IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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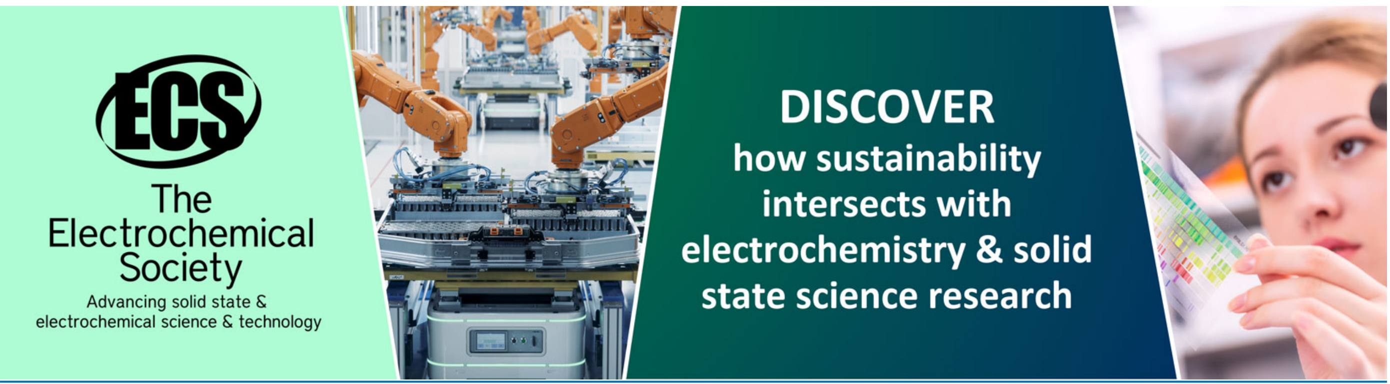
To cite this article: A A Almaleeh *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **705** 012054





# A Review on the efficiency and accuracy of localization of moisture distributions sensing in agricultural silos

**A A Almaleeh[1], A Zakaria[1, a], S M M S Zakaria[2], L M Kamarudin[3], M H F Rahiman[4,] A S A Sukor[1], Y A Rahim[5] and A H Adom[1]**

[1]Centre of Excellence for Advanced Sensor Technology (CEASTech), Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[2]School of Microelectronic Engineering; Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[3] School of Computer and Communications Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[4]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[5]School of Manufacturing Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

Email: ammarzakaria@unimap.edu.my

**Abstract**. The moisture distribution in the silos depends upon various seeds parameters such as type and size of seeds, amount of storage, external weather, and storage period as well as structural and environmental factors. It is very difficult to predict moisture distribution in silos effectively while taking all the above aspects into consideration. This study aims to investigate the efficiency and accuracy of localization of moisture distributions sensing in agricultural silo. The work is mainly focussed on three major elements: Radio Frequency (RF), tomographic imaging and classification process using machine learning. In particular, RF-based signal and volume tomographic images are used to predict the moisture distribution. Furthermore, computational intelligence techniques such as artificial neural network (ANN) is applied to develop models based on previous data. The generalization of these models towards new set of data is discussed in making sure a successful application of a model. A detailed study of the relative performance of computational intelligence techniques has been carried out based on different statistical performance criteria.

***Keywords.*** *Radio-frequency, Microwave energy, artificial neural network, Moisture Measurement.*

## 1. Introduction

Moisture determination has been a major problem in many branches of store grain for many years particularly in the agricultural silos. Accurate moisture determination testing in silos is very important in managing and selling paddy and grain. This is because each grain has a completely different ideal moisture determination. Inaccurate Moisture determination measurements will lead to lower head grain. Once milled at wrong moisture content, it will endure additional drying cost and loss of quality especially when the paddy is dried too much. Furthermore, if the grain is just too wet in storage, harvested paddy will become wetter than necessary and this can contribute to the loss in profit when the paddy is sold. Therefore, it is important to develop moisture measurement systems to determine exact moisture content (MC).

Radio Frequency (RF) based volume tomography is considerably a quite new and challenging area, especially for non-invasive 3D imaging technologies which the primarily concept idea is adopted from Electrical Capacitance Volume Tomography [1]. In conventional electrical capacitance tomography, the measured capacitance will be placed between plates combinations. Then, it is used to reconstruct 2D images of moisture distribution. Similarly, RF based volume tomography are also constructed to have multiple layers of antenna measuring different attenuation of the transmitted signal. To reconstruct 2D images, the multi-path or diffraction of the signal from the silo walls is considered as a source of distortion to the final reconstructed images. Time of Arrival approaches may be able to mitigate the effect of distortion. However, it may not be true for all conditions. When grain samples have different layers of moisture, 2D image reconstruction can be quite complicated.

3D tomography reconstruction can also be accomplished by stacking frames from a sequence of time intervals of measurements. However, the volumetric profile of the dielectric distribution (in this case will be based on the signal attenuation), may be incoherent due to difference of grain size, shape, and etc. Various challenges remain associated with such reconstruction and need to be handled intelligently. Baseline measurements need to be captured prior to the assessment or handled properly during the tomography imaging. However, when comes to the actual implementation, these baseline information may not be available or difficult to obtain. To counter these issues, the mapping process could incorporate or employ intelligent machine learning approaches.

