Online ISSN Print ISSN

http://amresearchreview.com/index.php/Journal/about

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 7 (2025)

Design and Implementation of IoT of a low power IoT Network for smart agriculture using LoRaWAN and Solar-powered Sensors

Syed Muhammad Shakir Bukhari[1], Rehman Akhtar[2]

Article Details

Keywords: IoT, Smart agriculture, Solar-powered Sensors

[1]**Syed Muhammad Shakir Bukhari**
Teaching and Research Assistant, Department of Industrial Engineering, University of Engineering and Technology Peshawar
smshakirbukhari@gmail.com
https://orcid.org/0009-0003-7596-8171

[2]**Rehman Akhtar**
Associate Professor, Department of Industrial Engineering, University of Engineering and Technology, Peshawar
Rehman_akhtar@uetpeshawar.edu.pk

ABSTRACT

This study focuses on the International Monetary Fund (IMF) programs' impact on macroeconomic stability in Pakistan, and whether this investigation helps determine how

Introduction: The demand to eat and the need to transfer to sustainable agricultural production has led to the adoption of high technologies within the sphere of agricultural production. It is crucial need and necessity to develop and integrate a low-power network of IoT in smart agriculture through LoRaWAN and solar energy-powered sensors and look into that in the best possible way possible.

Materials and Methods: The IoT system includes solar-powered sensors that monitor the key agricultural indicators such as the moisture of the ground, temperature, and humidity. The sensors deliver information to a main server through intelligent LoRaWAN technology. The network is low-power, scale-able, and trustworthy with the focus on the promotion of sustainable agriculture practices.

Results: The findings point to the fact that the IoT network can provide accurate and reliably acquired information on the condition of the farms, enabling farmers to take the proper decisions and utilize the available resources to a maximum. The solar energy-driven sensor can survive a long time without the noticeable decline in its efficiency, whereas the LoRaWAN technology provides the long-range communication option.

Conclusion: The study notes the potential of the IoT technology to transform the way agriculture is conducted so that it is both sustainable and less demanding on the environment. The LoRaWAN technology in combination with solar-powered sensors, applied in the experiment, can provide a practical and efficient approach to the practical application in smart agriculture as farmers will have the opportunity to obtain real-time data and make the appropriate decisions.

Introduction

The Real life examples of how many industries can be changed by Internet of Things (IoT) include agriculture where we are able to monitor and control a given activity in real-time. The integration of the IoT technologies in smart agriculture provides a potential solution to terminate the need to use more resources and achieve better yields without engaging in any form of wastage and sustainable agricultural practices. However, the application of the IoT in the farming industry is exceptionally hard, particularly in the rural areas with poor power delivery and networks. The study has shown that the usage of IoT in farming can increase the crops production by up to 20% and decrease water consumption by up to 30%. When related to the power supply/network connection limitations, the research intends to produce and implement a low-power IoT-based network on smart agriculture based on LoRaWAN and solar-powered sensors [1].
LoRaWAN is a radio technology of LIWPANs that functions well in IoT application in agriculture because it has the capability of long-range transmission, lower power consumption, and larger number of devices are supported. The features allow it to be the most suitable way of remotely monitoring and controlling the agricultural resources over expanded geographical regions. Research findings have indicated that LoRaWAN can squeeze data over quite long distances compared to its power consumption in a rural area of up to 15 kilometers. In rural areas where there is little access to the grid, a clean energy-efficient alternative of powering IoT devices is by the use of solar-powered sensors. This study tries to achieve a low maintenance, environment-friendly, and stable Internet of Things network in smart farming by combining LoRaWAN with the solar-powered sensor [1,2]. This characteristic is particularly when it comes to rural agricultural settings where accessibility to the maintenance might not be easy [1,3].

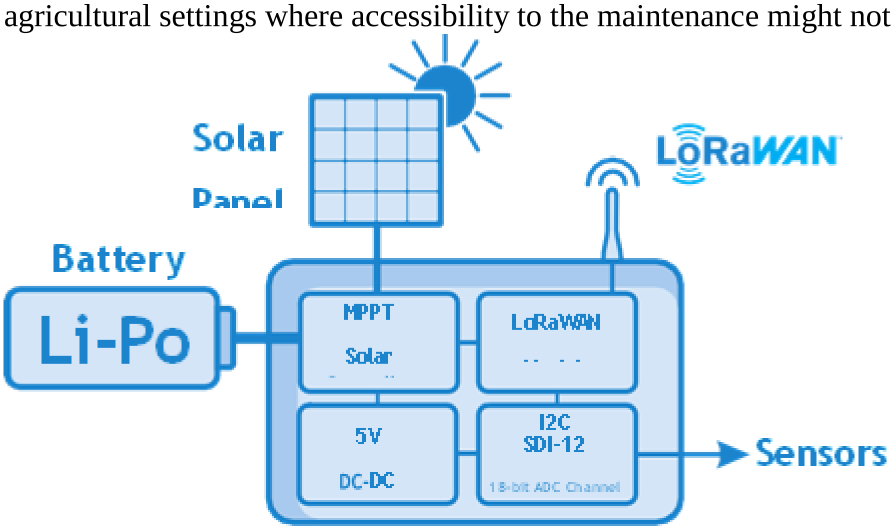

Fig.1: LoRaWAN system node overview [7].

