UNIVERSITY OF THE
WEST *of* SCOTLAND
UWS

UWS Academic Portal

Novel Approach Using Passive UHF RFID for Grain Moisture Detection

Ainaa Syamim Mohd Radzi[14], Latifah Munirah Kamarudin[14,] Latifah Mohamed[2], Ammar Zakaria[34], Mohd Hafiz Fazalul Rahiman[34], Syed Muhammad Mamduh Syed Zakaria[34], David Lorater Ndzi[5]

[1] Faculty of Electronic Engineering Technology, Universiti Malaysia Perlis (UniMAP), Arau 02600, Perlis, Malaysia
[2] Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Arau 02600, Perlis, Malaysia
[3] Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Arau 02600, Perlis, Malaysia
[4] Centre of Excellence for Advanced Sensor Technology (CEASTech), Universiti Malaysia Perlis (UniMAP), Arau 02600, Perlis, Malaysia
[5] School of Computing, Engineering and Physical Science, University of the West of Scotland Paisley, United Kingdom

```
ainaasyamim@studentmail.unimap.edu.my,latifahmunirah
@unimap.edu.my,latifah@unimap.edu.my,ammarzakaria@un
imap.edu.my,hafiz@unimap.edu.my,smmamduh@unimap.edu.
                  my,David.Ndzi@uws.ac.uk
```

Abstract. This paper proposes a novel method to detect moisture hotspots and irregularities in rice grain storage using low-cost passive UHF RFID technology. Experiments were designed with a UHF RFID handheld reader to test rice moisture levels of 12%, 16%, 20% and 24%. Two containers were used in the study where Container A was filled with grains with a 12% moisture level and container B is inserted into Container A and contains 2 kg rice samples of varying moisture contents. The RFID reader was positioned outside the container to measure the received signal strength indicator (RSSI) from the RFID tags placed within the containers. The attenuation of the signal is analyzed to obtain a correlation between moisture content (MC) and RSSI values. Results show a positive correlation between the RSSI and MC of rice which can be used to identify inconsistencies in moisture distribution in stored grain. An empirical model has been proposed which can be used to estimate RSSI values given the moisture content or vice versa for RFID operating at 915 MHz.

Keywords: Moisture Content (MC), UHF RFID Tag, RSSI, Rice

1   Introduction

Grain maintained at a moisture level of 14% or less can be stored for more than 6 months [1][2]. The most critical problems for safe grain storage are temperature and moisture content (MC). Fluctuations of temperature and humidity outside the storage container without aeration significantly affect grain conditions, resulting in the migration of moisture from one location to another [3]–[5]. Moisture migration causes mold and insect growth in high moisture areas, leading to deterioration in grain quality. For long-term storage, rice grain must be dried to lower moisture content, typically around 14%. As a result of moisture migration, the detection of MC changes in storage is challenging.

Researchers have carried out numerous studies to determine the moisture content of grains [6]–[10]. However, the methods often used are tedious, time-consuming and expensive [11]. Wireless moisture sensing techniques could be used to measure moisture content more efficiently using Radio Frequency (RF). The application of Radio Frequency Identification Technology (RFID) system may lead to wireless moisture sensing for different applications. Currently, there are no studies that use RFID technology in grain moisture detection. Most of the current RFID-based moisture sensing methods have difficulties identifying moisture changes in coarse grains and are less sensitive to the tag locations [12]. Thus, this paper proposes a novel method to detect moisture irregularities in rice grain in storage (silos) using passive ultrahigh-frequency (UHF) RFID technology.

2   Related Work

It is challenging to maintain the quality of rice grain in varying temperature and moisture conditions [13]. Most rice-growing regions have an equatorial climate with heavy rains, high temperature and humidity throughout the year. During seasonal transition periods, stored grains are at risk due to moisture migration within the grain mass. Moisture migration occurs when warm or cool conditions outside the storage bin create conditions for moisture convection inside the grain store [14]. This air and moisture movement caused by external temperature changes is most evident when there is a large mass of grain and large seasonal temperature changes. Localized moisture monitoring systems are often ineffective in detecting uneven moisture distribution.

