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To cite this article: A A Almaleeh *et al* 2021 *J. Phys.: Conf. Ser.* **2107** 012059

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RF signal calibration for improvement of 3D mapping image to locate moisture distribution in rice silo

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Abstract. Grain storage is an important part of the post-harvest quality assurance process. The moisture level of the grains during storage is one of the primary problems. The current method of measuring rice grain moisture content is based on random sampling, which is relatively localised, and there is no real-time moisture content measurement available. The RF signal was used to build a new technique for detecting moisture and its presence in rice in real-time in this paper. The mapping of an RF signal, in particular, can be transformed into volumetric tomographic images that can be used to forecast moisture distribution.

1. Introduction

Moisture determination has been a major issue in several industrial sectors, particularly grain storage facilities, for many years. In silos, moisture content is defined as the weight of water given as a percentage. Moisture measuring equipment should be used to determine grain moisture content (MC) in real time. An anaerobic chamber allows for moisture control while also inspecting the product's quality. The moisture measurement for Wi-Fi signals is based on the grain carrier's high water permittivity, as well as the use of grain properties and frequency characteristics, i.e.

The relaxation process in polar liquids and its lack of dependency on ionic conductivity [1], It also ensures a simple automatic method of production process control, with excellent sensitivity under harsh environmental and industrial situations. Based on grab sampling [2] [3] [4] and individual random single [5] or multi-point measurements [6], some researchers used capacitive sensors [7], and others used microwave technique that uses high frequency [8] [9] [10]. Unfortunately, the antenna's orientation has a significant impact on the measurement's accuracy and sensitivity in both procedures. The 2.4 GHz Wi-Fi signal is non-hazardous and quicker. Dust and water vapour, which have a negative impact on infrared readings, have no effect on Wi-Fi transmissions [4].

To handle the linked difficulties of real-time localization and measurement of grain moisture content, non-destructive measurement techniques based on Wi-Fi signals must be developed.

This study is being piloted to see if there is a good way to quantify the efficiency and accuracy of moisture distribution sensing localization in rice. This was attempted in two experiments; where the first experiment was conducted to demonstrate on how the existence of moisture content in rice has



affected the Wi-Fi 2.4 GHz signal values. In contrast, the second experiment showed that the mapping of the RF signal could be mapped into volumetric tomographic images, which can be used to predict the moisture distribution.

2. Background

This part will cover the history and theory of radio-frequency localization methods, as well as the backdrop of radio tomographic imaging. Because Wi-Fi is also radio signals, the ideas used in this study are the same as those used in radio tomography imaging. It is also clear that using Wireless and Sensor Networks (WSN) for tomographic imaging is efficient, cost-effective, precise, and easy.

2.1. Received Signal Strength Indicator (RSSI)

The RSSI circuit calculates the receiver's received signal intensity, which is shown by the RSSI circuit. RSS-based localization systems do not require additional hardware because most sensors already have an RSSI circuit built in. The decibel (dB) unit is commonly used to measure RSSI.

2.2. Linear Formulation

The network's physical area is used for the communication between the wireless nodes and the radio signals. An object might absorb, reproduce, alter or scatter some of the transmitting power within this area. Using radio signal power attenuation, the RTI system tries to produce a cross-sectional picture vector of a region. A shadowing-based picture vector [11] was the most often utilised method in prior research. Each radio link is modelled as an ellipse, with focus points at the sender and recipient nodes [11][12]. Any physical object within such an elliptical zone is deemed to be obstructing the relevant radio link, causing signal attenuation.

The final solution for image construction using conventional Least Squares [11] can be written as:

$$X = (W^T W + \alpha (D_X^T D_X + D_Y^T D_Y))^{-1} W_Y^T \quad (1)$$

In Eq. 1, Where Y is the vector containing all of the distinct link RSS data, X is the attenuation picture to be estimated, W is the weight matrix, DX and DY are the horizontal and vertical operators, and T is the operator's time [11].

2.3. Wi-Fi Signal Moisture Measurement

Wi-Fi Signal moisture measurement is based on the high absorption of radio waves with a frequency near 2.4 GHz when compared to the carrier material, as well as the use of frequency characteristics of material properties such as the relaxation process in polar liquids and the lack of ionic conductivity dependence.

3. Hardware Component

One ESP-12F with three LEDs makes up the hardware component. As seen in figure 1. The power LED is one, while the TX and RX LEDs are the other two. The LED illuminates when the node is in communication with the access point. For this experiment, a total of 16 nodes were employed.

