SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Mechanics

Journal homepage: https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Exploring the Opportunities of Applying RFID Technology in Smart Agriculture

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ARTICLE INFO

Article history:
Received 27 September 2024
Received in revised form 29 October 2024
Accepted 4 November 2024
Available online 30 November 2024

Keywords:
RFID; RFID tag; smart agriculture; plant monitoring

ABSTRACT

This paper explores the opportunities of applying RFID (radio-frequency identification) technology in smart agriculture. With the projected increase in global population and the resulting higher demand for food production, the agricultural industry is under pressure to find more efficient and sustainable ways to meet these needs. Radio-frequency identification (RFID) technology has been recently adopted in the agriculture industry as a means of improving efficiency and productivity towards achieving smart agriculture. RFID technology is revolutionizing smart agriculture, offering automation, real-time monitoring and data-driven decision-making. Integrating RFID tags with plants and soil samples optimizes resource utilization, crop health management, traceability and quality assurance. RFID in smart agriculture offers opportunities for resource optimization, crop health management, traceability and automation. Leveraging RFID technology, farmers can elevate productivity, reduce costs, improve sustainability and meet global demands. Adopting RFID in agriculture revolutionizes traditional practices, enabling efficient and sustainable farming. RFID-enabled traceability enhances food safety, quality assurance and transparency in the food supply chain. The objective of this paper is to explore the potential of RFID technology in smart agriculture and highlight the significance of effective RFID antenna design for optimizing food production, addressing global challenges and fostering a more efficient, sustainable and resilient agricultural sector.

1. Introduction

Global population growth is expected to increase to 9.7 billion in 2050 and 10.4 billion in 2100, according to the United Nations (UN) forecast [1]. An increase in the global population causes high demand in the plant and food production which significantly increase the load on the agricultural

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https://doi.org/10.37934/aram.127.1.144154

industry [2]. The agricultural industry is the major supplier of food production for humans and animals. To cope with enormous demand, the industry has now migrated from conventional to smart agriculture. Smart agricultural strategies emerge because of the rapid development of innovative technology. Smart agriculture helps to improve efficiency of plant production, save labour and costs and improve the quality of the crops. With the aid of emerging technologies like the radio frequency identification (RFID), Internet of Things (IoT), artificial intelligence, cloud computing and wireless sensor networks (WSN), the agriculture business has progressed from traditional to smart agriculture. This change was made possible by integrating sensing, actuation and computer technology into traditional agriculture [2-4].

RFID sensing technologies are one of the most promising emerging technologies that have expanded beyond just tracking livestock or food to also keeping track of how plants and crops are growing [5]. The Internet of Things (IoT), which connects a huge number of devices using various access technologies to share data and interact, uses RFID system to perform tasks. RFID technology is an essential enabling method for the IoT sensing layer. It is a wireless technology that uses electromagnetic waves to detect, trace and identify objects, animals or people. RFID technology debuted in the past 70 years ago. It only began to be used more extensively in the early 2000s, but it is now rocketing and continuing to develop quickly [6]. RFID sensor is a crucial enabling technology for the IoT applications especially for smart agriculture industries. The RFID sensor tags offer contactless sensing, wireless data transfer, wireless power, flexibility, non-line-of-sight transmission and multiple tag simultaneous reading [7]. The RFID system consists of a reader, tag and computer host. This technology uses radio waves to enable communication between a reader and a tag. The reader sends a signal to the tag, which responds with information-carrying signals. Unique data, such as the GS1 Electronic Product Code, can be encoded on RFID tags and attached to items, cartons or pallets based on the application. There are two typical categories of RFID tags which are active and passive. The active tags are equipped with the battery while the passive tags do not consist of battery, instead they use backscattering signal from the reader to power on the integrated chip. The absence of an internal power source makes passive RFID tags smaller and more portable for a variety of uses than active RFID tags. RFID tags can also be divided into three categories based on the frequency bands in which they operate: low frequency (LF), high frequency (HF) and ultra-high frequency (UHF). HF and UHF RFID tags provide a faster data rate than LF tags [8]. Contrary to commonly used barcodes, RFID does not require a clean label, which makes it advantageous for agricultural operations [9].

