sensor types, operating systems, communication issues, maintenance, power supply, etc. After a deep review of these data, basic guidelines have been proposed for the deployment of WSNs in any application scenario related to agriculture. In [16], authors have performed real-time deployment for monitoring the agricultural land. They have designed a WSN system based on IRIS motes to monitor the humidity, temperature and light intensity. TinyOS and MS Visual Studio were used to program the IRIS motes and a GUI tool for displaying the results respectively.

In [17], authors have carried out two operations for agricultural monitoring. Firstly, they designed an irrigation system for watering agricultural land automatically. Then after, they designed a system to sense the key parameters, Potassium (K), Nitrogen (N) and Phosphorus (P) for improving crop quality and quantity. Their system was managed via an ARM 7 Processor and the monitored data were sent to the remote station with the aid of IoT (internet of things). In WSN algorithms can improve the data packet transmission efficiency by up to 25% and also helps to prolong the lifetime of Wireless Sensor Networks to achieve efficient data transmission [49].

In [50], authors provided a survey of tending resource-efficient and secure techniques used with distributed estimation algorithms over WSN. In [39], authors have performed a short survey on the implementations and usage of artificial intelligence in smart agriculture. In addition, various machine learning techniques for smart agriculture are also discussed. Some other survey papers related to smart agriculture can be found in [41], [42], in which, the authors have discussed different challenges and proposed some solutions to be faced in smart agriculture.

Fig. 1 portrays the smart agriculture deployment architecture equipped with modern techniques, paradigms, and technologies in order to provide strong technical support in speeding the agricultural transformation and development [30]. The smart agriculture system collects the key information from the cultivated field via sensing and communication devices [31]. The key information includes soil pH, soil moisture, humidity, temperature, water level, and so on (more classifications of agricultural sensors are given in Table.1). Agricultural production increases by continuous monitoring of these parameters [31].

The smart agriculture system requires immense quantities and different types of sensor nodes to cover the whole field. These sensor nodes are tiny in size with limited battery power [32]. So, whenever the battery of these nodes is depleted, they halt the sensing operation, and the network lifespan is shortened. Hence, it is essential to provide a continuous supply of energy to the smart agriculture system, for which it would be better to opt and energy harvesting techniques for avoiding the battery depletion of these low powered sensor nodes.

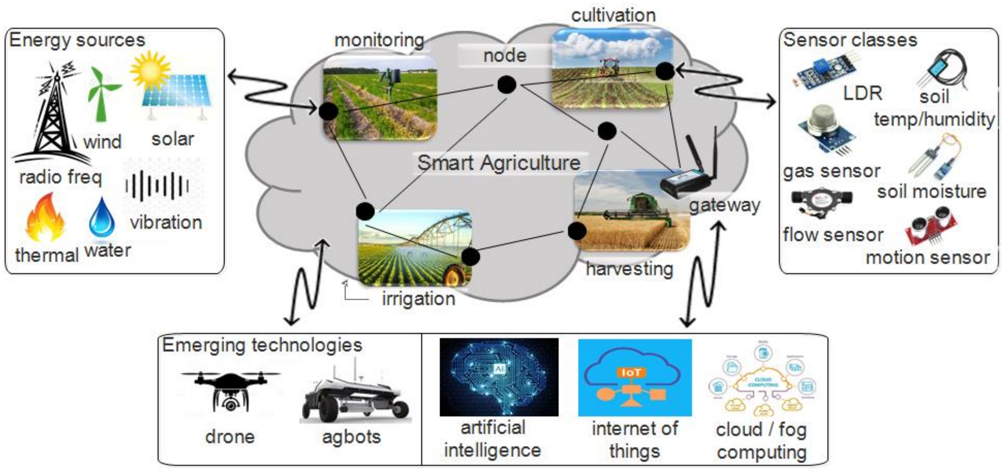


Fig. 1. Deployment architecture of smart agriculture.

There are various energy harvesting techniques, such as solar, wind, thermal, vibrations, radio frequency (RF), water, and so on [33]–[35], [40]. The on-board field information collection and consequent actions are the great challenges in agriculture. The data collected from a large field or crop monitoring requires extensive time and effort. For example, performing soil analysis with crop and environmental monitoring requires regular field trips or even multiple times for certain crops. This is highly exhaustive as it requires too much time and manpower along with expenditures to collect the sample and on-field data.

Thus, thanks to the sensing technologies, which collect the field data and monitor the crops by providing comfort to the farmers. There are several sensing devices and kits in hundreds of thousands and are available in different taxonomies. These sensor taxonomies include [38]: i) Measurement, ii) Technology, iii) Material, iv) Operating principle, v) Conversion techniques and vi) Application areas. We classify the agricultural sensors into these groups i) Chemical, ii) Physical, and iii) Mechanical. Table 1 includes an additional breakdown of these sensors.

3.1.1 Sensing Technologies

Sensing technologies experience explosive creativity, activities, exciting applications, and innovations in the agricultural sector. Various technological firms and entrepreneurs show their diversity and willingness to enter a gigantic field of agriculture. Here we discuss some sensing technologies along with their extensive products and their sensory role in the agricultural sector. Table 1 provides a review on different agricultural sensing technologies.