Several methods proposed to determine the MC of grains can be classified as direct and indirect measurement techniques. Direct and indirect approaches can be used in a wide range of applications including laboratories, processing lines and in the field [15]. The direct method involves measuring weight loss by removing water from a sample and an indirect method utilizes electronic instruments to measure electric characteristics from which MC is determined [16]. Recently, research has focused on non-destructive moisture measurements based on electrical resistance [17], capacitance [18], microwave [19], Nuclear Magnetic Resonance (NMR) and Near-infrared spectroscopy

(NIR) [20] measurements. These methods provide reliable measurements and faster results. One drawback of these methods is that they can only be used for a small quantity of grain to approximate the moisture content of the grain in a storage container [11].

Recent developments have focused on sensing systems based on wireless moisture detection to ameliorate the drawbacks of existing methods. Some studies have identified that RFID technology could offer an appropriate solution in sensing applications. [21] and [22] showed that UHF RFID tags can act as moisture sensors because the tags can be read remotely when the tags buried at different depths in the soil to estimate the moisture content. This system provided a cost-effective and simpler installation at shallow depths. In [23], soil moisture sensing was developed based on UHF RFID tags for landslide monitoring. However, this solution has the limitation that it is ineffective in urban areas. Moreover, there are no studies that use RFID technology to detect grain moisture content. Hence, this paper proposes to detect moisture content through the use of RFID technology. This method measures the Received Signal Strength Indicator (RSSI) as a sensing metric to investigate the correlation between the radio frequency (RF) signal metric and MC of grains.

3   Experimental System

A UHF RFID system is composed of an RFID reader, antenna and RFID tag [12]. The RFID reader emits an RF signal at specific frequencies. Most commercial RFID readers offer three sensing parameters; Minimum Response Threshold (MRT), RSSI and phase. RSSI is used as a sensing parameter in this study.

3.1   UHF RFID handheld reader

Fig. 1. ORCA-50

The RFID handheld reader used is ORCA-50 which has a 3 dBi gain circularly polarised integrated antenna and operates in the 840-960 MHz frequency range [24]. This device is designed based on Impinj Indy R2000 chip and has a multi-tag identification ability.

3.2 UHF RFID tag

Fig. 2. PMT-06W UHF RFID tag

RFID tags are small and use power from the radio waves to transmit data to the RFID reader. Fig. 2 shows PMT-06W tags used in this study. PMT-06W tag provides stable readability when attached to a metallic surface and can be read at ranges up to 8 m depending on the TX power of the RFID reader [25].

3.3 Root Mean Square Error (RMSE)

RMSE is used to determine the accuracy of the fitted model to the data [26]. Generally, RMSE is defined as

$$RMSE = \frac{\sqrt{\sum_{i=1}^{n}(P_i - O_i)^2}}{n} \tag{1}$$

Where P_i is the predicted value, O_i is the obtained value and n is the total number. Note that the difference between the actual values and the predicted values is known as residuals.
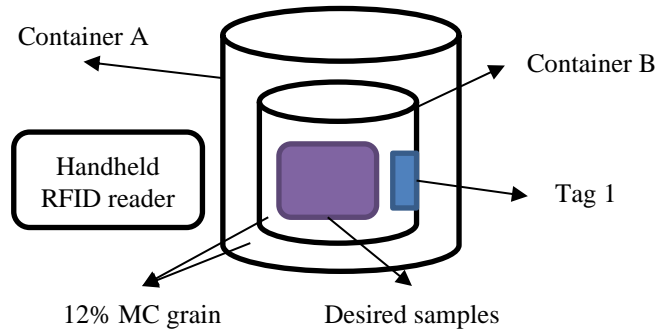
4 Design of Experiment