The LoRaWAN gateway is one of the key components of such IoT network and serves as an interface between the sensor nodes and the main server. The sensor nodes deliver their information to the gateway, which further transfers it to the server when it has to be analyzed and processed. Research has verified that gateways play a crucial role in the LoRaWAN networks, which serve multiple nodes and guarantee high performance of data delivery. Since the remote areas where the agricultural purposes are implemented, the gateway is going to be designed to work on low power, perhaps even on solar power or renewable sources. This will make the entire network run efficiently without environmental cost involved and minimal cost of operation [2,3,4].
Implementation of this IoT network will be done through several phases, including installation of

sensors, setting of nodes, and testing network. The sensors will be placed so strategically in strategic places on the farm fields to measure relevant parameters, and LoRaWAN nodes will be set to transmit data at the most optimal temporal times to achieve the best trade off between information resolution and power consumption. It has been established that the optimization of LoRaWAN nodes is the paramount role to play in maximizing the performance and reliability of IoT networks utilized in the agricultural applicatives. The network shall be tested based on reliability, coverage, and data accuracy to ensure that the network is able to support the need of smart agricultural applications. Data gathered on the sensor nodes will then be processed to give light to the situation of agriculture such that farmers can make decisions with neither loss nor gain. These can be in terms of irrigation scheduling to the soil moisture content, altering agricultural management activities as per weather expectation, or warning crop condition degradation. Researchers have also determined that data analytic applications in the agricultural field can be used to maximize the production and save resources. The real-time data that will be facilitated in the network of IoT will allow it to intervene at the correct time and create a bigger impact concerning the production of crops and conserving resources [2,4].

The fact that LoRaWAN and solar-powered sensors were introduced to smart agriculture can be considered a giant step toward applying IoT technologies in rural areas and areas where precious resources are scarce. This research aims at closing the technological gap in farm practices by providing a low-power, wide-area network solution, which can run on renewable energy sources sustainably. Research can affect more than just increasing the agricultural yield because it will also contribute to the health of the environment since the carbon impact of traditional farming activities will decrease [4].

The use of IoT technologies in agriculture is an issue that has gained more and more attention in recent years, as one of the major unsolved challenges in the country is to raise crop yields, reduce food waste, and improve the extent of sustainable farming. Some studies have demonstrated the prospects of IoT to transform the agricultural process and enable the farmers to make evidence-based decisions to optimize resource use. Using LoRaWAN and solar-powered sensors in smart agriculture is basically a good answer on how to solve the issues of the agriculture industry, as it is low-maintenance, reliable, and eco-friendly IoT network [5,6,7].

Development and implementation of LoRaWAN energy-efficient IoT network infrastructure in smart agriculture and the corresponding deployment of solar-powered sensors would become a green and effective solution to the problems face by the agriculture industry. It is with the help of state-of-the-art IoT systems and resources that can be renewed that this research aims to create a low-maintenance and reliable network that will be able to merge to optimize agricultural output and minimize impact on the environment. This increased food demand in the world together with limit competence of climatic change has necessitated adoption of new and sustaining agricultural styles. Smart agriculture that integrates modern technologies, including the application of the Internet of Things (IoT) offers the sufficient answer to the farmers to grow more and reduce the losses to promote environmentally-friendly practices. A more prominent role in smart agriculture is sensor technology so that to a farm resources may be monitored and controlled. However, sensors installations in the rural areas are very difficult, particularly in the area of power supply and network connectivity. A solar-powered sensor offers a green solution to power IoT devices on farms as a means of sustainability and a renewable process [8,9].

Reference	Manufacturer	Standard	Power Supply	Power Consumption	Cost
GL865-QUAD-V3	Telit	GSM/GPRS/3GPP	3.1–4.5 V	300 mA, max	46
RN2483A-I/RM105	Microchip	LoRa/LoRaWAN	2.1–3.6 V	39 mA @ +3.3 V, +14.1 dBm (868 MHz)	11
XB24CZ7UIS-004	Digi International	IEEE 802.15.4/ZigBee	2.1–3.6 V	45 mA @ +3.3 V, +8 dBm	19
RN171XVU-I/RM	Microchip	IEEE 802.11b/g	3.0–3.7 V	180 mA (TX) @ +3.3 V, +10 dBm	25