TABLE I. AGRICULTURAL SENSORS CLASSIFICATION

Class	Type	Classification
Chemical sensors	pH sensor	Soil and water quality monitoring
	Biosensor	Glucose and acids
	Gas sensor	Pollution and air quality

Physical sensors	Temperature sensor	Soil, plant, crops, and environment
	Humidity sensor	Soil and environment
	Watermark sensor	Soil humidity
	Rain sensor	Environmental monitoring
	Electrical conductivity	Soil monitoring
	Leaf wetness sensor	Tress, crops, and plants
	Terrestrial sensor	Weather and environmental monitoring
	Color sensor	Nutrient monitoring
	Passive Infra-red	Environmental monitoring
	Underwater sensor	Salinity, solvents, and quality
	Underground sensor	Soil compaction and moisture
	Solar radiation	Crops and plants
Mechanical sensors	Pest detector	Pest and bug detection
	Pressure sensor	Soil compaction
	Vibration sensor	Soil and atmosphere
	Wind sensor	Speed and direction of air
	Motion sensor	Environmental monitoring
	Water flow sensor	Irrigation
	Water level sensor	Ground and underground

3.1.2 Libelium Smart Agriculture Xtreme [58]

This smart agriculture tool kit offers numerous onboard sensors developed by Libelium. This kit allows various communication protocols, e.g., LoRaWAN (Long Range Wide Area Networks), Wi-Fi (Wireless Fidelity), ZigBee, Sigfox, and 4G. This Smart Agriculture Xtreme seeks a variety of applications based on IoT, for example, precision farming, greenhouses, weather station, and irrigation. The main advantage of Libelium kits is that they are solar powered.

3.1.3 Smart Pot [51]

Parrot Pot has introduced a smart pot, especially for indoor farming within an in-situ Bluetooth communication module. This smart pot is also a suitable ingredient for greenhouses and urban farming. Various sensors are embedded in this smart pot, for example, sunlight, soil moisture, temperature, and fertilizer levels, which help in continuous monitoring of the plants.

3.1.4 Open Garden platform [52]

Open Garden platform has capabilities to monitor three different setups: 1) indoor farming (greenhouse and vertical farming) 2) outdoor farming (crops, gardens, etc.), and 3) hydroponics (water sensors). The Open Garden platform can be equipped with multicommunication modules, such as 3G, Wi-Fi, or GPRS module. The sensed data can be propagated via any of these communication protocols. The indoor/outdoor setup kits include temperature, humidity, light levels, drip (indoor) / sprinkler (outdoor) water pumps, and so on. The hydroponics kit includes many water sensors: moisture, humidity, conductivity, pH, growing light, oxygen pump, etc.

3.1.5 X-ray Computed Tomography [54]

X-ray Computed Tomography (CT) has the capabilities to examine water content, conductivity, and configuration of the soil by using images. In [56], authors have used X-ray CT images to quantify the hydraulic conductivity of bulk soil. Another work using CT images was reported in [57] to air- and water-filled pore space and structure of the soil. In [55], a novel work on X-ray CT and image processing was reported to calculate the root-water absorption in the soil.

3.1.6 The Arable Mark [59]

The Arable Mark has designed an irrigation management kit for smart agriculture. Farmers can use this tool to irrigate their crops properly and precisely. This tool acquires the field data, such as soil moisture, crop water scarcity, and precipitation in order to provide the required water to crops. This helps in avoiding over- and under-irrigation.

3.1.7 GreenIQ [61]

The Eastern Peak provides an agricultural field device for irrigation purposes and is named GreenIQ. This is suitable for greenhouses and house gardens. It irrigates the gardens using a sprinkler controller.

3.1.8 Grofit climate monitoring system [60]

The Grofit introduced this system for agricultural climate monitoring, it offers a Bluetooth based monitoring system with a propagation area of up to 200 meters. This can measure air humidity, temperature, and solar radiation. Grofit also provides a cloud to access information related to their devices.

3.1.9 MeteoHelix IoT Pro [63]

The allMeteo designed MeteoHelix IoT (Internet of Things) Pro hardware, especially for agricultural environmental monitoring based on IoT and WSN. It offers a broad number of sensing parameters, for example, solar radiation, rain gauge, pressure, pollution, dew, humidity, temperature, and so on. This is only suited for terrestrial monitoring. This greatly helps in solving the meteorological solutions.

3.1.10 SKY-LoRa Weather Station [64]

Farmers can use this weather station kit to forecast any uncertain environmental and weather occurrences, such as rain and wind. This tool kit uses the LoRa communication protocol to communicate with the master sensor node. Its communication coverage is approximately 600 m.

3.1.11 EC1 Speed controller [65]

This device performs its operation upon monitoring the atmospheric conditions and then toggling the condition of different devices. This controller helps to control various agricultural field devices and equipment by turning on/off the machines.