This paper to explore the potential of RFID technology in smart agriculture and highlight the significance of effective RFID antenna design for optimizing food production, addressing global challenges and fostering a more efficient, sustainable and resilient agricultural sector. With the projected increase in global population and the resulting higher demand for food production, the agricultural industry is under pressure to find more efficient and sustainable ways to meet these needs. Smart agriculture, which leverages innovative technologies, offers a solution by optimizing crop production, reducing costs and improving crop quality. RFID technology plays a vital role in smart farming by enabling automatic identification and tracking of objects using radio waves. RFID tags can be attached to plants and soil samples, allowing for automation, real-time monitoring and data-driven decision-making. However, designing effective RFID systems in the agricultural context poses challenges, particularly related to antenna impedance matching. Additionally, it presents various RFID antenna designs and their impact on performance, read range and reliability. The comparative analysis of different RFID antenna designs provides insights into their advantages and limitations. The tag's antenna must match well with the chip impedance, which can vary depending on the tag's placement on different objects. To achieve consistent tag performance, designers must address the loading impact caused by the backing objects. Various RFID tags with unique features can be designed for different agriculture applications. RFID tags can be attached to the plant leaves to monitor the local climate and embedded in the plants to monitor their growth. The paper provides further discussion on the design and evaluation of passive UHF tags.

2. Smart Agriculture

Smart agriculture is created by incorporating sensing, actuating and computing technology with traditional agriculture [4]. It is a new method of agricultural production that uses big data, artificial intelligence (AI) and the Internet of Things (IoT) to deeply integrate these modern information technologies. As a result, it enhances agricultural information perception, quantitative decision-making, intelligent control, precise investment and individualized service. The agricultural sector has evolved from the traditional agricultural era since 1784 until around 1870, which was controlled by human and animal resources. This era faces the challenge of operational inefficiency. In the 20th century, the era of mechanized agriculture began. However, it comes with another challenge: ineffective resource use. After that, high-speed automatic agriculture was developed between 1992 and 2017, albeit at the expense of a low level of intelligence. Later in 2017, smart agriculture emerged, marked by automated operations and the use of cutting-edge technologies [10].

The Internet of Things (IoT), which connects a huge number of devices using various access technologies in order to share data and interact, is a critical tool for achieving the growth of smart agriculture. Meanwhile, RFID is a key component in the IoT system. RFID technology has been widely employed in various agricultural sectors, including food traceability [11-14], soil moisture monitoring [5,15,16], plant inventory [9], farm machinery, chipping animals and seed identification [17], cold chain monitoring [18] orchard management [19] and worker safety [20-22]. RFID tags have been employed in agriculture sectors for many applications such as tracking and monitoring vegetables during transportation and storage, food traceability [21], agricultural unmanned vehicles [23] orchard management [19], plant growing environment, soil conditions, plant growth and the harvests quality [5] and tracking system for the worker safety [21].

Antennas Smart farming technology, including RFID technology, addresses several challenges in modern agriculture [6]. Here are some of the key issues that can be addressed using technology such as Smart farming helps optimize the use of resources such as water, fertilizers and pesticides for resource optimizing. By implementing RFID technology, farmers can monitor soil moisture levels, nutrient requirements and pest infestations more accurately. Additionally, crop health and disease management will do some early detection and prevention of diseases, pests and weed infestations are crucial for maintaining crop health. RFID technology enables continuous monitoring of plant conditions, detecting deviations from normal growth patterns and identifying potential threats. In today's global food market, consumers increasingly demand transparency and traceability. RFID technology can be used to track agricultural products from farm to market, providing detailed information about the origin, production methods and handling processes for traceability and quality assurance.

