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Enhancing Agriculture through Wireless Sensor Networks

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Solar-powered wireless sensor networks (WSNs) play a crucial role in modern agriculture, enhancing crop yield and quality while reducing labor requirements. By employing sensors and communication technologies like ZigBee and Bluetooth, these networks collect real-time data on various environmental parameters, facilitating remote monitoring and prompt action by farmers. Leveraging solar energy through photovoltaic (PV) systems, these WSNs ensure sustained power supply, enabling autonomous operation even in remote areas. Recent studies highlight the effectiveness of solar-powered WSNs in diverse agricultural applications such as automated irrigation, soil sensing, and weather monitoring. Integration of PV technology with WSNs offers simplicity in installation and long-term energy sustainability, making them an attractive choice for farmers seeking efficient and self-sustained agricultural practices.

Keywords: *Crop yield enhancement; Long-term sustainability; Photovoltaic systems; Remote monitoring; Solar-powered WSNs.*

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1. INTRODUCTION

Solar-powered wireless sensor networks (WSNs) revolutionize agriculture by integrating advanced technology into traditional farming. Precision agriculture (PA) combines agriculture with information technology to boost crop yield while minimizing labor. Sensors collect real-time data on crucial parameters like temperature and soil moisture, transmitted via WSNs for remote monitoring. IoT enhances efficiency with low-cost connectivity, enabling applications like livestock monitoring and automated irrigation (Rahul et al., 2018). Energy harvesting, particularly solar power, addresses WSNs' battery limitations, ensuring sustainability. Solar-powered WSNs offer clean, extended energy solutions, transforming agricultural practices.

In this context, this paper delves into the significance and implementation of solar-powered WSNs in agriculture, highlighting recent advancements, energy harvesting techniques, and real-world implementations. Through an in-depth exploration, we aim to underscore the transformative potential of solar-powered WSNs in driving agricultural innovation and sustainability.

2. MATERIALS AND METHODS

Utilizing solar power in agricultural wireless sensor networks (WSNs) involves integrating photovoltaic (PV) technology with sensor nodes. Various studies demonstrate its effectiveness in applications such as automated irrigation, soil sensing, and weather monitoring, highlighting its simplicity in setup and long-term sustainability.

2.1 Leveraging Solar Power for Agricultural Wireless Sensor Networks

The concept of Precision Agriculture (PA) combines agriculture with information technology to enhance crop yield and quality. Crop yield monitoring, at 61.4%, is the predominant PA technique (Vuran et al., 2018). Various technologies like ICT, sensors, information processing, and GIS are utilized to boost profitability and reduce labor in agricultural practices (Feng et al., 2019). Sensors integrated into agriculture enable real-time data collection of vital parameters like temperature, soil moisture, and atmospheric conditions. This data, collected via a wireless sensor network (WSN), can be

analyzed for informed decision-making. In this modern technology era, farmers can also monitor the crops and can operate all digitized gadgets and computers, facilitating prompt action (Abdu and Salamah, 2011 and Thakur et al., 2019). WSN, the second-largest network globally, enhances efficiency and sets the groundwork for broader Internet of Things (IoT) adoption in agriculture (Abo-Zahhad et al., 2015 and Syafarinda et al., 2018).

2.2 Wireless Sensor Network (WSN)

A wireless sensor network (WSN) comprises sensor nodes (motes) forming an ad-hoc network to sense, measure, and gather environmental data. Each node consists unit of a power, sensing, computing, and communication (Akbari, 2014, Kumar and Ilango 2018 and Thakur et al., 2019). Nodes detect real-time ecological phenomena, converting them to digital signals for processing and storage in the computing unit. Processed data is then shared via the communication unit with other nodes or end users. Nodes can communicate with a server/base station in centralized or decentralized architectures, employing various topologies like mesh or star. WSN and its components is shown in Fig. 1. As depicted in the illustration, a Wireless Sensor Network (WSN) typically comprises numerous sensor nodes and a gateway node. Key attributes of WSNs include their ease of application, capacity for scalability to vast scales, node mobility, and robustness. These networks excel in capturing data from physical phenomena rather than relying on individual sensors. Consequently, the malfunction of a single node will not significantly impact the entire network (Akhtar and Rehmani, 2015 and Kiani and Seyyedabbasi, 2018).