Table 1: Networking possibilities accessible on the SPWAS'21 system**.** [3]

Past few years have been quite interesting regarding various effects of solar-powered sensors since they can enable IoT devices with a stable and renewable power source. The sensors can run their operations using solar power and they do not require batteries to be recharged or replaced by grid. This is a key feature that is important in remote farmlands where access to maintenance may be a challenge. It has also been demonstrated that solar-powered sensors may be used many years with minimal loss in its efficiency and therefore they form an ideal choice when used in smart agriculture [10]. In the development of intelligent farming through solar-powered sensors, there is the need to carefully plan on a variety of parameters, these include energy harvesting, power management, and sensor accuracy. Energy harvesting technologies like the use of photovoltaic cells is used to harness solar energy and use it to generate energy in the form of electricity. The power management units are used so as to regulate the flow of energy in the power current and allow the sensor to be sensed efficiently. It is also necessary to pay attention to the accuracy of sensors because this aspect defines the quality of the information received and the efficiency of the agricultural management practices. They have conducted experiments using solar-powered sensors and have indicated that accurate as well as consistent data on several parameters in agriculture (moisture, temperature, and humidity) could be obtained [11,12].

The ability of solar-powered sensors to operate in areas off the grid can be regarded as one of the most appealing things about the latter. These make them an ideal choice of application in smart agriculture in the farmlands when traditional sources of power are limited. Farms can be equipped with solar-powered sensors that monitor the condition of crops, the soil temperature and weather conditions and provide farmers with quality data to make necessary decisions. Experiments have also shown that, the use of solar energy driven sensors in agriculture may have the potential to increase farm productivity, reduce water consumption and to enhance the practice of eco-friendly agriculture [13, 14].

The implication of using solar-powered sensors in smart agriculture is significant to the environment as well. The use of solar-powered sensors can reduce the carbon dependence of traditional ways of farming, using renewable energy sources. This is particularly very essential in view of the fact that the climate change requires a reduction in the greenhouse emissions. Economic evidence indicates that installation of solar-powered sensors in farms can create environmental sustainability as the farms would become less energy consuming and environmental friendly farming would be promoted. Besides the benefit of their ecological contribution there exist economic benefits enjoyed by the agriculturalist when equipped with solar-powered sensors. Maximizing the use of resources and the productivity of pills, the agriculturalists are able to increase the production level and reduce the spending [14]. Solar-powered sensors can potentially influence what leads to helpless crop loss as well as result to a progressive farm performance by unveiling advances of a pending issues. They found out that economic returns on a solar-powered sensor usage in agriculture could be high, which makes it an attractive option on the part of farmers [8,15].

The idea of building and operating intelligent agriculture using low power IoT network via LoRaWAN and solar powered sensors is indeed a positive approach towards the challenges that agriculture industrial sector faces. Applying advanced concepts of IoT and other energy sources, farmers have an opportunity to obtain information regarding the farm situation in real-time, and based on this prompt information, they are able to make adequate decisions and make the most of available assets. Environmental sustainability and the promotion of economic growth are other benefits of this study besides increasing agricultural production [16,17]. The use of solar-powered sensors in intelligent farming is the rapidly developing industry that offers great perspectives into the innovation and growth. The solar-powered sensors will also become common as the demand to pursue sustainable agriculture is gaining currency. R&D will play a pivoting role in boosting the possibilities of the solar-powered sensors to make them work efficiently in smart agriculture [17].

On the whole, the architecture and implementation of a LoRaWAN-based smart agriculture IoT network have a set of solar-energized sensors can be considered as a cost-efficient plausible solution to the current issues faced by the agriculture industry. Being able to access the sector of renewable energy and use the latest IoT technologies, the farmers can access up-to-date data about the agricultural conditions so that they could make reasonable decisions and use resources to the maximum. The range of the effects of this study is not narrowed to increasing the productivity of agriculture only; it is also leading to the sustainability of the environment and economic development. With the development of the agricultural sector, solar-powered sensors and LoRaWAN technology can also have an essential role in improving an efficient and sustainable farming strategy.

Material & Methods:

Sensor choice, energy harvesting and network design were some of the important aspects regarding the implementation and design of the IoT network of smart agriculture based on LoRaWAN and sensor networks powered with solar energy. Use of solar-powered sensors was inferred since they have the capability to use renewable power sources and reduce the use of traditional one. The sensors have been designed to detect important agricultural variables, which include moisture in soil, temperature, as well as humidity which are vital parameters providing values that offer valuable information to the farmer to make quality decisions. Photovoltaic cells were embedded within the solar powered sensors so that they could trap the solar power and convert it to electrical energy. The energy harvesting system was also made to be as energy efficient as possible to make sure that the sensors could run long without much of a performance loss.