3. Radio Frequency Identification (RFID) in Smart Agriculture

RFID overcomes the problem of inaccuracy and error food chain record by enabling food traceability for improving efficiency and reliability. Hamani *et al.,* [24] reported the utilization of RFID technology for the traceability in fishery supply chain management. RFID is used to ensure fish quality and security. RFID technology uses radio waves to enable communication between a reader and a tag. The reader sends a signal to the tag, which responds with information-carrying signals. Unique data, such as GS1 Electronic Product Code, can be encoded on RFID tags and attached to items, cartons or pallets based on the application. RFID technology can be compared to barcode technology in terms of accessing information about products or pallets, but RFID tags do not require a clear line of sight and can scan whole pallets or truckloads of items at a rate of up to 700 objects per second. This makes RFID tags beneficial for increasing supply chain visibility and efficiency through smart label tracking [19].

RFID technology is divided into two categories: those that require a battery and those that don't. Devices that actively transmit data are called transponders, while passive devices are referred to as tags. Active tags are more expensive and larger but have a longer life expectancy with current battery technology. Passive tags are cheaper and smaller, but have less data storage capacity, a shorter reading range and require a higher-powered reader. Semi-passive RFID tags have a battery that powers the circuitry, but still interact through the reader's power [9]. RFID is a wireless technology used for data collection and processing. It has two main applications: vicinity (long-range) and proximity (short-range). RFID is commonly used in track and trace applications, which can operate over long distances or in proximity [13]. The greenhouse cultivates plants in a controlled, insect-free environment. Maintaining appropriate moisture levels is crucial and RFID tags can help. Workers currently inspect pots daily, but RFID tags can do the job more effectively. RFID tags are durable and can withstand severe weather conditions. They also have a read range of up to tens of meters and do not require a direct line of sight. The tags can be concealed, making them less vulnerable to wear and tear. Additionally, RFID technology enables multi-tag reading, unlike barcode systems. The greenhouse has previously utilized RFID tags to monitor and manage plants. Finally, RFID tags are inexpensive and are the best option for this greenhouse.

4. Smart Agriculture Tracking System

The performance of conventional dipole RFID tags is significantly affected when near metallic objects. To improve the performance, a metallic plate can be placed at a quarter wavelength distance from the tag, but this method is not widely accepted. When a metallic object is close to the tag, surface currents induced by the antenna's current can cause interference, leading to a decrease in performance and eventually stopping the tag from operating. The ground plane is important for protecting antennas against the metallic host material. Most designs are patch antennas made up of a dielectric substrate, a conducting patch and a ground plane. In transmission mode, a time-varying signal excites the patch, creating electric fields between the ground plane and patch and radiation happens at the patch's edges. Surface currents only emerge on the surface of the ground plane contacting the substrate. The patch antenna is insulated from the host metallic item when functioning. The optimum option for low-profile planar designs for metallic mountable tags is the patch antenna with a substrate thickness of 0.01λ to 0.05λ [20]. To optimize a tag's size and read range, designers may need to compromise one for the other. One technique for reducing tag size is slotting a patch, which forces the surface current to travel a greater distance and reduces the resonant frequency. A multi-slotted tag design has been proposed as seen in Figure 1, featuring an inductive loop attached to a chip, stimulated by the slotted patch and linked to the ground for impedance matching. This design has a total dimension of 50501.6 mm3 and a detection range of 5 m [14].

Fig. 1. Multiple-slotted tag was proposed by Koskinen, Rajagopalan and Rahmat-Samii [14]

According to Lin, Chen and Mittra [15], a bowtie-shaped tag is introduced. As seen in Figure 2(a), the chip is situated in the middle of the symmetric patch and every patch is linked to the ground plane through holes. Dobkin and Weigand [10] describe a design for an antenna tag that uses stepped impedance patches attached to a ground plane through a shorted wall instead of vias. The patches are densely packed with slots and can be modified to match the antenna's impedance. The tag has a size of 88600.76 mm3 and a read length of 5.4 m with an EIRP of 4 W. The design is simpler than other comparable systems, which attach the centre-fed patch to the ground at the sides [17,18].