Fig. 3. Design of the experimental setup using UHF RFID handheld reader

Fig. 3 depicts the experimental setup used to measure the impact of varying moisture contents in stored rice using the UHF RFID reader and tag. The setup used two containers; container A was filled with rice that will have a fixed moisture content for all

measurements whilst container B was inserted into container A and surrounded by the rice in contain A. Container B will contain rice samples with the different moisture contents to simulate uneven moisture distribution in a rice silo. In the setup, a PMT-06W tag was attached to the wall of container B such that it was furthest from the RFID reader to ensure that the signal passes through the rice in both containers. The transmitted signal from the RFID reader is modulated by the RFID tag and radiates back to the reader which measures the RSSI. It should be noted that the received RSSI is the composite effect of forward and backward signal transmission through the medium (rice) and any influence from the environment (assumed to be constant for all measurements).

4.1   Grain Sample Preparation

Fig. 4. Grain samples of 2000g each

The initial MC of the rice samples was determined using a moisture meter. The average MC was 12%. Fig. 4 shows the rice samples which were divided into sample bags of 2 kg each. The samples were conditioned to three different moisture levels of 16, 20 and 24% using the following expression [27]:

$$M_w = \frac{W_i\left(M_f - M_i\right)}{100 - M_f} \tag{2}$$

In this equation, M_w is the mass of distilled water added (kg), W_i is the initial mass of sample (kg), M_i is the initial moisture content of the sample (% d.b) and M_f is the final moisture content of the sample (% d.b). To achieve the desired moisture level, distilled water was added using Eq. (2). The samples were poured into polyethylene bags and stored for days in a refrigerator at $4°C$ to ensure that the moisture was evenly distributed. Subsequently, the samples were stored at room temperature and the MC of each sample was measured using a moisture meter to ensure that they were 16, 20 and 24%. Due to the surrounding climate, the samples showed varying moisture levels in each experiment.

4.2   Experimented Setup

The setup consists of two plastic containers and one metal container being used as an enclosure. Two sets of measurements were conducted; one with the setup without metal container and another with the whole setup in a metal container, as shown in Fig.

5. The distance between the tag and the reader for containers A and B was set to 11.5 cm and 7.5 cm. For each sample, at fixed frequency and power settings, 20 RSSI measurements were taken.

Fig. 5. The experimental setup with metal (M) and without metal (WM) container.

5 Experimental Results

5.1 915 MHz at Different TX Power Level

For each rice sample, measurements were conducted with three TX power levels; 20, 25 and 30 dBm. Tag 1 is attached to container B in which the samples with different MC levels were placed. Fig. 6 shows plots of the average RSSI values against moisture content (with and without metal container) at 20, 25 and 30 dBm TX power. The average RSSI values show an increasing trend with increasing moisture content. Table 1 summarizes the average RSSI for the various MC levels at 915 MHz with varied TX power. In this study, RMSE and the R^2 values were used to measure the quality of the fitting. Table 2 presents the empirical equations which can be used to estimate the RSSI values (in dB) given the moisture contents (in percentage). The results show that whilst the RSSI values increased with an increase in the TX power, the increase is small. There are no significant differences between the results obtained with and without the metal container. Although the empirical equations have been presented separately in the table, the relationship between the RSSI and moisture content at 915 MHz can be approximated using the following equation;

$$RSSI_{(dB)} = 0.76 * MC_\% - 59.35 \tag{3}$$

It is worth noting that the value of -59.35 may be influenced by changes in TX power and therefore may increase or decrease. Moreover, the measured RSSI values also depend on the distance between the tag and the reader. Care would therefore need to be exercised to ensure that it is above the noise floor of the reader.