In agricultural contexts, Wireless Sensor Networks (WSNs) are typically categorized into two primary types: terrestrial and subterranean. Terrestrial WSNs (TWSNs) involve deploying sensor nodes above the ground to assess land conditions. Subterranean WSNs (UWSNs) employ sensor nodes placed within the soil of agricultural fields for sensing and monitoring the soil conditions (Bader et al., 2014 and Kiani and Seyyedabbasi, 2018). Different technologies within Wireless Sensor Networks (WSNs) facilitate efficient data communication based on their application. These technologies include ZigBee, Bluetooth, Wibree, WiFi, GPRS, and WiMAX (Table 1).

Table 1. Different available communication technologies for WSNs

Specifications	Technologies				
	Zigbee	Bluetooth	Wi-Fi	GPRS 2G/ 3G/4G	WiMax
Standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.11a, d,g,n	-	IEEE 802.16. A,e
Frequency band	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz	2.4 GHz
Range	10-100 m	100 m	32 m	Coverage area of GSM	30moles
Data rate	20 Kbit/s to 250 Kbit/s	1 Mbps	11-54 mbps	5-100 kbps/ 200 kbps/ 0.1-1 GB	50-100 Mbps
Power consumption	Low	Medium	High	Medium	Medium
Cost	Low	Low	High	Medium	High
Modulation/protocol	DSSS, CSMA/ CA	FHSS, GFSK	DSSS/ CCK, OFDM	SNDTCP, LLC	OFDM
Security	128 bits	64 or 128 bits	128 bits	128 bits	160 bits

Source: (Thakur et al., 2019)

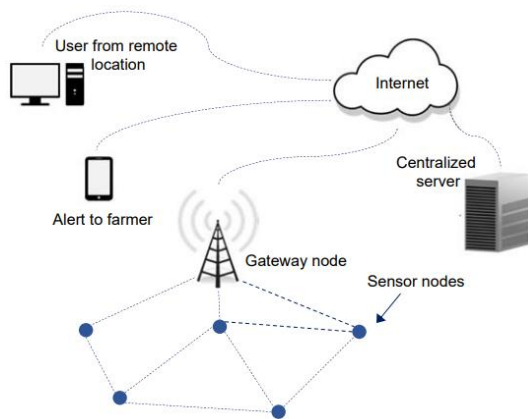


Fig. 1. The general Architecture of a WSN
Source: Kumar and Ilango, 2018 and Thakur et al., 2019

2.3 Internet of Things (IoT)

The Internet of Things (IoT) encompasses a network of inexpensive, energy-efficient physical objects equipped with embedded electronics, sensors, and connectivity, facilitating data exchange. Processed data is sent to cloud computing via a gateway for storage and decision-making (Fig. 2) (Wark et al., 2007, Na and Isaac, 2016 and Heble et al., 2018). The main goals of using IoT networks in agriculture are improving efficiency as well as increasing accuracy and profitability.

IoT systems include, automated irrigation, soil sensing and monitoring of livestock and weather (Ojha, 2015, Navulur et al., 2017 and Varun et al., 2018). For instance, IoT sensors gather ambient and soil moisture data for automated

irrigation, preventing crop over- and underwatering. Additionally, IoT-based livestock monitoring ensures proper care and feeding of animals (Dataflair, 2019). Communication technologies in IoT, along with their frequencies and coverage distances, are detailed in Table 2.

2.4 Methods of Energy Harvesting for Wireless Sensor Networks

A primary limitation of Wireless Sensor Networks (WSNs) is the finite battery capacity of sensor nodes. In the past researchers have been developed the technique to tackle this issue, focusing on energy-efficient. Energy harvesting techniques enable sensor nodes to harness diverse sources such as solar energy, mechanical vibration energy, and wind energy, converting them directly into electricity (Fig. 3). Batteries are used to store the harvested energy. For instance, solar energy can charge sensor node batteries during the day for night time operation. Additionally, nodes can enter low-power sleep modes to conserve energy when battery levels are low (Jawad et al., 2017 and Pooja et al., 2017).

2.5 Utilizing Solar-Powered Wireless Sensor Networks in Agricultural Settings

Solar energy, via photovoltaic (PV) technology, can be employed in agriculture using Wireless Sensor Networks (WSNs) (Jawad et al., 2017 and Nurzaman et al., 2018). Solar cells provide sustainable energy for sensor nodes, though solar energy availability varies with time and

season (Pooja et al., 2017). Despite limitations such as reliance on disposable lithium batteries, emerging power supply methods like supercapacitors and rechargeable batteries show promise. A typical solar PV system for WSNs comprises solar modules, control circuits, and batteries, enabling extended and clean energy provision (Li and Shi, 2015, Zou et al., 2016 and Cong et al., 2017).