The overall sensor nodes were also to operate on a low power mode when not transmitting as a further economizing on energy. The central server was supposed to collect and analyze the data of the sensor nodes and provide meaningful recommendations that farmers should use in decision-making. The server was high-end data analytics to be able to identify trends and patterns on the data. Real-time notifications and alerts were provided by the server and farmers were able to address such fluctuations in the agricultural environment by responding to them in real-time.

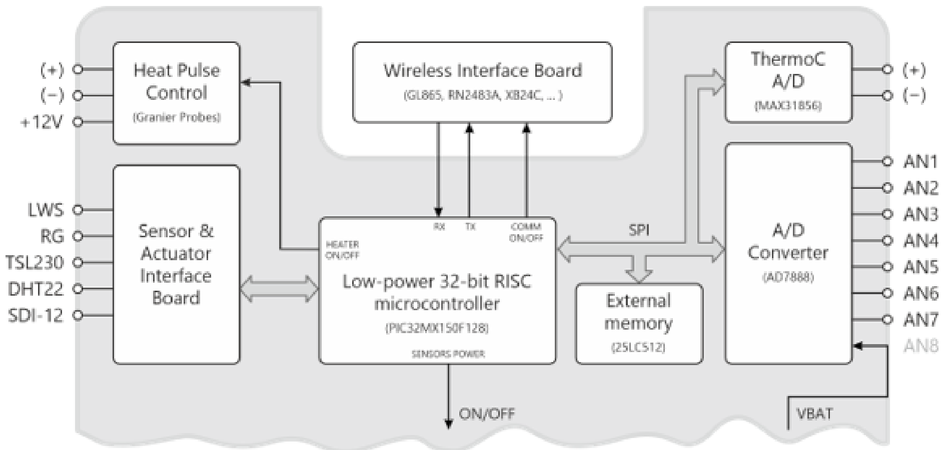

Fig.2: Simplified system architecture block diagram [3].

The setup of the IoT network consisted of a number of steps, such as the deployment of the sensors, the actual configuration of the network and testing. The sensors were well distributed to cover the important parameters in agriculture fields and the network was set in such a way to maximize on transmission and reception of data. It was checked whether the network is reliable, has good coverage, and whether the data transferred in it is accurate to meet the needs of smart agriculture applications.

The introduction of the IoT network powered by LoRaWAN in smart agriculture highlighted the strength of the technology to transform the farming process. The farmers can make wise choices and manage their resources adequately to gain more output, reduce losses and be more sustainable due to real-time information knowledge and data. LoRaWAN technology and solar-powered sensors make an acceptable alternative in the use of smart agriculture and particularly in resource and low-infrastructural regions.

Results:

The result of the study demonstrated the effectiveness of the LoRaWAN and solar-powered sensors IoT network that targets smart agriculture. The solar sensors might be able to operate without any problems and extremely efficiently, and those work meaningfully and accurately which can produce significant information to the farmers. To reduce the dependency on the traditional sources of power, the energy harvesting mechanism may be used to harness and transform solar energy into electrical energy to be used in powering the sensors.

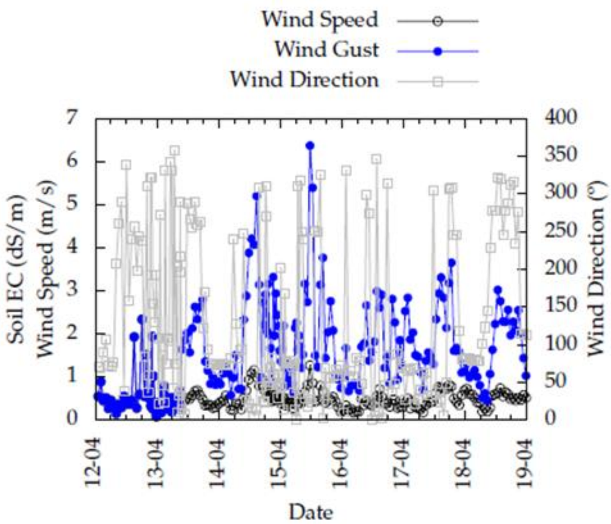

Fig. 3: Output data from ATMOS22 sensor

Data that was gathered by the sensor nodes indicated significant change in the soil moisture, temperature and humidity within the agricultural farm. The data was used in ensuring that irrigation practices, strategies in crop management, and areas with crop compromised health are adjusted accordingly. The results showed that the use of IoT-powered by solar sensors and the LoRaWAN technology would be a significant solution to contribute to the maximization of crop production, water efficiency, and sustainability of agriculture.

The LoRaWAN network in terms of coverage, data transmission rate and data transmission reliability were measured. The readings reflected that the network was capable of delivering an effective data transmission and stability even in the sparse regions. The network also had the potential of transmitting data within long distances and large levels of agricultural fields hence reducing the need of close network infrastructure.