Table 1. RSSI value of tag 1

Two Approaches	Moisture Content (%)	Average RSSI (dBm)		
		Power (dBm)		
		20	25	30
Metal Container (M)	12	-50.5	-48.5	-44
	16	-46.5	-42.5	-40
	20	-44.5	-41	-37.5
	24	-41	-37	-34
Without Metal Container (WM)	12	-49.5	-46.5	-39
	16	-49	-45.5	-40
	20	-47	-42	-37
	24	-40.5	-36.5	-32.5

Table 2. Empirical Equations for Different TX Power Level

Power (dBm)	Setups	Empirical Model	R-Intercept (R²)	RMSE
20	Metal Container (M)	$y = 0.76x - 59.35$	0.98	0.54
	Without Metal Container (WM)	$y = 0.72x - 59.55$	0.81	2.12
25	Metal Container (M)	$y = 0.90x - 58.45$	0.94	1.03
	Without Metal Container (WM)	$y = 0.83x - 57.70$	0.91	1.34
30	Metal Container (M)	$y = 0.81x - 53.50$	0.99	0.37
	Without Metal Container (WM)	$y = 0.56x - 47.25$	0.76	2.49

a) RSSI vs MC at 20dBm
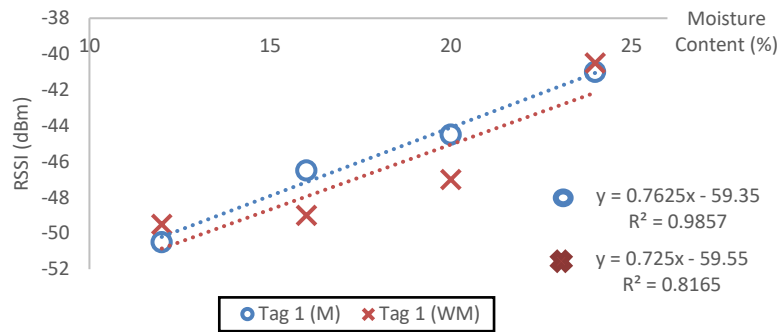
b)   RSSI vs MC at 25dBm
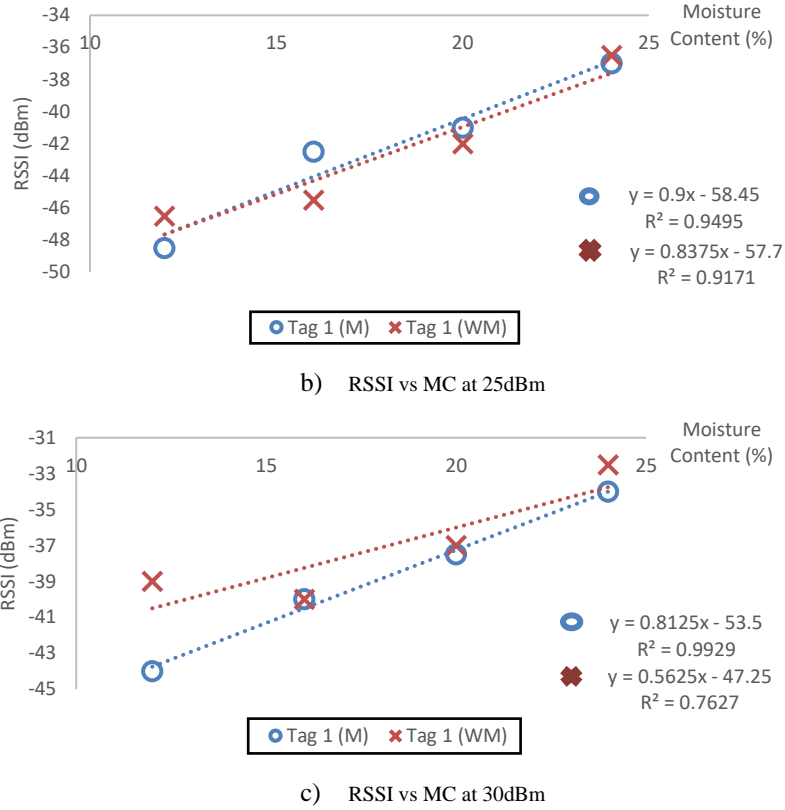

c)   RSSI vs MC at 30dBm

Fig. 6. Average RSSI vs MC of Tag 1 with (M) and without (WM) metal container at 915MHz

5.2   Impact of Frequency on RSSI

Tests were conducted to evaluate the impact of frequency on RSSI. The MC of the samples used for 915, 916, 917, 918 and 919 MHz measurements were 12%, 16%, 20% and 24%. The TX power was set to 30 dBm for all measurements. Fig. 7(a) and (b) present RSSI values for individual frequencies. In both approaches, RSSI values increase as the moisture contents increases. Table 3 summarizes the average RSSI values for all frequencies.