Pooja et al. (2017) proposed a solar-powered automated irrigation system tailored for remote regions. Solar panel setup employed for solar pumping and irrigation system (Fig. 4). Soil moisture and temperature data were gathered by a sensor node network and transmitted to a remote station (Leah et al., 2010). The study found solar PV irrigation to be cost-effective for small, distant field applications compared to conventional energy sources.

Zhang et al. (2017) devised a wireless monitoring node employing solar PV panels attached with an automated tracker designed for paddy field settings. The nodes captured various field

parameters such as moisture, temperature, pH, water level, and light intensity. Processed data was then transmitted to remote monitoring software via a GPRS module (Fig. 5). The incorporation of an automatic tracker enhanced solar PV panel efficiency, with the battery was charged using panel during daylight hours via a controller.

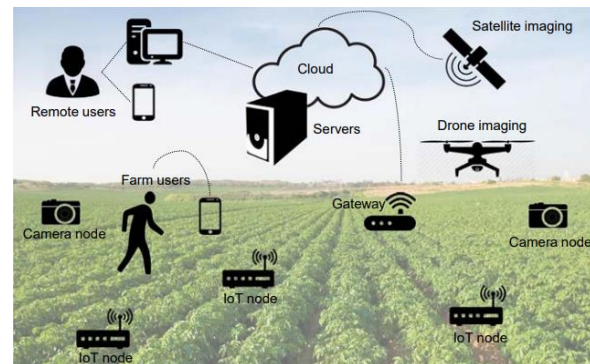


Fig. 2. Schematic view of IoT deployment in the field

Table 2. Different available communication technologies for IoT

Technology	Standard	Downlink/ uplink	Range (m)	Operating frequency (MHz)	Year of discovery
RFID ^a	Wireless	100 kbps	2	0.125-5876	1973
IEEE 802.15.4	6LoWPAN	250 kbps	30	826 and 915	2003
Z-Wave ^b	Wireless	100 kbit/s	30	868.42 and 908.42	2013
LTE ^c	3GPP, LTE, and 4G	100 Mbps	35	400-1900	1991
LoRa ^d	Wireless	0.3 37.5 (kb/s)	3000-5000	169, 433, and 868 (Europe) and 915 (North America)	2012
NFC ^e	ISO 18092	106, 212, or 424 Kbits	>0.2	13.56	2004
UBW ^f	IEEE 802.15.3	11-55 Mbps	10-30	2400	2002
M2M ^g	Open to All Communication	50-150 Mbps	5-20	1-20	1973
6LoWPAN ^h	Wireless	250 Kbps	30	915	2006

^a Radio-frequency identification.

^b Zensys wave.

^c Long-term evolution.

^d Longrange.

^e Near field communication.

^f Ultrawide band.

^g Machine to machine.