4. SAMPLE MOISTENING

Rice should be kept at a safe moisture content of 14 to 16 percent [13]. The moisture level of rice samples was raised in this study using the moistening approach utilised in earlier studies [14] [15] [16]. By adding a specific amount of distilled water Q as estimated from Eq. 2, a sample with high moisture content can be obtained.

$$Q = W_i(M_d - M_i) / ((100 - M_d)) \% \text{ wb} \quad (2)$$

Wi: Initial mass of the sample in kg, Mi: Initial moisture content of sample as % wb. Md: Desired moisture content of the sample in % wb. Q: Mass of water to be added in kg. Grain moisture content is often measured on a wet basis (wb) [17].

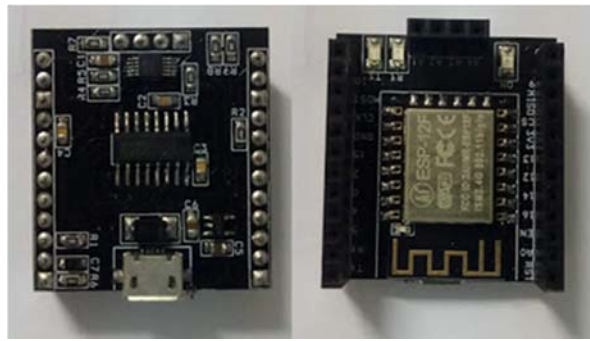


Figure 1. The Wi-Fi node's hardware implementation

Using this formula, the bag sample had 250g of rice in it, and the rice sample was wet. The initial moisture content of each sample was measured using a commercial moisture metre (Meter OGA TA-5) to moisten it. Once this is done and the initial weight of the samples is known, the amount of distilled water (Q) needed to moisten the samples can be estimated using the method given in Eq. (2). The needed amount of distilled water was then added to each sample, and the polyethylene bags were then resealed. The samples were then kept moist for 72 hours at a temperature between 4 and 6 °C to ensure even water distribution [18]. The samples were brought to room temperature ten hours before the experiment. Bag samples are depicted in figure 2.



Figure 2. Sample of the rice bags with the high moisture ratios

5. Experiment

5.1. Single Column 1D-Measurement

This experiment was carried out to show that the presence of moisture in rice has an impact on Wi-Fi RSSI values.

In this experiment, two ESP-12F modules were employed as senders and receivers, as illustrated in figure 3.a. The test container is made from (Acrylic board). With a length of 100 cm and a width of 10 cm, one transmitter and one receiver are installed out on the ends of the container.

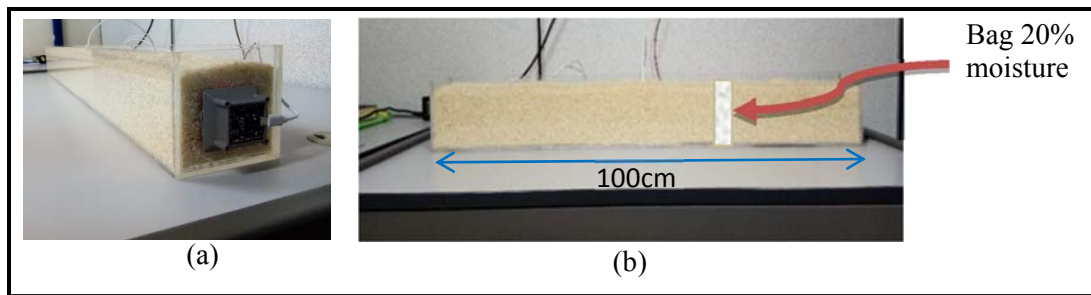


Figure 3. Location of the Sample bag in the test container within the network

In the first experimental testing process for testing with a normal rice sample (14% natural moisture [13]). The rice sample was placed at a height of 10 cm in the test container, in the centre of the transmitter and receiver. In the second experiment, three bags of rice samples were prepared, and there were increased moisture ratios to 20%, 25%, and 30% (as described earlier), as shown in the figure 3.b. The rice bag samples were placed in the container in random places, as shown in the example in figure 3. b. Initially, data was collected with one bag, then with two bags, and preceded until data was collected with three bags. RSSI measurements were taken every time for a period of 20 minutes, as shown in figure 4.