Table 3. RSSI Tag 1 for the individual frequency at 30dBm
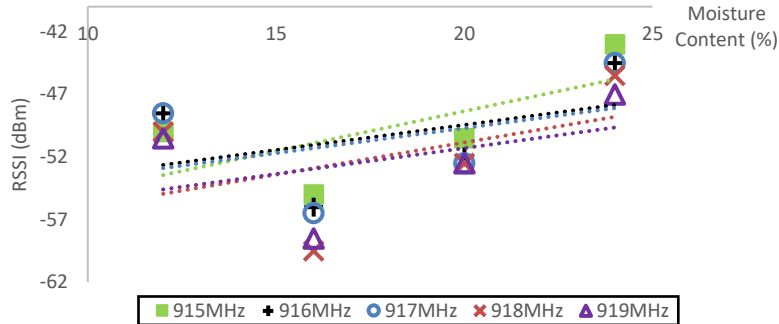
Frequency Range (MHz)	Moisture Content (%)	Average RSSI (dBm)	
		Metal (M)	Without Metal (WM)
	12	-50	-50
915	16	-52	-55
	20	-41.5	-50.5
	24	-32.5	-43

	12	-57	-48.5
916	16	-59	-56
	20	-39.5	-52
	24	-33.5	-44.5
	12	-78.5	-48.5
917	16	-57	-56.5
	20	-50.5	-52.5
	24	-34	-44.5
	12	-65.5	-50
918	16	-72.5	-59.5
	20	-62	-52.5
	24	-47.5	-45.5
	12	-66	-50.5
919	16	-72	-58.5
	20	-60.5	-52.5
	24	-48.5	-47

From Fig. 7 and Table 3, the results and trends of RSSI with varying moisture content are not consistent, except for measurements conducted at 915 MHz. There is greater consistency in the results with the metal container for the other frequency than without. Further investigations are required to ascertain the reasons. Overall, the increase in RSSI values with increasing moisture contents could be attributed to surface propagation of radio waves in a wet medium compared to scattering when the media is dry. Surface waves experience lesser attenuation than scattered waves.
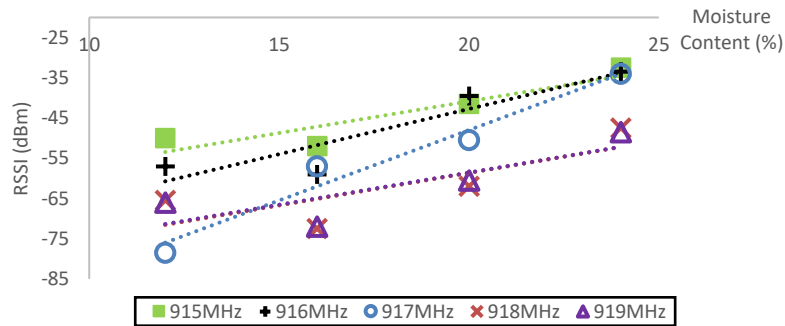
a) RSSI vs MC with metal (M) container