^h IPv6 low-power wireless personal area network

Source: Khanna and Kaur, 2019

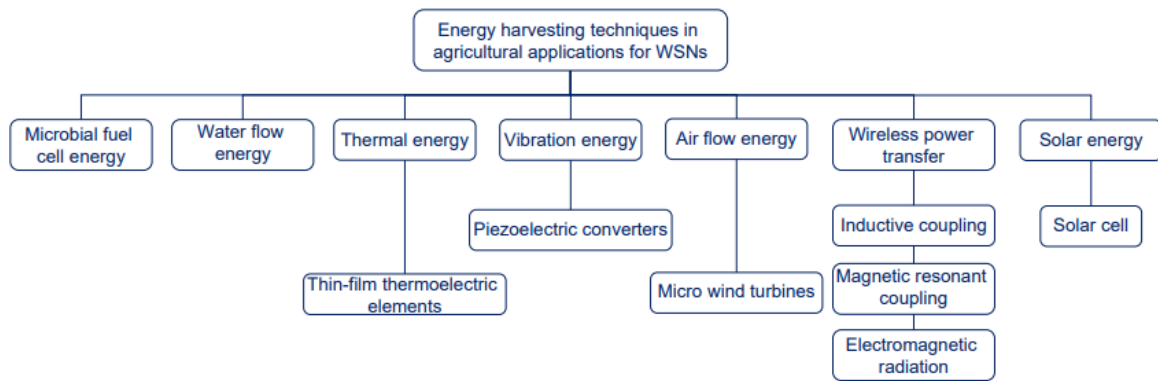


Fig. 3. Energy-efficient schemes in agriculture for WSNs

Source: Jawad et al., 2017

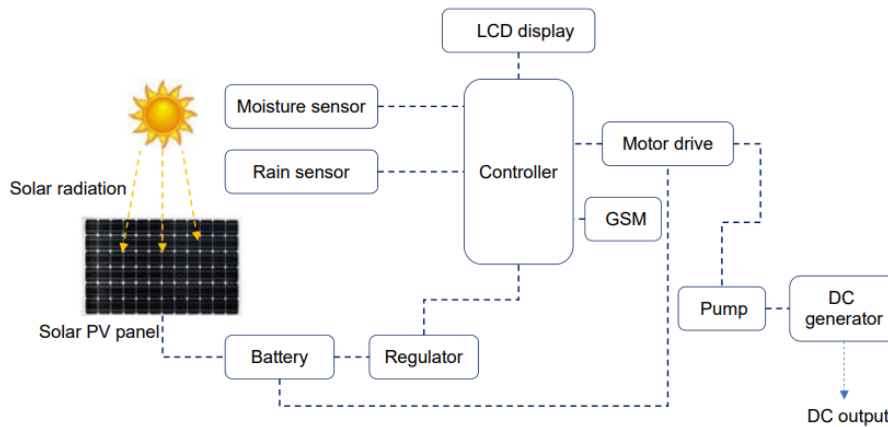


Fig. 4. Block diagram of a solar-powered irrigation system based on WSNs

Source: Pooja et al., 2017

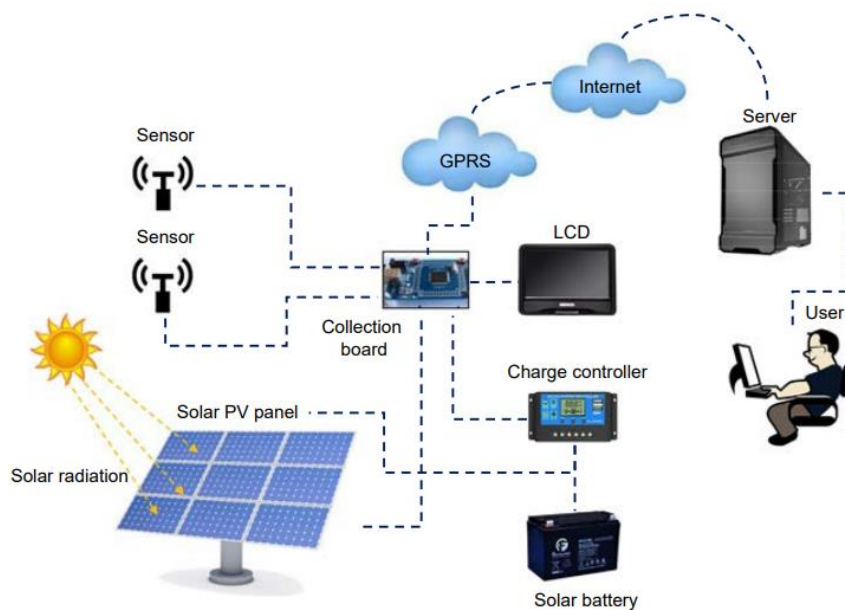


Fig. 5. The overall framework for a solar-powered WSN system developed

(Bhangale and Bhide, 2019)