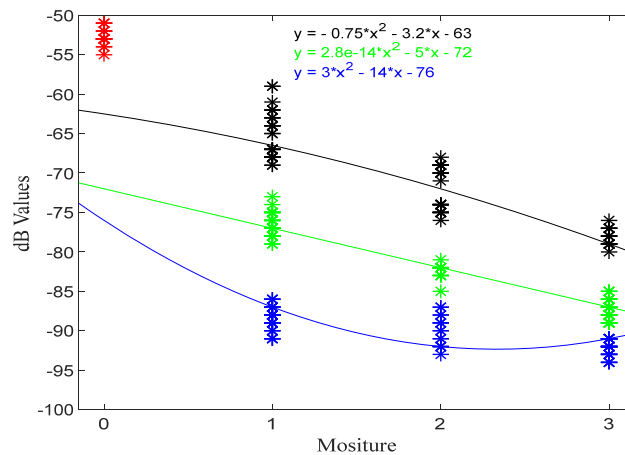


Figure 4. The impact of various moisture ratios and amounts on Wi-Fi RSSI values

Wi-Fi RSSI values were discovered to be affected by varied moisture ratios and quantity by plotting the gathered data as shown in figure 4. (Number of bags used). Therefore it can be concluded that the moisture content in rice affects the decrease in the RSSI measurements.

5.2. 2D Area Measurement

In this experiment, 16 nodes of ESP-12F modules were used as the transceivers. The test container was developed as a square of 50X50cm and 60cm high. The rice sample was placed in the test container at a height of 50cm. All ESPs were installed out of the container at 25cm height. 4 ESPs on every side with the distance between any two nodes set to be 10cm, as shown in figure 5.

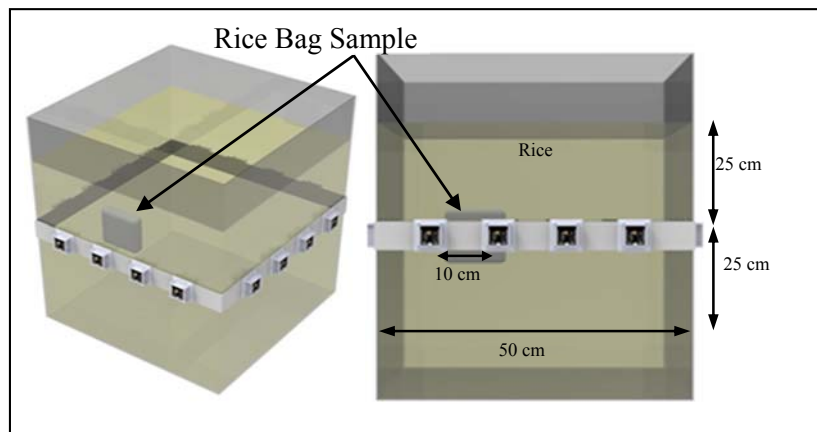


Figure 5. 3D dimensions of the system

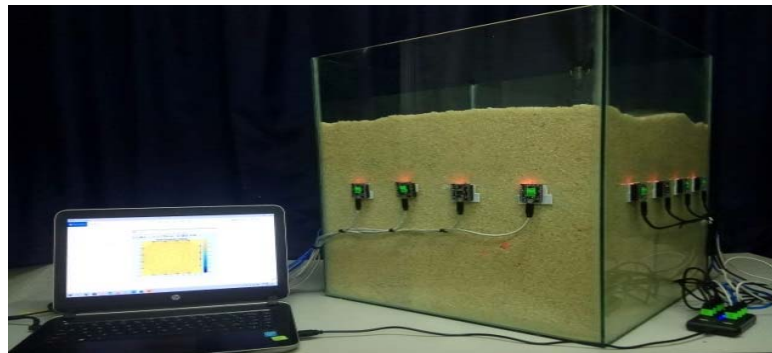


Figure 6. The container with rice and 16 ESP nodes

All the ESP nodes were connected directly to the PC through USB-Hub shown in figure 6. Power was provided to the nodes, and they were made ready to gather data.

A peer-to-peer network was used to conduct the FR signal. The first data set was obtained with rice containing 14% moisture within the network area. Figure 8. Shows the rice which is empty from high moisture. The bag sample was then placed in the rice container at the same level as the measured RSSI values in the network region, as shown in figure 5, and figure 7. Every minute, the ESP would check for RSSI readings. MATLAB was used to read the data directly. Approximately 100 lines of data were collected.