b) RSSI vs MC without metal (WM) container

Fig. 7. Average RSSI at the individual frequency

6 Conclusions

For agriculture, the moisture content of grain is very important to maintain the quality long-term. This study has focused on investigating RF signal attenuation at different rice moisture levels using UHF RFID. Generally, silos are the largest storage containers that contain moisture hotspots and irregularities in rice grain storage. As this is the first method using RFID technology in detecting the moisture content of rice grain, two plastic containers were used instead of silos. A metal container was used to investigate the impact reflected signals on RSSI values measured by a handheld RFID reader. This knowledge is deemed important because the practical implementation of the technique proposed and studied in this paper will involve measuring in silos that may be made of metal. Based on Fig. 6 and 7, the RSSI shows a positive correlation and linear pattern with moisture contents. This also shows that RSSI can be used to detect irregularities in stored rice grain by comparing values with benchmarked figures. Using root mean square error (RMSE) and R^2 to assess the quality of fitted curves, an empirical model has been proposed that allows RSSI values or moisture contents of rice to be estimated at 915 MHz. The study has also revealed the impact of TX power on measurement results indicating that the range needs to be balanced against TX power to ensure that there is a sufficient signal-to-noise ratio of the returned signal. However, this method requires more experiments to improve the system for detecting moisture content.

7 Acknowledgement

References

[1] K. N. H. Terry J. Siebenmorgen, "Impacts of Delayed Drying on Discoloration and Functionality of Rice Kathryn N. Haydon 1 and Terry J. Siebenmorgen 1,2," pp. 1–28, 2017.

[2] "Grain storage - IRRI Rice Knowledge Bank." http://www.knowledgebank.irri.org/training/fact-sheets/postharvest-management/storage-fact-sheet-category/item/grain-storage-fact-sheet?tmpl=component&print=1 (accessed Jan. 27, 2021).

[3] R. L. Croissant, "Managing Stored Grain," *Crop Ser. Prod.*, vol. no. 0.117, no. 1987, p. 4, 1987.

[4] M. T. Talbot, "Moisture Migration in Stored Grains 1," pp. 1–3, 2002.

[5] T. W. A. Guide, "The WA Guide to High Moisture Harvest Management , Grain Storage and Handling," *East*.

[6] N. A. M. Ramli, M. H. F. Rahiman, L. M. Kamarudin, A. Zakaria, and L. Mohamed, "A Review on Frequency Selection in Grain Moisture Content Detection," in *IOP Conference Series: Materials Science and Engineering*, Dec. 2019, vol. 705, no. 1, doi: 10.1088/1757-899X/705/1/012002.

[7] M. S. M. Abdullah, M. H. F. Rahiman, A. Zakaria, L. M. Kamarudin, and L. Mohamed, "A Review on Moisture Measurement Technique in Agricultural Silos," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 705, no. 1, 2019, doi: 10.1088/1757-899X/705/1/012001.

[8] A. A. Almaleeh *et al.*, "A Review on the efficiency and accuracy of localization of moisture distributions sensing in agricultural silos," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 705, no. 1, 2019, doi: 10.1088/1757-899X/705/1/012054.

[9] M. S. M. Abdullah, L. M. Kamarudin, M. H. F. Rahiman, M. H. F. Rahiman, L. Mohamed, and A. Zakaria, "Simulation of Radio Tomographic Imaging for Measurement Rice Moisture Content," no. August, pp. 62–67, 2020, doi: 10.1109/iccsce50387.2020.9204958.

[10] N. Azmi, L. M. Kamarudin, L. Mohamed, A. Zakaria, M. H. F. Rahiman, and N. A. Abdul Latiff, "Influence of moisture content in rice on radio signal strength indicator readings at 2.4GHz," Jul. 2019, doi: 10.1109/SENSORSNANO44414.2019.8940086.

[11] D. K. Nath and P. Ramanathan, "Non-destructive methods for the measurement of moisture contents - A review," *Sensor Review*, vol. 37, no. 1. Emerald Group Publishing Ltd., pp. 71–77, 2017, doi: 10.1108/SR-01-2016-0032.

[12] J. Wang, L. Chang, S. Aggarwal, O. Abari, and S. Keshav, "Soil moisture sensing with commodity RFID systems," *MobiSys 2020 - Proc. 18th Int. Conf. Mob. Syst. Appl. Serv.*, pp. 273–285, 2020, doi: 10.1145/3386901.3388940.