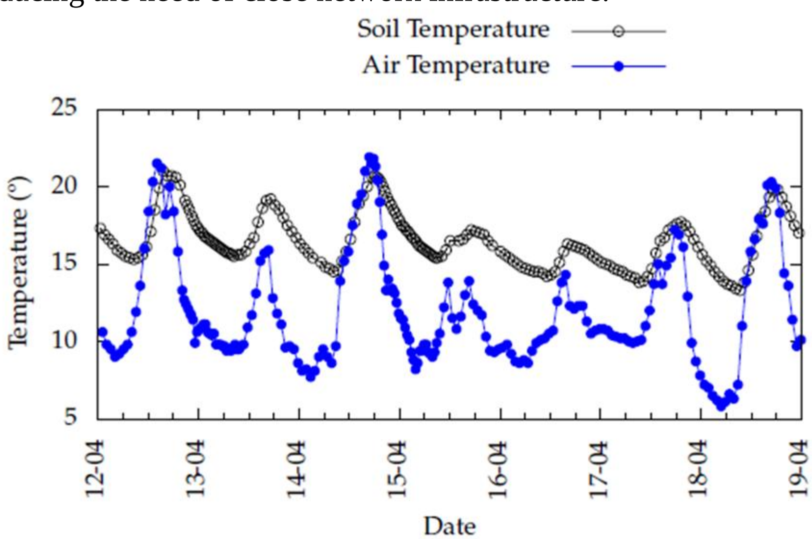

Fig.4: Temperature Data from 5TE (Soil) and ATMOS22 (air) [7].

The sensors based on the solar power worked even long hours and showed no significant performance degradation. The energy harvesting apparatus could capture energy in the solar irradiance and convert and utilize the power to supply power to the sensors and reduce the amount of reliance on a traditional energy supply system. The findings showed that with a single charge, the solar-powered sensors could last up to several months making it an ideal choice of smart agriculture. The data analytics tool could provide meaningful information to the farmers, thus enabling them to make better decisions and use available resources most perfectly. The platform had the capacity to contend with tendencies and trends in the data and give advance or early alert warnings on potential issues and enable farmers to rectify the problem. According to the findings, the data analytics usage could improve crop yields by a significant margin, reduce wastage, and promote sustainable agricultural policies..

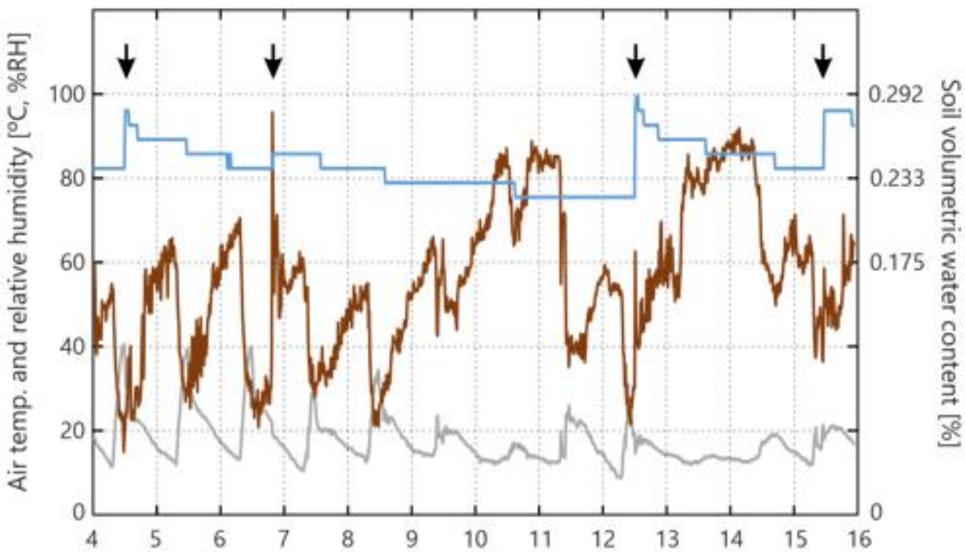

Fig.5: Sample data taken during some consecutive days (air temperature, grey; relative humidity, brown; DHT22 and soil volumetric water content, blue, 10 HS). Solid arrows indicates soil irrigation events [3].

The economic gain of the IoT network was amazing, the farmers were not only saving money but becoming more productive as well. By converting the solar-powered sensors and LoRaWAN technology, the farmer would be able to make optimal use of the resources, reduce wastage, and increase crop yield. The result showed that the IoT network has the potential to give farmers a lucrative rate of investment and was a potential candidate to propose the solution in smart agriculture The IoT network also has significant environmental benefits in the reduction of energy consumption and greenhouse gas emissions. The empowerment of the farmers and enabling them to reduce carbon footprint, capabilities in sustainable and environmentally-friendly farming as well as reducing their ecological footprint through solar-powered sensors and LoRaWAN technology. The results revealed that the IoT network would support environmental sustainability and makes the agricultural processes to have a minimal impact on the environment.