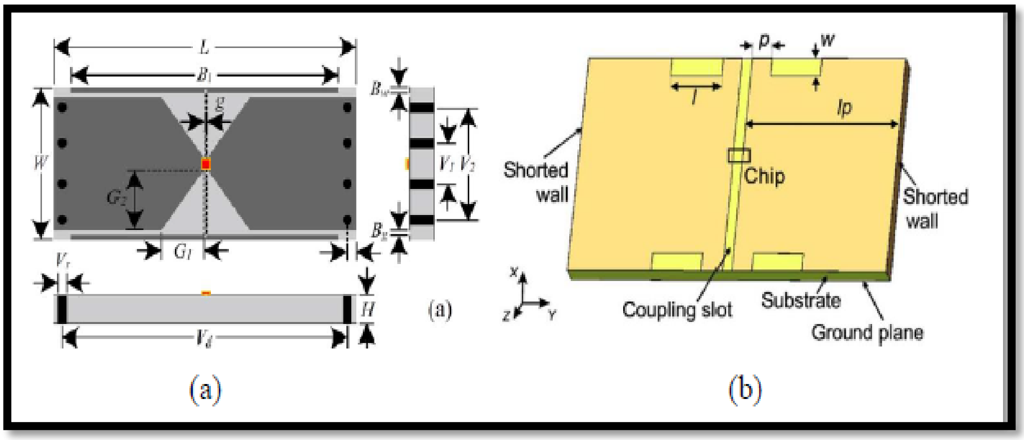

Fig. 2. Tags feed on the centre: (a) Bowtie tag as described by Lin *et al.,* [15] (b) As described by Polivka and Milan Svanda [16], a stepped impedance tag

Figure 3 illustrates the design proposed by Choo and Ryoo [22], between both the ground as well as the dipole, a protective intermediate decoupling layer is deployed. The actual dimensions are 95*25*3.6 mm3 and the read-range is 6.2 m when the EIRP is set to 4 W. In the approach suggested in [24], perpendicular bars are employed as an intermediary layer. These bars simultaneously protect and stimulate the tag's multi-resonant states.

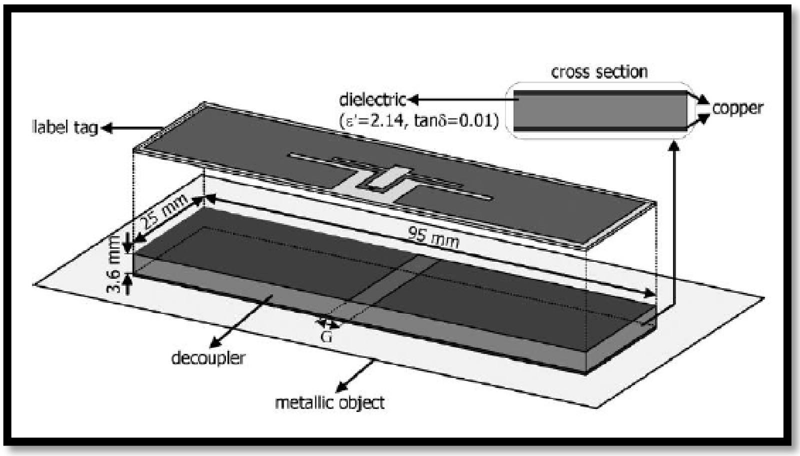

Fig. 3. A dipole tag protected by a decoupled presented by Choo and Ryoo [22]

The author of Genovesi and Monorchio [25] presented a three-arm folded dipole that could be matched to an RFID chip. Figure 4 illustrates the design's prototype 4(a). The author reduced the antenna's length by removing one of the dipole arms and attaching it to the ground through holes, as seen in Figure 4 [26,27].