The main system is elaborated in Fig. 2. Numerous devices come together to make the main system. These devices include IRIS motes [10], various sensors and a display screen to monitor the data. In this research, our nodes are connected wirelessly in a way of direct topology to communicate with the sink located at the base station. Each IRIS

Fig. 2. Block diagram of the system

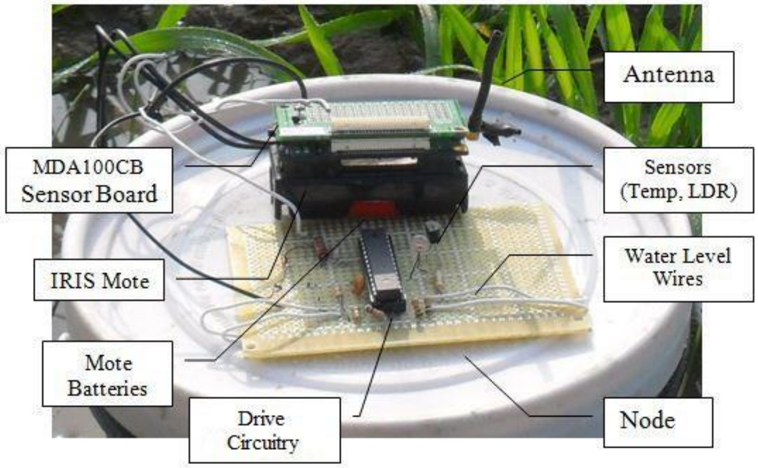


Fig. 3. Complete picture of a sensor node

mote is connected to a sensor board. The main control station collects sensed information from individual nodes, which is later on directed to the sink node. MIB520CB USB board [11] is used to connect the sink node with the computer via a serial USB port. GUI interface is provided for the visualization of measured data to users.

4.1 Sensor Node with IRIS

Fig. 3 shows the complete picture of the sensor node with its peripherals. Its peripherals include IRIS motes [10], MDA100CB Board [25], Temperature sensor [26], LDR sensor, water level sensor and drive circuitry. For this work, three sensor nodes are used, which are wirelessly connected via direct topology with a sink or base station with the aid of IRIS motes. Sensor nodes can acquire temperature, LDR and water level data of irrigated Wheat fields. The base station is connected to a computer, where acquired data is monitored and stored in a database for post-processing aspects. Batteries keep the sensor nodes alive till the work is done.

4.2 Deployment of nodes

We performed the deployment of sensor nodes in an agricultural field of the Wheat crop (see Fig. 4). Fig. 4 shows the real-time deployments of the sensor nodes. The sink was about 50-60m away from the sensing field, while sensor nodes were placed at a distance of about 20-30m from each other.

Fig. 4. Physical deployment site of sensor nodes

We deployed various sensor nodes consisting of temperature, LDR and water level sensors to sense the agricultural data of Wheat crops. Experiments were conducted for 10 (ten) weeks, consecutively to obtain the results from the sensing field. The nodes transmit the sensed data via direct topology [15], [28]. The sink node is directly connected with all nodes for access to the sensed data.

5.1 Implementation in TinyOS

A small operating system named TinyOS [24] is used to program the IRIS motes by interfacing the MIB520 interface board with a computer via serial communication. The code for IRIS motes is developed in the Nested C language. Despite being a small Linux-based operating system TinyOS comes with various built-in applications, which makes the programming of IRIS motes much easier. We programmed four IRIS motes, one for the base station (as a sink) and the other three for the sensing field (as a sensor node). Each IRIS possesses a unique ID.

The programming flowchart for sink and sensor nodes is depicted in Fig. 5. The sink node is serially connected to a computer/ laptop with the help of MIB520CB programmable board. The data is displayed in a GUI tool and in the meantime stored in a database so that users can easily observe the measured data. Whereas, sensor nodes are deployed at the field site (as shown in Fig. 4). Once the sink nodes receive the data from sensor nodes, it will display that measured data on the GUI tool. The sensor nodes measure the temperature, LDR, and water level of the Wheat field and then each sensor node transmits the measured data to the sink node using direct topology. Sink nodes and sensor nodes can communicate with each other via a wireless medium.

5.2 Implementation in MS Visual Studio

The main GUI tool (refer to Fig. 6) is developed in Microsoft Visual Studio [29]. The purpose of designing the GUI tool is to display the measured data of each sensor of each node. In the GUI tool, all three sensor nodes are recognized with node ID and three sensors (temperature in degrees Celsius, LDR in light/dark (in form of LUX in the database) and water level in inches). The data received by the sink node from the sensor nodes are sent to a computer for display on the GUI tool through serial communication via a USB port. At first, GUI is loaded, in which default values are displayed then for receiving the measured data, the sink node must be interfaced serially via MIB520 USB interface board with PC by initializing the port on which it is connected. After the initialization process, the measured data of each node is displayed on the GUI tool and updated into the database accordingly. The database can be imported into the data log window by clicking the button to display the data log available on the GUI tool. The database can also be viewed in MS Access: an office application.

This system has been deployed in the irrigated (shallow-water based) Wheat field for monitoring three different agricultural parameters (temperature, light and water level). The deployment results are depicted in Fig. 6. Fig. 6a. shows the temperature measured by three different sensor nodes located at different points in the Wheat field (refer Fig. 4) for consecutive 10 (ten) weeks.

6.1 Temperature Measurement

Fig. 6b shows the comparison between the two temperatures i.e. one is the actual temperature (i.e., standard temperature) of the deployment location and the other is the measured temperature by the sensor nodes. It is obvious that the average temperature as measured by the sensor nodes should be equal to the actual temperature. Well, a minor difference in readings is also acknowledged, this difference might be accorded due to different issues, such as power consumption and the distance between the sink node and sensor nodes. It is seen that the average difference between the two mentioned temperatures is 3-4 degree Celsius. This difference can be reduced and more accurate and reliable results can be obtained if the temperature sensors are calibrated properly and by minimizing the interferences, network issues, etc.