The mean-based filtering technique was utilised in this study, and the mean was calculated by analysing the measurements taken during the experiment. The generic high-moisture model was constructed by taking into account all of the obtained threshold values. This experiment's steps are depicted in diagram figure 9.

The link difference RSSI measurement Δy can be stated as in Eq. 3 when Δd is the attenuation image, Δy is all distinct links RSSI measurements, n is a noise vector, and W is the weighting matrix.

6. Evaluation of the Results

This section will analyse the research findings, and because this is an image-based study, a user evaluation is the most appropriate method. However, the findings are analysed using an RF signal mapping approach due to its practicality.

As seen on the surfaces of figure 7, inside the network area measured RSSI values, there are many small high voxels that are disturbing the signal from the rice. Figure 8, Shows the result after comparing D1 and D2; the rice disturbing has been canceled and only raises the moisture content area.

The voxels that are crossed by RF signal and have high moisture content are higher than voxels that have less moisture or normal moisture content.

$$\Delta y = W \Delta d + n \quad (3)$$

In this experiment, three different moisture ratio samples were placed in random places, and plotting images as shown in figure 10.

7. Conclusion

The baseline knowledge of the RF signal tomographic imaging achieved by moisture distribution in rice is introduced in this study work. Accuracy improvement solutions now in use have been found to be totally hardware-based and to cost a large amount of CPU power. Our research article includes a robust statistical methodology to improve accuracy. The creation of moisture detection and its presence in rice with a real-time RF signal, as well as the measurement of area moisture content, are two major accomplishments in this research arena.

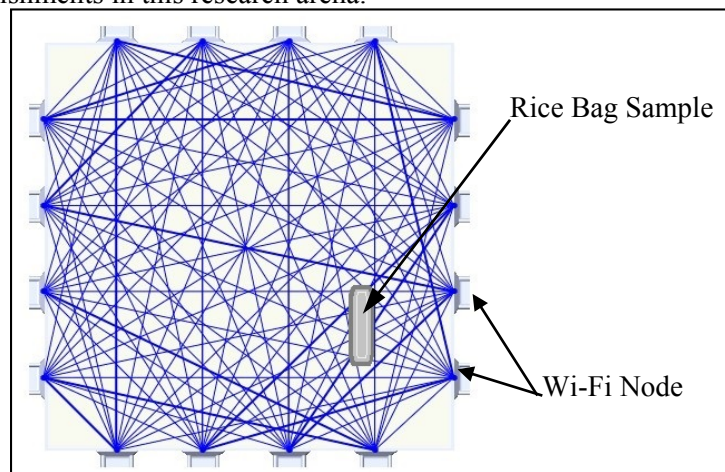


Figure 7. Illustrates the topology of the RF signal links

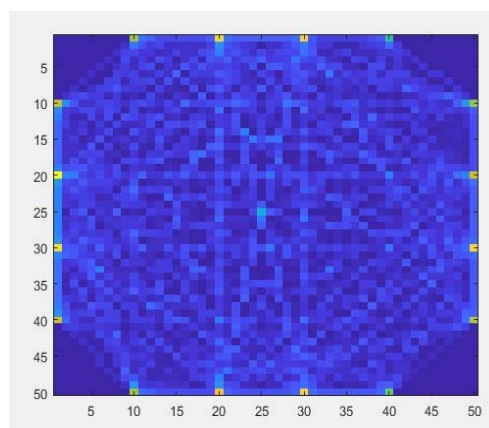


Figure 8. RF network with rice 14% moisture

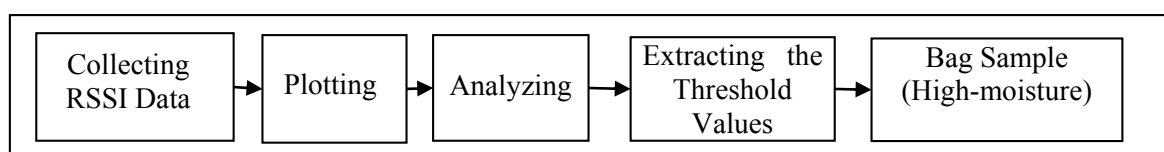


Figure 9. Low diagram of the high-moisture model building process.