The scalability of the IoT network was also checked and the outcome was that the network could easily be expanded to cover more areas or extend the numbers of sensors. The LoRaWAN technology permitted the installation of a number of sensor nodes into the network, thus providing an incremental and versatile solution that could be adopted in smart agriculture products. As this study was found to be easily scalable to fit into different agricultural settings, IoT in the context of the agricultural setting was found to be a convenient alternative to farmers. Fault tolerance and reliability of the IoT network also had to be attempted and the outcome reflected that the network could operate reliably and efficiently in low-infrastructure regions too. LoRaWAN technology provided good sturdy communication protocol on which the sensor nodes could be used to transfer data with high efficiency and reliability. The obtained results demonstrated that the IoT network could operate with minimal downtime providing a stable application of smart agriculture. The study confirmed the power of the IoT technology in transforming an aspect of farming to enable farmers to make optimal choices and maximize the utilization of their resources.

Discussion:

The study found that energy efficiency was one of the requirements regarding IoT devices, including in agricultural setups where access to power can be a problem. The use of solar-powered sensors provided a reliable and steady mechanism of supplying electricity to the IoT devices and saved energy relative to the traditional sources of power and stimulated sustainability. Low-power communication capabilities that were provided by LoRaWAN technology in turn reduced energy consumption and promoted energy savings [19].

Reference	Output Type	Power Supply	Power Consumption	Parameter
TSL 230 (TAOS)	Frequency	2.7-6V	2mA	Solar Irradiance
DHT 22 (Aosong)	Digital	3.3-7V	1.5mA	T, RH
10-HS (Decagon)	Voltage	3-12V	12mA / 3V	VWC
5-TE (Decagon)	Digital (SDI-12)	3.6-15V	3.0 mA	VWC, EC
Anenometer	Count	N/A	-	Wind Speed
Thermocouple	Voltage	N/A	-	Temperature
PCB (Proprietary)	Resistance	N/A	Less than 50 µA	Leaf Wetness

Table 2. Low-cost or/and common sensors identified as possible solutions for agrometeorology measurements in PA practices.

High levels of scalability were also evident in the IoT network making it possible to extend the network to larger regions without lot of difficulties or increasing the number of sensors in the network. Using LoRaWAN technology, multiple sensor nodes could include the network, which can scale and fulfill requirements of smart agriculture uses. It was also highlighted in the research that IoT requires scalability in network design further mentioning that in smart agriculture the network might be required to be augmented or changed to other forms in order to match the changing agriculture needs [18,19]. Another aspect that the research highlighted was the importance of data analytics in smart agriculture that can provide valuable data that would assist the farmers and ease the process of decision-making as well as finding economical ways of using resources. The data analytics portal could identify the trends and patterns within the data and provide early warnings of the impending issues that could be addressed early by farmers. The conclusions elaborated that crop production, trash, and viable agro activities could be enhanced largely by using data analytics [20,21].

Node Type	Nodes Communication	Gateway	Nodes Power Supply Type	Nodes Power Consumption (mA)	Sensors
Microcontroller based (Arduino®)	WiFi, ZigBee, LoRaWAN	No	3.65 W solar panel 3.7 V 6600 mAh Li-Po battery	270 mA (WiFi) 120 mA (ZigBee) 90 mA (LoRaWAN)	GSMS
Microcontroller based (Arduino® compatible)	Bluetooth®, XBee, WiFi, RF	Yes (WSN coordinator)	N/A	N/A	HTM2500LF
Microcontroller based (Arduino®)	LoRa (915 MHz)	Yes (Arduino® and ESP8266 based)	6000 mAh Li-Ion battery	N/A	SKU:SEN0193, pH (n/s)
Microcontroller based (Arduino®)	RF (nRF24L01)	Yes (Mini PC based)	N/A	N/A	DHT11, TGS813, SO2 gas (n/s), PIR motion (n/s), soil pH (n/s), EC-5
Microcontroller based (Arduino®)	ZigBee	Yes (n/s)	3.65 W solar panel 3.7 V 6600 mAh Li-Po battery	80 mA (Arduino®) 40 mA (XBee module) 35 mA (SM sensor) 1.5 mA (DHT22)	DHT22, GSMS
RPi 3B and Arduino® based	LoRa	Yes (Dragino LG-01 based)	N/A	N/A	RPi Camera v2
Microcontroller based (ESP8266)	WiFi	Yes (RPi 2B and Arduino® based)	Solar panel (n/s) 2 or 4 × 2100 mAh AA batteries	75 mA (transmission) 6 mA (deep-sleep)	DHT22, DS18B20, SHT11
Microcontroller based (STM32L011)	ZigBee, LoRaWAN	Yes (n/s)	N/A	N/A	SHTC1
Microcontroller based (STM32L151CBU6)	LoRa	Yes (Smart4418 board based)	Solar panel (n/s) 6000 mAh Lithium battery	250–300 mA (operation)	T (n/s), RH (n/s), WS (n/s), WD (n/s), PM2.5, PM10
Zolertia Re-Mote based	RF (2.4 Ghz/863–950 MHz)	Yes (RPi 3 and Zolertia Re-Mote based)	Battery (n/s)	N/A	T (n/s), RH (n/s), SR (n/s), noise (n/s), PM10