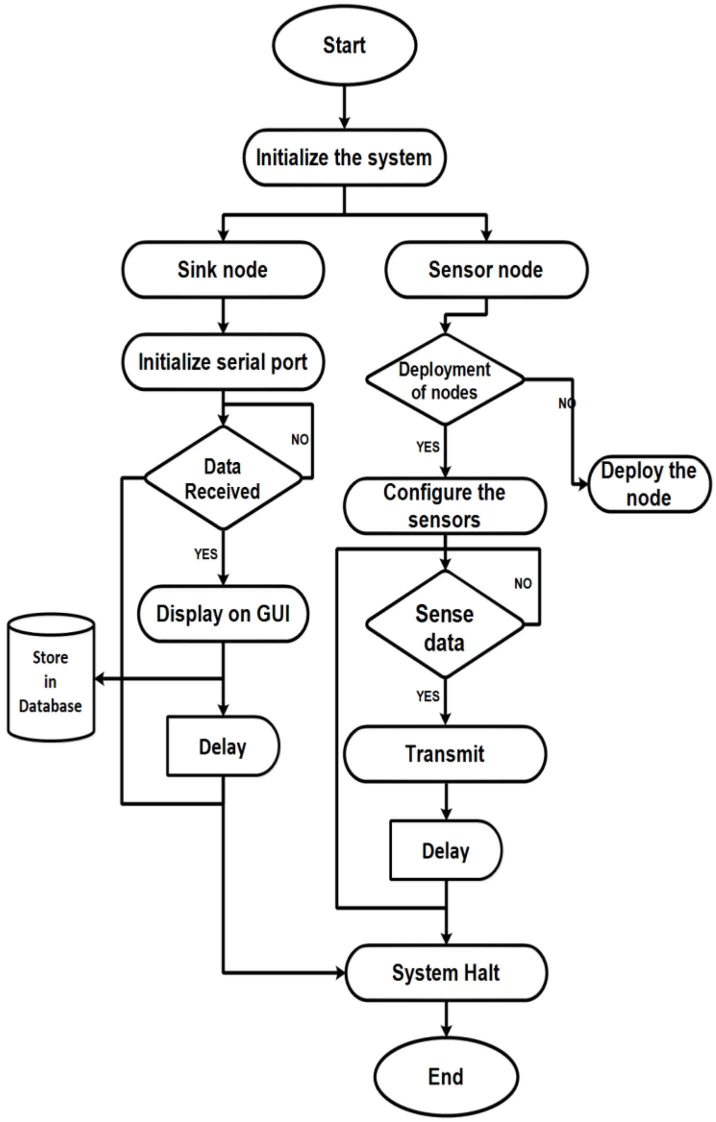
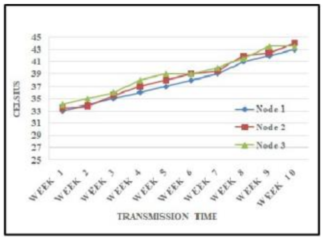
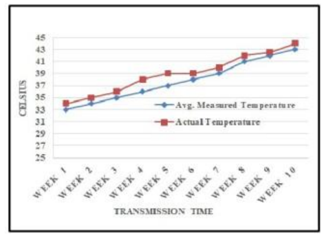


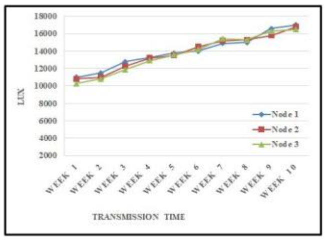
Fig. 5. Flowchart for sink and sensor nodes



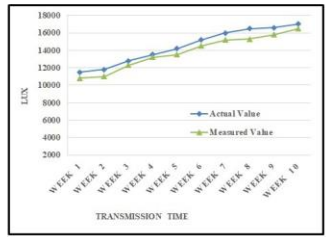
(a) Temperature measurement



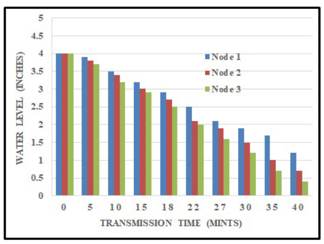
(b) Temp. measurement (actual v/s measured)

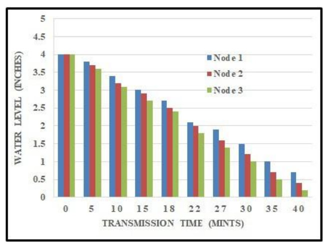


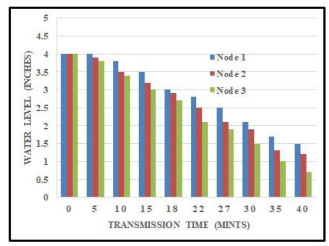
(c) LI measurement



(d) LI measurement (actual v/s measured)







(e) 1st irrigation (f) 2nd irrigation (g) 3rd irrigation

Fig. 6. Deployment results

6.2 Luminous Intensity (LUX) Measurement

Fig. 6c describes sunlight detection in terms of Luminous Intensity (LI) for 10 consecutive weeks. We measured the LI during day time because there is no sunlight at night. It is measured in LUX. The LI is very necessary for crops to complete the process of photosynthesis [27]. Hence, the crops are dependent on sunlight for their growth. Different states of sunlight at different moments are mentioned in the form intensity unit LUX in Fig. 6c. Fig. 6d. shows the comparison between measured LI versus actual LI.