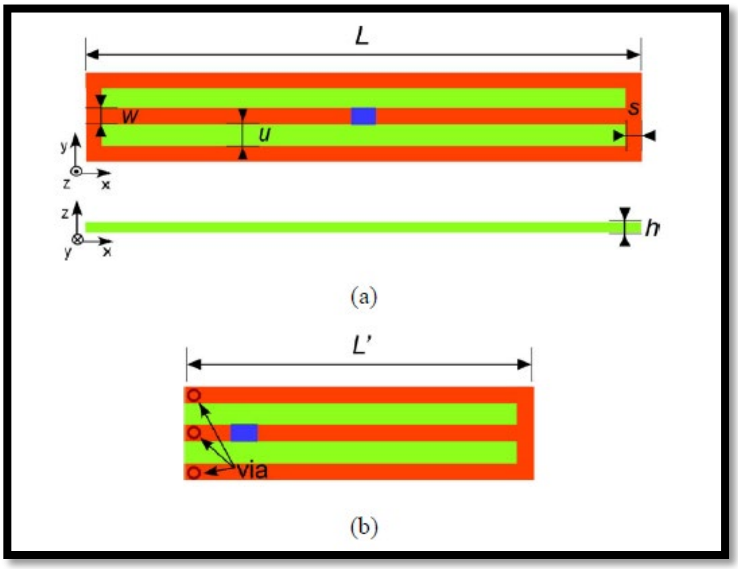

Fig. 4. A multiple-arm folded dipole (a) The fundamental design (b) Practical design introduced by Genovesi and Monorchio [25]

4.1 Comparison Study-Based on Design Structure

Table 1 compares different RFID antenna designs, highlighting their dimensions, radiation characteristics, operating frequency and read range. It shows that the choice of antenna design has a significant impact on the read range and reliability of RFID systems, with each design offering unique advantages and limitations.

Table 1
Summary of the main features of the selected design studies

Ref No.	Design structure	D (mm)	EIRP (W)	B (MHz)	RR (M)	Summary
[12]	T-matched folded dipole antenna	140×50×5	100×10^3	866.6	3	Antenna mounted perpendicularly on a conducting surface using ANSYS HFSS for simulations, but mismatched impedance with specified tag IC led to reduced reading range.
[14]	Multi-slotted tag antenna	50×50 ×1.6	-	916	5	Slots on patch antennas make the current travel further, making the antenna longer and lower in frequency.
[15]	Looped-bowtie type of RFID metal tag	68×30 ×3	0.4	860-960	3.3	Prototype has a read range of 3.0-3.3 m on metallic objects using 0.4 W EIRP radiation power, but it's not enough for vehicle tracking.
[16]	Stepped impedance shorted coupled-patches antenna	88×60 ×0.7	1	866	5.4	the paper introduces "stepped impedance patches" made of closely spaced slots for customizable impedance antennas analysed with CST.
[28]	Planar inverted-F antenna	59×59 ×3	0.5	869	4.3	Tag orientation affects reading reliability of the antenna, resulting in 50-60% radiation effectiveness despite suitable bandwidth and radiation characteristics.
[29]	Single-layer T-matched dipole antenna	28×13 ×1.5	4	880	2.65	A ceramic polymer substrate was used to make a small tag with better isolation, but it has a shorter read range compared to other tags.
[22]	A dipole tag protected by a decoupling layer	95×25 ×3.6	4	912	6.2	Antenna design suitable for RFID with some inconsistent results between simulation and testing.
[25]	Three-arm folded dipole	125×14× 1.5	2	868	5	Antenna patterns were made with CST software. The author removed an arm from the tag's antenna, connected it to the ground with holes and increased production cost.
[30]	Double-bowtie antenna	80.5×74.5×1.5	4	866	7.9	The loop triggers the two patches, which offer dual-band frequency responses suitable for use with UHF RFID, but with a maximum read range of 7.9m as per the experiment.