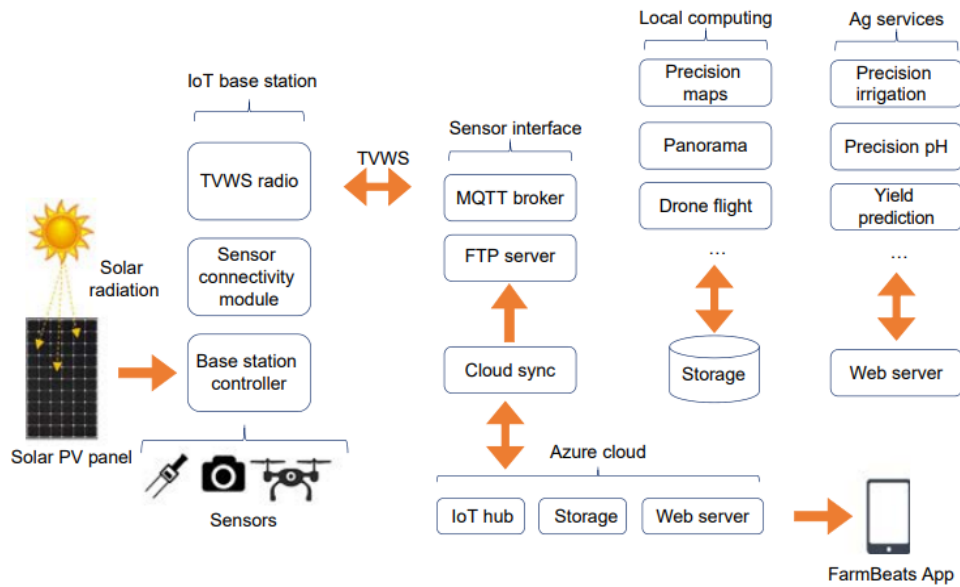


Fig. 6. Schematic diagram of the farm beats IoT platform

Source: Vasisht et al. (2017)

The scientist asserted that the suggested node could achieve accurate data communication, leveraging solar energy to meet system energy requirements. In a separate investigation by Vasisht et al. (2017), they introduced Farm Beats, an affordable IoT framework. This system facilitated data gathering from diverse sensors like cameras, drones, and soil sensors. Consisting solar-driven IoT base position and a smart entranceway, it ensured cloud service accessibility (refer to Fig. 6).

Li and Shi (2015) introduced an innovative intelligent solar energy-harvesting (ISEH) system tailored for WSNs. Comprising a photovoltaic (PV) panel, lithium-ion batteries, and control loop (Fig. 7), the system integrated a maximum power point tracking (MPPT) loop to optimize PV panel efficiency. Captured solar power could be keep in reserve in the battery, ensuring continuous operation of IoT nodes during low sunlight periods (Bhangale and Bhide, 2019). They emphasized the system's suitability for outdoor IoT sensor nodes due to its low-power nature and compatibility with energy-efficient equipment.

Chiochan et al. (2017) presumed a compact isolated solar panel system which can be used in Lingzhi mushroom farm. Utilizing an IoT framework with sensors, the system monitored solar cell and battery charging voltage for fog and sprinkler pumps as shown in Fig. 8. All photovoltaic data were gathered in a Blynk cloud service, facilitating real-time monitoring via a

Blynk app with time-series graph visualization. The study underscored the economic viability of solar systems in remote areas devoid of grid electricity. Furthermore, the combination of IoT technology with voltage and current sensors are an alternative power source for sensor based farming.

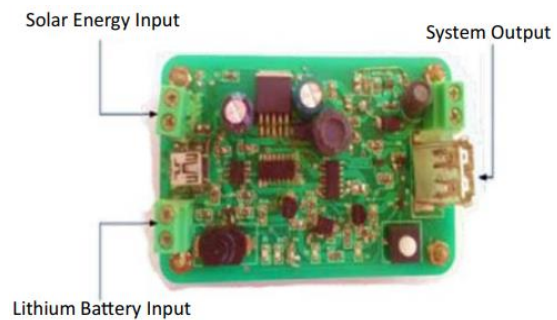


Fig. 7. Circuit board of the developed solar-powered ISEH system

Source: Li and Shi, 2015

Table 3 outlines recent research on WSN approach in agriculture, employing photovoltaic technology for power collection. These studies demonstrate the versatility of solar-powered WSNs in various agricultural tasks. Farmers favor integrating PV systems with WSNs for their straightforward setup and effective operation under adequate solar radiation. Moreover, solar PV systems offer a sustainable, long-lasting power source for sensor nodes, ensuring the system's self-sufficiency.