6.3 Water Level Measurement

Fig. 6e, Fig. 6f, and Fig. 6g plot the water levels of Wheat crops at different instant of times for 3 consecutive irrigations. We can observe that the readings for water level for all sensor nodes are different from each other with the passage of time; this is due to the rough surface layer of the Wheat crop field. Henceforth, by measuring water level, we can irrigate our crops accurately, precisely and timely. Moreover, it also helps in avoiding over and under irrigation. Thus, an ample amount of water can be saved. We provide a summary of the WSN-based smart agriculture application for Wheat crops, which is given in Table. 2.

TABLE II. SUMMARY OF THE WSN-BASED SMART AGRICULTURE APPLICATION FOR WHEAT CROPS

#	Parameter	Module	Description	Remarks
1	Pre-deployment	Input	Budget = good Outdoor Crop = Wheat Period = 10 weeks Area = 100m^2 Node density = 4 Random deployment	Ample amount is available Land/Field One crop season 1 sink node and 3 sensor nodes
2	Sensors	Input	Temperature Water level LDR	
3	Hardware and software	Input	Sink/sensor node = IRIS motes MDA 300 Water level sensor LDR OS=TinyOS	Different applications Temperature sensor For irrigation For sunlight detection Linux based OD
4	Communication	Communication	Topology = tree, direct Data rate = 1 message/30sec Node-node = Zigbee Node-sink = Zigbee BS-Server = WiFi Server-User = Internet	Also depends on the deployment area Application specific
5	Energy	Input	Rechargeable batteries	Can be replaced easily
6	Safety and maintenance	Output	Plastic casing Security cameras	Few can be used across the field

7.1 Requirement of Wheat Crop

The Wheat crop essentials and requirements are described in Fig. 8. According to it, the major requirements for the crops like Wheat are temperature, sunlight and water. So far, by keeping these parameters under consideration; the production rate and crop length can easily be estimated. If all or any of these significant parameters become less/more and are not maintained at their proper time, it will directly affect the production and quality rate of the crops, which is further clarified in Fig. 8. For further assistance and guidance, different Wheat researchers have provided the Wheat crop SOPs (Standard-Operating-Procedures), for example, season, crop length, irrigation period, harvesting time, and so on [62].

7.2 Users

There are two major users for the analysis of the results obtained during this work and that are farmers and researchers (or experts). The prime goal of this work is to provide essential up-to-date crop data and information to the farmers, landowners and researchers.

Parameters	Devices	Requirments	Comments
Temperature		80° to 100° F	temperature ∝ crop growth
LDR		Crop Length: 120 to 140 days	Light (sunny, dry, hot) = crop length decreases Dark (cloudy, fog, snow) = crop length increases
Water Level		5 to 6 Irrigations	3 inch/irrigation

Fig. 7. Wheat crops essentials

Farmers: These are the principal and main users of this system. In Pakistan, the farmers are either uneducated or have little education. That’s why in this system a simple GUI tool is used to display the results. By this, users can easily understand the results and take necessary actions accordingly.

Experts: The other users of this system might be highly professionals or agricultural experts. These people belong to research or agricultural training institutes. They can analyze the data in form of graphs, charts or statistical views. That’s why, the results are also provided in form of charts and graphs, according to the need of the user.

7.3 Future Directions

Sensor network technology is growing day by day, and numerous platforms and tools are introduced to minimize and reduce human interactions and contributions. This research work can be enhanced by using some/any of the following fields.

7.3.1 Wireless Platforms

We can implement different sensor network platforms, such as, Wasp mote Platform [19], Libelium Platform [19], Fleck Platform [5] and other platforms [5], [20], [21] for future correspondences.

7.3.2 Sensors

There are various other sensing devices, like physical sensors (humidity sensor, soil moisture, watermark sensor, and leaf wetness sensor), mechanical sensors (flow sensors, injectors, and valves) and chemical sensors (biosensor, gas sensor) available in the market [38]. By incorporating these sensors, this work can easily be enhanced.

7.3.3 Dynamic Controller

In this research, we haven’t used any sort of dynamic (mechanical) controller. Dynamic controllers are helpful to perform mechanical tasks such as sprinklers, irrigation monitoring, water flow control using valves, injection of pesticides, vibrators and so on [7], [8], [15].

7.3.4 Networking

In the wireless sensor network field, networking plays a pivotal role in all application domains in which a different number of sensor nodes are being employed. The researchers and application designers decide the networking according to the application and requirement scenarios. Classical networking (star, tree, P2P, mesh, bus topologies) [5], [7], [28], [44], opportunistic networking [3], [5], [45], and cognitive radios [46] are different classes of networking. Drones can also be used for networking purposes, such as measuring, intruder detection, and localization [43], [66], [67].