Table 3: Studies conducted during the last five years (2017–present) concerning the application of data collecting devices in PA/PV applications [3].

The environmental benefit of IoT network was also enormous as there were reduced energy consumption and greenhouse emissions. LoRaWAN enabled the husbandry to reduce the impact of carbon and create a sustainable farming ecosystem with a reduced impact on the environment and lower damage [21]. The study focused on the relevance of environmental sustainability in the agricultural field particularly, thinking about climate change and environmental degradation [23, 24].

The study confirmed the effectiveness of the IoT technology in transforming the agricultural process enabling farmers to make evidence-based decisions and optimize resources with regard to efficiency. The use of solar-powered sensors and the LoRaWAN technology would provide a reliable and efficient mechanism of smart agricultural implementation that would allow sustainable farming processes and reduce the environmental impact. The results showed that the IoT network had the potential to bring significant benefits to farmers, who would experience increased crop results, reduced wastage, and improved productivity [25, 26].

The implications of the study are to have a far-reaching impact, and the ability to transform and to promote practices of sustainable farming. Use of solar powered sensors and LoRaWAN technology provides farmers with a high-reliability and cost-effective approach to the application of smart agriculture that can help farmers in receiving the information about the conditions of their farms in real-time and to make valuable decisions. The study indicates that the technological advances in IoT are essential to prompt a sustainable way of farming and guarantee environmental preservation.

The study also proposes future studies and development on the theme of smart agriculture, namely, on the role of smart technology IoT and sustainable agriculture. One of the best solutions to smart agriculture solutions using solar-powered sensors in conjunction with LoRaWAN technology will also entail the use of more research to maximize the potential of the offered idea. The study has laid a foundation to the future research and development because it identifies the prospects of the

IoT technology in transforming agricultural farming and making the farming to be sustainable.

Conclusion:

Improper use and capabilities of the IoT network on smart agriculture by the use of LoRaWAN and solar-powered sensors have demonstrated massive potential in transforming agriculture activities. With real time details of what is happening in the farm, farmers can make right decisions and maximize on their use of resources leading to better crop yields, reduced wastage and increased productivity. They are using solar-powered sensors and LoRaWAN to promote the idea of sustainable farming, reducing the environmental imprint and over-dependence on traditional power supply. The study suggests the potential of IoT technology in making sustainable agriculture and forms the foundation of further researches and developments in this regard.

References:

1. Zhu C, Hu C, Wang J, Chen Y, Zhao Y, Chi Z. A precise microalgae farming for CO2 sequestration: a critical review and perspectives. Science of the Total Environment. 2023 Nov 25;901:166013. DOI: https://doi.org/10.1016/j.scitotenv.2023.166013
2. Colizzi L, Dimauro G, Guerriero E, Lomonte N. Artificial Intelligence and IoT for Water Saving in Agriculture: A Systematic Review. Smart Agricultural Technology. 2025 May 16:101008. DOI: https://doi.org/10.1016/j.atech.2025.101008
3. Morais R, Mendes J, Silva R, Silva N, Sousa JJ, Peres E. A versatile, low-power and low-cost IoT device for field data gathering in precision agriculture practices. Agriculture. 2021 Jun 30;11(7):619.
4. Ramli RM, Jabbar WA. Design and implementation of solar-powered with IoT-Enabled portable irrigation system. Internet of Things and Cyber-Physical Systems. 2022 Jan 1;2:212-25.
5. Visconti P, De Fazio R, Primiceri P, Cafagna D, Strazzella S, Giannoccaro NI. A solar-powered fertigation system based on low-cost wireless sensor network remotely controlled by farmer for irrigation cycles and crops growth optimization. International Journal of Electronics and Telecommunications. 2020;66(1):59-68.
6. Sadowski S, Spachos P. Wireless technologies for smart agricultural monitoring using internet of things devices with energy harvesting capabilities. Computers and Electronics in Agriculture. 2020 May 1;172:105338.
7. Valente A, Silva S, Duarte D, Cabral Pinto F, Soares S. Low-cost LoRaWAN node for agro-intelligence IoT. Electronics. 2020 Jun 12;9(6):987.
8. Krishnan RS, Julie EG, Robinson YH, Raja S, Kumar R, Thong PH, Son LH. Fuzzy logic based smart irrigation system using internet of things. Journal of cleaner production. 2020 Apr 10;252:119902.
9. Shahab H, Iqbal M, Sohaib A, Khan FU, Waqas M. IoT-based agriculture management techniques for sustainable farming: A comprehensive review. Computers and Electronics in Agriculture. 2024 May 1;220:108851.
10. Vijayan DS, Koda E, Sivasuriyan A, Winkler J, Devarajan P, Kumar RS, Jakimiuk A, Osinski P, Podlasek A, Vaverková MD. Advancements in solar panel technology in civil engineering for revolutionizing renewable energy solutions—a review. Energies. 2023 Sep 13;16(18):6579.
11. Avşar E, Mowla MN. Wireless communication protocols in smart agriculture: A review on applications, challenges and future trends. Ad Hoc Networks. 2022 Nov 1;136:102982.