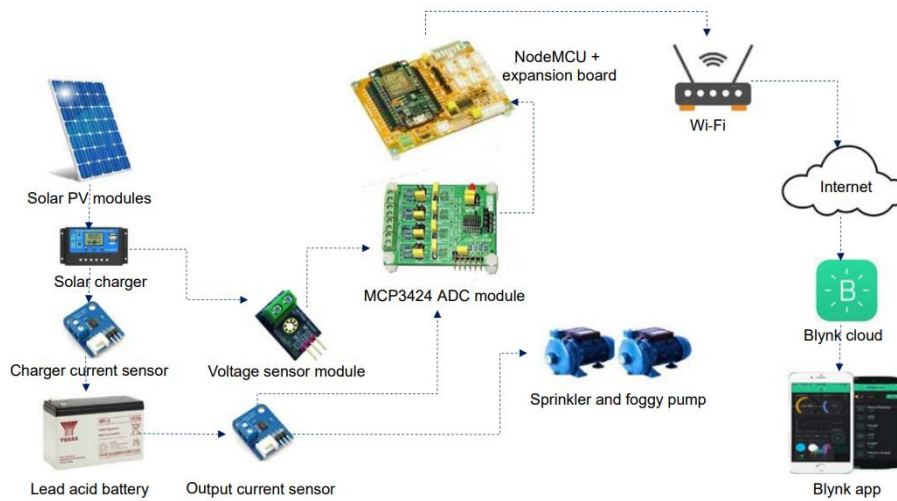


Fig. 8. Concept layout of the IoT for a solar cell system with Blynk
 Source: Chieochan, et al., 2017

Table 3. PV-powered WSNs utilized in agricultural activities

Wireless "device"	Sensors/actuators	Application	Main findings	Reference
GPRS/3G	Wind speed and direction, temperature, humidity, rain gauge, water, and pH levels	Weather monitoring	The battery support for sensor node operation was limited to 7 days.	Nguyen et al. (2016)
nRF24L01 IEEE 802.11b/ g/n (Wi-Fi) and cloud computing	Air temperature, wind speed and direction, leaf wetness, soil moisture, air humidity, rain volume/ fertilizers or spraying chemicals and watering system	Precision agriculture applications	The proposed system has an acceptable efficiency; • The system's structure is a little complex; • The architecture is suitable for use in a wide range of PA activities.	Khattab et al. (2016)
GSM module/ LoRa	Soil temperature and moisture, air temperature and humidity, and light intensity/alert messages	Automation in greenhouse	The system has been optimized for large-scale applications; • To measure environmental parameters, the module empowers the module; • Multiple parameters can be shown on a mobile application	Ilie Ablachim et al. (2016)
Wi-Fi/ GSM modem	Soil moisture, humidity, and temperature	Automated irrigation	PV power is more affordable for microirrigation systems; • PV power is cost-competitive for small, remote irrigation applications; • Precise utilization timing makes the system more efficient and low-cost.	Pooja et al. (2017)

3. RESULTS AND DISCUSSION

The fusion of wireless sensor networks (WSNs) and the Internet of Things (IoT) within agriculture has sparked a revolutionary transformation, markedly enhancing crop yield monitoring by 61.4% in precision agriculture (PA). Leveraging technologies like information and communications technology (ICT), sensor technology, and geographic information systems (GIS) has significantly boosted profitability and slashed labor demands in farming activities. WSNs, comprising sensor nodes with diverse components, facilitate real-time data capture and analysis, empowering remote monitoring of crops and equipment. This technology's scalability, mobility, and resilience across different topologies amplify agricultural efficiency. Additionally, categorizing WSNs into terrestrial and underground types extends their utility in land assessment and soil monitoring. The amalgamation of WSNs with IoT opens avenues for cost-effective and low-power connectivity among physical entities in agriculture, enabling seamless data transmission and cloud-based processing.

These advancements in agricultural applications, including livestock supervision, smart irrigation, soil analysis, and weather surveillance, strive to optimize resource utilization and bolster profitability. Addressing the challenge of limited battery capacity in sensor nodes, diverse energy harvesting techniques, particularly solar energy, have emerged. Solar-powered WSNs furnish sustainable and enduring power sources, ensuring self-sufficiency and sustainability in agricultural operations, especially in remote field deployments. This integration marks a watershed moment in technology-driven precision farming, empowering farmers to achieve heightened efficiency and productivity while mitigating environmental impact.

4. CONCLUSION

The integration of wireless sensor networks (WSNs) and the Internet of Things (IoT) in agriculture has revolutionized traditional farming practices, enhancing crop monitoring and resource management. Solar-powered WSNs offer sustainable energy solutions, ensuring self-sufficiency in remote agricultural operations. These technologies pave the way for precision farming practices, enabling real-time monitoring and decision-making for optimal resource utilization. Further research and development in

this field are crucial for addressing challenges and unlocking the full potential of technology-driven agriculture.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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