In this paper, we presented various sensing technologies that enable smart agriculture. In addition, we have performed a case study on Wheat crops. This work aims to minimize efforts and problems, which are being faced by the farmers while cultivating their crops. This work is based on the real-time deployment of sensor nodes in an irrigated Wheat field. We use IRIS motes as the WSN platform for incorporating as a sink and as sensor nodes. The IRIS motes were programmed in TinyOS and equipped with temperature, LDR and water level sensors to measure the field data. We measured these parameters; because, the cropped length has been estimated by analyzing the temperature and LDR parameters and by measuring water level, over-irrigation can be avoided.

Meanwhile, the measured data is transmitted as a base station accordingly. Where measured data is displayed, and analyzed on a GUI tool, which is developed in MS Visual Studio 2008. The results can easily be understood by every user without concerning any research expert. The database is used to maintain up-to-date information about collected data from the sensor nodes. This work offers much relaxation to the users for the measurements of required parameters of the crops, their presence at the field site all the time is not required, just once time performs the deployment of the nodes and gets the measured data at their workplace, base station and so forth.

Acknowledgment

The authors appreciate the contributions of Quaid-e-Awam University of Engineering, Science, and Technology (QUEST), Nawabshah and Sir Syed University of Engineering and Technology (SSUET), Karachi to execute this work.

REFERENCES

[1] Ahsan, A., and Ahmed, B., ”Identification of the type of agriculture suited for application of wireless sensor networks”. Russian Journal of Agricultural and Socio-Economic Sciences, 2012, 12(12).

[2] Fahmy, Hossam Mahmoud Ahmad. ”WSN applications.” Concepts, Applications, Experimentation and Analysis of Wireless Sensor Networks. Springer, Cham, 2021. 67-232.

[3] Reyes-Yanes, Abraham, et al. ”Wireless Sensing Module for IoT Aquaponics Database Construction.” International Journal of Electronics and Electrical Engineering 9.2, 2021: 43-47.

[4] Joshi Sarang, P., and R. U. Chavhan. ”Monitoring of Agriculture Parameter through Sensors for Productivity Enhancement.” New ARCH-International journal of Contemporary Architecture 8.2, 2021, pp. 1552-1560.

[5] Karim, S., and Shaikh, F. K., ”Wireless Sensor Network-Based Smart Agriculture.” In Opportunistic Networking, CRC Press 2017, pp. 251-276.

[6] Goel, Swati, Kalpna Guleria, and Surya Narayan Panda. ”Machine Learning Techniques for Precision Agriculture using Wireless Sensor Networks.” SPAST Abstracts 1.01, 2021.

[7] Anurag, D., Roy, S., and Bandyopadhyay, S., ”Agro-sense: Precision agriculture using sensor-based wireless mesh networks.” In Innovations in NGN: Future Network and Services, 2008. K-INGN 2008. First ITU-T Kaleidoscope Academic Conference (pp. 383-388).

[8] Garcia-Sanchez, A. J., Garcia-Sanchez, F., and Garcia-Haro, J., ”Wireless sensor network deployment for integrating video-surveillance and data-monitoring in precision agriculture over distributed crops.” Computers and Electronics in Agriculture, 75(2), 2011, pp. 288-303.

[9] Singh, I., and Bansal, M., ”Monitoring water level in agriculture using sensor networks.” International Journal of Soft Computing and Engineering, 1(5), 2011, pp. 202-204.

[10] Habtoor, M.S. and Rowaihy, H., ”Performance evaluation of IRIS and LOTUS motes when communicating in real environments”. International Journal of Distributed Sensor Networks, 12(2), 2016, pp.7347158.

[11] Datasheet MIB520. Programmable board. http://www.memsic.com/userfiles/files/Datasheets/WSN/6020-0091-04 a mib520cb-t.pdf, (last accessed on Febuary 20, 2022).

[12] Balendonck, J., Hemming, J., Van Tuijl, B. A. J., Incrocci, L., Pardossi, A., and Marzialetti, P., ”Sensors and wireless sensor networks for irrigation management under deficit conditions (FLOW-AID)”. In: Conference Proceedings CD of the International Conference on Agricultural Engineering”. Agricultural & Biosystems Engineering for a Sustainable World. EurAgEng (European Society of Agricultural Engineers). 2008.

[13] Devadas, R., Jones, S. D., Fitzgerald, G. J., McCauley, I., Matthews, B. A., Perry, E. M., and Kouzani, A. Z., ”Wireless sensor networks for in-situ image validation for water and nutrient management.” In ISPRS 2010: Proceedings of ISPRS Technical Commission VII Symposium,. Institute of Photogrammetry and remote sensing, Vienna University of Technology, 2010, pp. 187-192.

[14] Valente, J., Sanz, D., Barrientos, A., Cerro, J. D., Ribeiro, and Rossi, C., ”An air-ground wireless sensor network for crop monitoring.” Sensors, 11(6), 2011, pp. 6088-6108.

[15] Ruiz-Garcia, L., Lunadei, L., Barreiro, P., and Robla, I., ”A review of wireless sensor technologies and applications in agriculture and food industry:

state of the art and current trends." Sensors, 9(6), 2009, pp. 4728-4750.

[16] Rahu, M. A., Kumar, P., Karim, S., and Mirani, A. A., "Agricultural Environmental Monitoring: A WSN Perspective." University of Sindh Journal of Information and Communication Technology, 2(1), 2018, pp. 17-24.

[17] Raut, R., Varma, H., Mulla, C., and Pawar, V. R., "Soil Monitoring, Fertigation, and Irrigation System Using IoT for Agricultural Application." In Intelligent Communication and Computational Technologies, 2018, pp. 67-73.