[13] "Storing Grain Outside This Fall? Keep It Dry & Cool." https://www.agriculture.com/news/crops/sting-grain-outside-this-fall-keep-it_2-ar45050 (accessed Jan. 27, 2021).

[14] P. Hansen, B. C.- Crop, and P. Ks, "In- In -sitú measurement of moisture in stored commodities."

[15] M. Vera Zambrano, B. Dutta, D. G. Mercer, H. L. MacLean, and M. F. Touchie, "Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review," *Trends Food Sci. Technol.*, vol. 88,

no. April, pp. 484–496, 2019, doi: 10.1016/j.tifs.2019.04.006.

[16]   M. M. Content, C. Quality, and M. Formation, "Determination of Moisture Content 1.," pp. 1–6, 2015.

[17]   S. S. Lawal, K. C. Bala, and M. B. Adeyemi, "Development of resistance type moisture measuring device for grains," *Leonardo Electron. J. Pract. Technol.*, no. 30, pp. 255–268, 2017.

[18]   W. Ponglangka, "Paddy rice moisture content meter," *ICCAS 2015 - 2015 15th Int. Conf. Control. Autom. Syst. Proc.*, no. lCCAS, pp. 1709–1713, 2015, doi: 10.1109/ICCAS.2015.7364632.

[19]   T. K. Bhuiya, T. Upadhyay, S. Thakur, and R. Harsh, "Design and development of microwave based moisture measurement system," in *IEEE MTT-S International Microwave and RF Conference 2015, IMaRC 2015*, Feb. 2016, pp. 192–195, doi: 10.1109/IMaRC.2015.7411427.

[20]   C. V. K. Kandala, G. Konda Naganathan, and J. Subbiah, "NIR reflectance method to determine moisture content in food products," *Reflection, Scatt. Diffr. from Surfaces*, vol. 7065, no. August, p. 70650U, 2008, doi: 10.1117/12.793267.

[21]   R. Aroca, A. Hernandes, D. Magalhães, M. Becker, C. Vaz, and A. Calbo, "Application of Standard EPC/GEN2 UHF RFID Tags as Soil Moisture Sensors," *Proceedings*, vol. 1, no. 2, p. 10, 2016, doi: 10.3390/ecsa-3-s5001.

[22]   R. V. Aroca, A. C. Hernandes, D. V. Magalhães, M. Becker, C. M. P. Vaz, and A. G. Calbo, "Calibration of Passive UHF RFID Tags Using Neural Networks to Measure Soil Moisture," *J. Sensors*, vol. 2018, 2018, doi: 10.1155/2018/3436503.

[23]   S. F. Pichorim, N. J. Gomes, and J. C. Batchelor, "Two solutions of soil moisture sensing with rfid for landslide monitoring," *Sensors (Switzerland)*, vol. 18, no. 2, pp. 14–16, 2018, doi: 10.3390/s18020452.

[24]   "Product_Shenzhen RodinBell Technology Co., Ltd. Guangdong." http://www.rodinbell.com/en/ProductDetail.html?ID=12423 (accessed May 17, 2021).

[25]   N. Azmi *et al.*, "Rf-based moisture content determination in rice using machine learning techniques," *Sensors*, vol. 21, no. 5, pp. 1–20, 2021, doi: 10.3390/s21051875.

[26]   G. Mahesh, D. Balachander, and T. R. Rao, "RF propagation measurements in agricultural fields for Wireless Sensor Communications," *Proc. IEEE Int. Conf. Circuit, Power Comput. Technol. ICCPCT 2013*, pp. 808–812, 2013, doi: 10.1109/ICCPCT.2013.6528846.

[27]   A. Hossein Mirzabe, M. Barati kakolaki, B. Abouali, and R. Sadin, "Evaluation of some engineering properties of cucumber (Cucumis sativus L.) seeds and kernels based on image processing," *Inf. Process. Agric.*, vol. 4, no. 4, pp. 300–315, 2017, doi: 10.1016/j.inpa.2017.07.001.