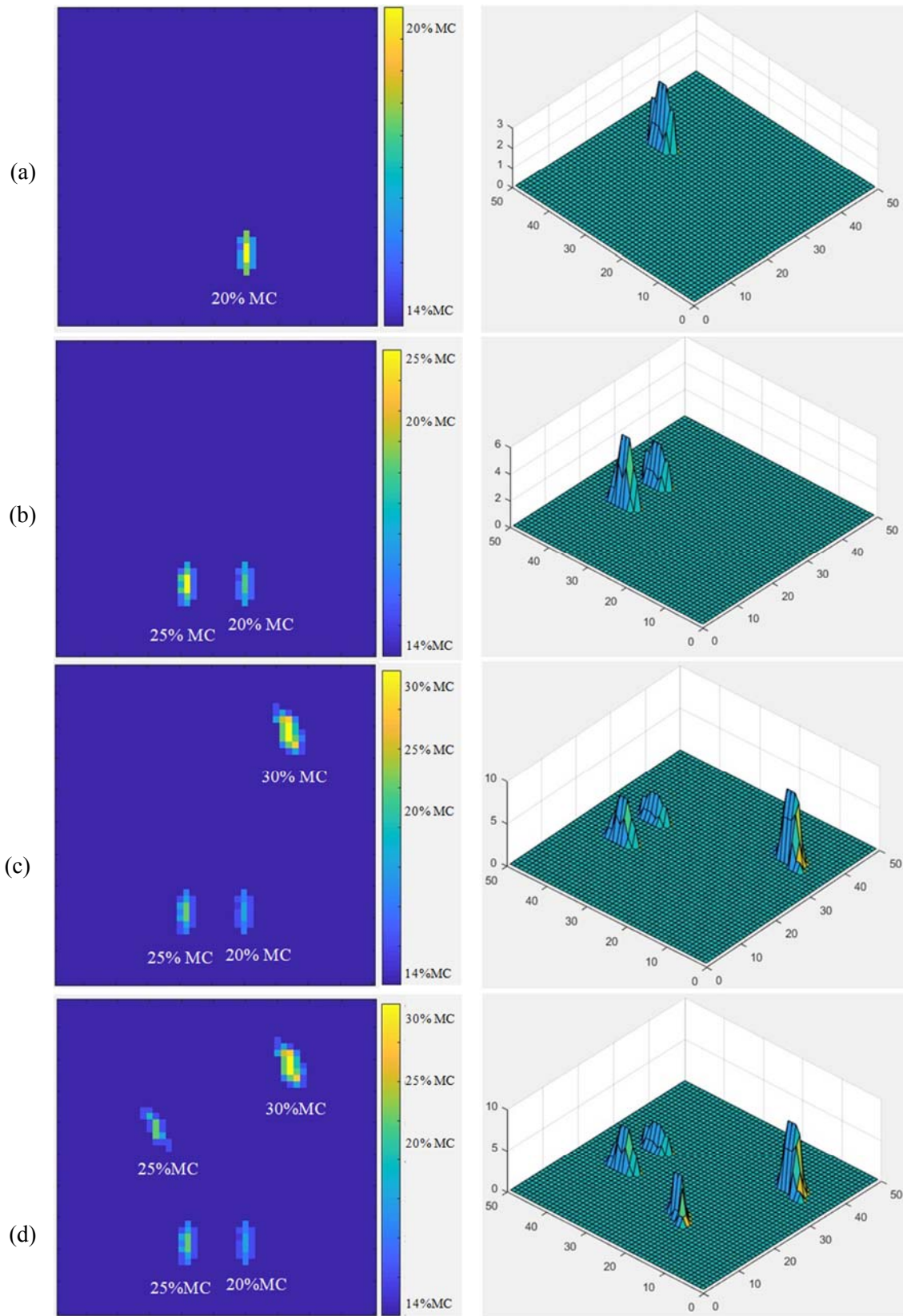


Figure 10. Experiment (a) test one Bag 20% MC. Experiment (b) test two Bags 20% MC and 25% MC. Experiment (c) test three Bags 20% MC, 25% MC and 30% MC. Experiment (d) test four Bags 20% MC, 25% MC, 25% MC and 20% M

Acknowledgements

The above Research was supported by the Ministry of Education (MOE) through Fundamental Research Grant Scheme (Ref: TRGS/1/2018/UNIMAP/02/4/3) with the title: Intelligent machine learning technique for predicting the moisture distribution and providing quantification assessment using Deep Convolutional Neural Network. The authors also thank the Government of Malaysia and Universiti Malaysia Perlis (UniMAP) for the facilities and technical support, and also the authors would like to congratulate IPMA Sdn. Bhd. for providing technical knowhow and access to the equipment for this research work.

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