[18] Toth, G., Hermann, T., da Silva, M. R., and Montanarella, L., "Monitoring soil for sustainable development and land degradation neutrality." Environmental monitoring and assessment, 190(2), 2018.

[19] Guide, Technical, "Agriculture Board 2.0". document version: v4.002/2013, Libelium Communications Distribuidas S.L. http://www.libelium.com. 2013.

[20] Kusy, B. "Opal sensor node: Computation and communication in WSN platforms." 2012.

[21] F. K. Shaikh, S. Karim, S. Zeadally and J. Nebhen, "Recent Trends in Internet-of-Things-Enabled Sensor Technologies for Smart Agriculture," in IEEE Internet of Things Journal, vol. 9, no. 23, pp. 23583-23598, 2022.

[22] Mampentzidou, I., Karapistoli, E., and Economides, A. A., "Basic guidelines for deploying wireless sensor networks in agriculture." In Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2012 4th International Congress on, 2012, pp. 864-869.

[23] Kumar, K. A., Lingam, P. G., and Rao, K. M., "Wireless Sensor Based Remote Monitoring System for Fluoride Affected Areas Using GPRS and GIS. International Journal of Computer and Technology (IJCTT) volume, 7, 2014, pp. 178-182.

[24] Levis, P., Madden, S., Polastre, J., Szewczyk, R., Whitehouse, K., Woo, A., and Culler, D., "TinyOS: An operating system for sensor networks." In Ambient intelligence, Springer, Berlin, Heidelberg. 2005, pp. 115-148.

[25] Datasheet, MDA100CB, Data acquisition board. http://www.memsic.com/userfiles/files/Datasheets/ WSN/mts mda datasheet.pdf, (last accessed on Febuary 20, 2022)

[26] Datasheet, Temperature Sensor. http://www.ti.com/lit/ds/symlink/lm35.pdf, (last accessed on Febuary 20, 2022).

[27] Bareja, B.G., "What is Light Intensity, Effects on Plant Growth." April 2011.https://www.cropsreview.com/light-intensity.html

[28] Pijl, Anton, et al. "Remote sensing vs. field-based monitoring of agricultural terrace degradation." International Soil and Water Conservation Research 9.1, pp.1-10. 2021.

[29] Powers, L., and Snell M., "Microsoft visual studio 2008 Unleashed." Pearson Education, 2008.

[30] N. Ahmed, D. De, and I. Hussain, "Internet of things (iot) for smart precision agriculture and farming in rural areas," IEEE Internet of Things Journal, vol. 5, no. 6, pp. 48904899, 2018.

[31] M. S. Farooq, S. Riaz, A. Abid, K. Abid, and M. A. Naeem, "A survey on the role of iot in agriculture for the implementation of smart farming," IEEE Access, vol. 7, pp. 156 237156 271, 2019.

[32] I. Akyildiz, W. Su, Y. Sankarasubramanian, and E. Cayirci", A survey on sensor networks," IEEE Communications Magazine, vol. 42, no. 5, pp. 102114, August 2002.

[33] S. Karim, M.A. Rahu, A. Ahmed, A.A. Mirani, G.M. Jatoi, "Energy Harvesting for Water Quality Monitoring using Floating Sensor Networks: A Generic Framework." Sukkur IBA Journal of Emerging Technologies 1.2, 2018, pp. 19-32.

[34] F. K. Shaikh and S. Zeadally, "Energy harvesting in wireless sensor networks: A comprehensive review," Renewable and Sustainable Energy Reviews, vol. 55, pp. 10411054, 2016.

[35] S. Zeadally, F. K. Shaikh, A. Talpur, and Q. Z. Sheng, "Design architectures for energy harvesting in the internet of things," Renewable and Sustainable Energy Reviews, vol. 128, p. 109901, 2020.

[36] Sivagami, A., Pavai, K., Sridharan, D., and Murty, S.A.V., "Energy and Link Quality based Routing for Data gathering tree in wireless sensor networks under TINYOS-2. X." arXiv preprint arXiv:1005.1739, 2010.

[37] Vijayalakshmi, A., and Ranjan P.V., "Code Strategy Algorithm for Online Power Quality Monitoring of Electrical Equipment using WSN under Tiny-OS Environment." Journal of Theoretical & Applied Information Technology 57.3. 2013.

[38] White, R. M. "A sensor classification scheme". IEEE Transactions on ultrasonics, ferroelectrics, and frequency control, 34(2), 1987, pp.124-126.

[39] F. K. Shaikh, M. Memon, N. A. Mahoto, S. Zeadally, and J. Nebhen, "Artificial intelligence best practices in smart agriculture," IEEE Micro, vol. 42, no. 1, pp. 1724, 2022.

[40] F. K. Shaikh, M. Memon, and S. Zeadally, "Simultaneous wireless information and power transfer in internet of things," Energy Harvesting in Wireless Sensor Networks and Internet of Things, p. 223, 2022.

[41] B. B. Sinha and R. Dhanalakshmi, "Recent advancements and challenges of internet of things in smart agriculture: A survey," Future Generation Computer Systems, vol. 126, pp. 169184, 2022.