4.2 Comparison Study-Based on Monitoring Parameters in Agriculture

A discussion of the rise of smart agriculture, which aims to automate crop growing using new technologies such as RFID tags. RFID applications are compared in four areas of agriculture, including plant growth environments, soil quality/condition, plant life and harvest quality, all aimed at improving efficiency, yield and quality.

Table 2
Example of typical applications for chipless RFID sensors in the agriculture area

Measurands	Measurement-range	Sensitivity	Frequency-band	Read range
Temperature [31]	30-100$^\circ C$	0.3℃	135kHz	30cm
Moisture [32]	20-80%	2%	13.56MHz	-
Humidity [32]	20-80%	1%	13.56MHz	-

Table 3 summarizes different RFID technologies used in agriculture for environmental monitoring, soil conditions monitoring and harvest quality monitoring. It includes parameters, measurement range, sensitivity, technology type, frequency band and read range. Parameters measured range from temperature and humidity to soil salinity and pH. RFID tags with different frequency bands are used to measure these parameters. The table provides a concise overview of the various technologies used in agriculture to monitor different aspects of crop growth and health.

Table 3
Summarization of different RFID technologies used in the areas of agriculture

1. Environmental Monitoring					
Parameters	Measurement-range	Sensitivity	Technology-type (Sensor-type)	Frequency-band	Read-Range
Environmental Temperature [33]	0.3-59.6℃	1%	Chip-based RFID tag	860-960MHz	1.1m
Humidity [34]	55-90%RH	1.25%	IC integrated RFID tag	860MHz-1GHz	40cm
CO_2 [35]	1-400ppm	-	IC integrated RFID tag	2.45GHz	-
Oxygen level [36]	0-20ppm	0.5nA/%O_2	Chip-based RFID tag	300kHz-1GHz	-
Light intensity [34]	0-100lux	0.71lux	Chipless RFID tag	0.71GHz	10cm
2. Soil Conditions Monitoring					
Parameters	Measurement-range	Sensitivity	Technology-type (Sensor-type)	Frequency-band	Read-Range
Soil Temperature [37]	-25-100℃	15%	RFID tag	12.56MHz	40cm
Soil moisture [38]	-	2%	-	2.4GHz	1.2m
Soil salinity [39]	≥ 100℃/ ppm	.055g/L	Chip-based RFID tag	9.6MHz-1.1GHz	309.50mm
Soil pH [40]	pH4-10	pH7.7-7.8	Chipless RFID tag	3GHz-7GHz	-
3. Harvest Quality Monitoring					
Parameters	Measurement-range	Sensitivity	Technology-type (Sensor-type)	Frequency-band	Read-Range
Monitoring of Quality [41]	-40-105℃,30-100%RH	2.29%(temperature), 1.5%(humidity)	RFID tag	13.56MHz	0.3cm
Plant's temperature [42]	50-200℃	-	RFID tag	13.56MHz	-
Moisture [43]	7-40%RH	3%	Chipless RFID tag	915MHz	-
CO_2 [43]	0-100%	-	RFID tag	860-960MHz	-

5. Conclusion

RFID (Radio Frequency Identification) technology has the potential to revolutionize smart agriculture by providing automation, real-time monitoring and data-driven decision-making capabilities. By attaching RFID tags to objects such as plants and soil samples, farmers can improve resource optimization, crop health management, traceability and quality assurance in the agricultural sector.

In summary, the application of RFID technology in smart agriculture presents opportunities for resource optimization, crop health management, traceability and automation. Effective RFID antenna design is crucial for achieving reliable and consistent performance in agricultural applications. By leveraging RFID technology, farmers can enhance productivity, reduce costs, improve sustainability and meet the increasing demands of the global population.

Acknowledgement
This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot Q123). The authors would also like to thank the Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia for its support.

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