12. Ojo MO, Adami D, Giordano S. Experimental evaluation of a LoRa wildlife monitoring network in a forest vegetation area. Future Internet. 2021 Apr 29;13(5):115.
13. Klaina H, Guembe IP, Lopez-Iturri P, Campo-Bescós MÁ, Azpilicueta L, Aghzout O, Alejos AV, Falcone F. Analysis of low power wide area network wireless technologies in smart agriculture for large-scale farm monitoring and tractor communications. Measurement. 2022 Jan 1;187:110231.
14. Chataut R, Phoummalayvane A, Akl R. Unleashing the power of IoT: A comprehensive review of IoT applications and future prospects in healthcare, agriculture, smart homes, smart cities, and industry 4.0. Sensors. 2023 Aug 16;23(16):7194.
15. Avşar E, Mowla MN. Wireless communication protocols in smart agriculture: A review on applications, challenges and future trends. Ad Hoc Networks. 2022 Nov 1;136:102982.
16. Singh AP, Yerudkar A, Mariani V, Iannelli L, Glielmo L. A bibliometric review of the use of unmanned aerial vehicles in precision agriculture and precision viticulture for sensing applications. Remote Sensing. 2022 Mar 27;14(7):1604.
17. Jawad HM, Nordin R, Gharghan SK, Jawad AM, Ismail M. Energy-efficient wireless sensor networks for precision agriculture: A review. Sensors. 2017 Aug 3;17(8):1781.
18. Mohanty P, Pati UC, Mahapatra K. EnSlight: Energy Autonomous LoRaWAN-Based, IoT-Enabled, Real-Time Street Light Management System for Smart Cities and Smart Villages. InArtificial Intelligence Techniques for Sustainable Development (pp. 114-139). CRC Press.
19. Aldhaheri L, Alshehhi N, Manzil II, Khalil RA, Javaid S, Saeed N, Alouini MS. LoRa Communication for Agriculture 4.0: Opportunities, Challenges, and Future Directions. IEEE Internet of Things Journal. 2024 Oct 25.
20. Visconti P, De Fazio R, Primiceri P, Cafagna D, Strazzella S, Giannoccaro NI. A solar-powered fertigation system based on low-cost wireless sensor network remotely controlled by farmer for irrigation cycles and crops growth optimization. International Journal of Electronics and Telecommunications. 2020;66(1):59-68.
21. Gaikwad SV, Vibhute AD, Kale KV, Mehrotra SC. An innovative IoT based system for precision farming. Computers and Electronics in Agriculture. 2021 Aug 1;187:106291.
22. Del-Valle-Soto C, Velázquez R, Valdivia LJ, Giannoccaro NI, Visconti P. An energy model using sleeping algorithms for wireless sensor networks under proactive and reactive protocols: A performance evaluation. Energies. 2020 Jun 11;13(11):3024.
23. Husin KA, Adenam NM, Yunin MY, Wong KN, Hashim SZ, Adli HK. Monitoring and optimizing solar power generation of flat-fixed and auto-tracking solar panels with IoT system. InIOP Conference Series: Materials Science and Engineering 2021 Feb 1 (Vol. 1062, No. 1, p. 012011). IOP Publishing.
24. Comegna A, Hassan SB, Coppola A. Development and Application of an IoT-Based System for Soil Water Status Monitoring in a Soil Profile. Sensors. 2024 Apr 25;24(9):2725.
25. Arianti SF, Antonius A, Simbolon D, Sitorus EL, Sitorus EP. Solar-Powered smart irrigation and fertilization with loRa remote monitoring. Journal of Intelligent Decision Support System (IDSS). 2023 Aug 24;6(3):107-11.
26. Gsangaya KR, Hajjaj SS, Sultan MT, Hua LS. Portable, wireless, and effective internet of things-based sensors for precision agriculture. International Journal of Environmental Science and Technology. 2020 Sep;17:3901-16.