[42] W. Tao, L. Zhao, G. Wang, and R. Liang, "Review of the internet of things communication technologies in smart agriculture and challenges,"

Computers and Electronics in Agriculture, vol. 189, p. 106352, 2021.

[43] I. Bisio, H. Haleem, C. Garibotto, F. Lavagetto and A. Sciarrone, ”Performance Evaluation and Analysis of Drone- Based Vehicle Detection Techniques From Deep Learning Perspective,” IEEE Internet of Things Journal, vol. 9, no. 13, pp. 10920-10935, 2022.

[44] Bayrakdar, Muhammed Enes. ”Employing sensor network based opportunistic spectrum utilization for agricultural monitoring.” Sustainable Computing: Informatics and Systems 27 (2020): 100404.

[45] Mathapati, Mahantesh, et al. ”A Study on Secure Data Aggregation and Routing for Wireless Sensor Networks.” International Conference on Advanced Informatics for Computing Research. Springer, Singapore, 2020.

[46] Wang, L. F., and Wel, S. Q., ”Cognitive engine technology”.ZTE Communications, 2, 003. 2009.

[47] Habtoor, M. S., and Rowaihy, H., ”Performance evaluation of IRIS and LOTUS motes when communicating in real environments”. International Journal of Distributed Sensor Networks, 12(2), 7347158. 2016.

[48] Mythili, V., et al. ”SEAT-DSR: Spatial and energy aware trusted dynamic distance source routing algorithm for secure data communications in wireless sensor networks.” Cognitive Systems Research 58, 2019, pp. 143-155.

[49] Swami Durai, Senthil Kumar, Balaganesh Duraisamy, and J. T. Thirukrishna. ”Certain investigation on healthcare monitoring for enhancing data transmission in WSN.” International journal of wireless information networks, 2021, pp. 1-8.

[50] Jia, Xin-Chun. ”Resource-efficient and secure distributed state estimation over wireless sensor networks: a survey.” International Journal of Systems Science 52.16, 2021, pp. 3368-3389.

[51] Parrot Pot: smart pot, https://www.postscapes.com/wirelessplant-sensors/, (last accessed December 15, 2021).

[52] Open garden, https://www.cookinghacks.com/documentation/tutorials/open-gardenhydroponics-irrigation-system-sensors-plantmonitoring.html. (last accessed December 15, 2021).

[53] Apogee SQ-520, https://www.apogeeinstruments.com/sq-520-full-spectrum-smart-quantum-sensor-usb/. (last accessed December 15, 2021).

[54] Phoenix Nanotom 180NF, GE Sensing & Inspection Technologies GmbH, Wunstorf, Germany https://www.bakerhughesds.com/industrial-x-ray-ctscanners/phoenix-nanotom-m-3d-metrology-nano-ct. (last accessed December 15, 2021).

[55] Daly, Keith R., Saoirse R. Tracy, Neil MJ Crout, Stefan Mairhofer, Tony P. Pridmore, Sacha J. Mooney, and Tiina Roose. ”Quantification of root water uptake in soil using Xray computed tomography and imagebased modelling.” Plant, cell & environment 41, no. 1, 2018, 121-133.

[56] Tracy S.R., Daly K.R., Sturrock C.J., Crout N.M.J., Mooney S.J. and Roose T. ”Three dimensional quantification of soil hydraulic properties using Xray computed tomography and image based modelling”. Water Resources Research 51, 2015, pp. 10061022.

[57] Rogasik H., Crawford J.W., Wendroth O., Young I.M., Joschko M. and Ritz K. ”Discrimination of soil phases by dual energy x-ray tomography.” Soil Science Society of America Journal 63, 1999, pp. 741751.

[58] ”Libelium Smart Agriculture Xtreme”, https://www.libelium.com/iot-products/plugsense/smart-agriculture-xtreme, (last accessed on Febuary 20, 2022).

[59] ”Arable mark irrigation tool”, https://www.arable.com/solutions irrigation/, (last accessed on Febuary 20, 2022).

[60] ”Grofit climate monitoring system,” https://www.grofitag.com/product-page/grofit-iot-device-1/, (last accessed on Febuary 20, 2022).

[61] ”Greeniq” https://easternpeak.com/works/iot/, (last accessed on Febuary 20, 2022).

[62] ”Wheat Seed Production Techniques Manual”, District Agriculture Development Office, Sindhupalchwok, https://www.jica.go.jp/nepal/english/index.html, (last accessed on September 02, 2022)

[63] ”Meteohelix iot pro”, https://allmeteo.com/agricultureiot-weather-station, (last accessed on Febuary 20, 2022).

[64] ”Sky-lora weather station”, https://get.pycno.co/collections/allproducts/products/sky lora-and-wifi-weather-station. (last accessed on Febuary 20, 2022).

[65] ”Ec-1 controller”, https://growlink.com/shop/ec-1/. (last accessed on Febuary 20, 2022).

[66] I. Bisio, C. Garibotto, H. Haleem, F. Lavagetto, and A. Sciarrone. ”On the localization of wireless targets: A drone surveillance perspective.” IEEE Network 35, no. 5, pp. 249-255, 2021.

[67] I. Bisio, C. Garibotto, H. Haleem, and Lavagetto, ”Drone surveillance systemRF/WiFi-based drone detection, localization, and tracking: a surve,” Aviation Cybersecurity: Foundations, Principles, and Applications, 49, 2021.