This study aims to investigate suitable approaches that can measure efficiency and accuracy of localization of moisture distributions sensing in agricultural silo. This is done in three parts, where the first part reviews RF frequency operating at microwave band that gives the best response towards moisture content sensing at different temperature, humidity and grain type. Then, using tomography approach to assess the non-linear image reconstruction accuracy to examine moisture distribution in the silo. Finally, using intelligent machine learning techniques to measure and quantify the distribution of moisture level of rice grain in silo storage using the ANN models. This would benefit the agricultural sector in securing the food storage for the country and help to reduce damages of grain in the silos.

## 2. Radio Frequency Signal

Radio-frequency (RF) technique is basically principles are described for mistreatment including high frequencies and microwaves insulator properties, or permittivity, of grain for sensing moisture, or permittivity, of grain for sensing moisture through their correlation with moisture content. As a result of high correlations that occur at any frequencies between insulator properties of grain and quantity of water gift within the grain, the radio frequencies are useful in fast and non-destructive sensing of moisture content. Most of those dielectric-type moisture meters use frequencies within the range between about 1-20 MHz. After which the attenuation and phase shift were perceived to be functions of moisture content, grian hulk density, and temperature, illustrated that the determinations of temperature-compensated and density-independent moisture content were acquired with 15.2 GHz measurements on shelled corn [2].

Nearly 50 years ago, the permittivity of grain were obtained through the first quantitative data in the 1–50-MHz frequency range [3], [4]. At both lower and higher frequencies, measurements on grain samples were developed on techniques for dielectric proper-ties [5] [6]. More than 25 years ago, studies explicates the first report regarding data on dielectric properties of grain at microwave frequencies [7] [8]. Several sort of grain and soybeans were developed into models, covering wide frequency ranges [9] [10]. Even in recent times, there have been availability of additional data with respect to the function of moisture content, bulk density, and temperature on the dielectric properties of grain [11] [12]. There have been development of reviews recently publishes covering the RF range below 1 GHz [13] and at microwave frequencies in instrumentation for sensing moisture in cereal grains and other granular materials [14]. There are diverse types of moisture sensing instruments and sources of such moisture sensing equipment are identified in each of these reviews.

A microwave transceiver using a free-space transmission method was designed and implemented to construct the prototype grain moisture meter [15]. The constructed transceiver is illustrated in Fig. 1. A 10.5 GHz microwave signal at 11 Mw generated by an oscillator with a dielectric resonator [11] is transmitted through an isolator and radiated from a transmitting horn antenna into the sample holder. The microwave signal, attenuated by the grain, is collected by a receiving horn antenna and detected by a Schottky diode and RF impedance matching circuit with excellent frequency characteristic [16] [12]. The oscillator consists of a single source biased oscillator with a dielectric resonator, which has a high Q and good temperature stability. The detector converts input RF signal to dc voltage.

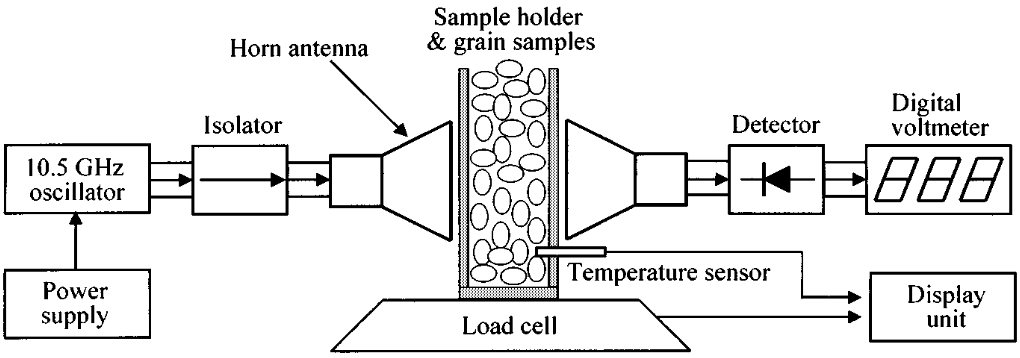



**Figure 1.** Schematic diagram of the prototype grain moisture meter [17].

## 3. Tomography Imaging

An investigation on the efficiency and accuracy of localization towards moisture distribution sensing based-on tomography method, the correlation between multiple RF attenuation information can be gathered and analysed using tomography method to locate the moisture distribution in the silo. The optimum number of RF points that act as the sensor in order to provide sufficient accuracy of tomography data. Hence, this enables cross-section images which disclose the information of the location of the moisture in the silo. Uneven nature of the moisture distribution is expected and therefore the tomography image reconstruction requires a non-linear reconstruction approach that results in 2D cross-section images of the silo. This 2D images will be used in the Machine Learning to predicting and assessment of the moisture distribution in the silo and provide moisture volume estimation.

Tomography Imaging Technique has successfully been applied an imaging modality in which internal three-dimensional conductivity distribution of the target is reconstructed on the basis of electrical measurements from the target surface and air voids, moisture [18]. And also this technique has been applied to geophysical monitoring, industrial process tomography and medical imaging. However, Tomography of concrete has been considered only in a few publications [19].

## 4. Machine Learning

Intelligent Machine Learning Technique for Predicting the Moisture Distribution and Provide Quantification Assessment Using Deep Convolutional Neural Network It has been a big challenge to predict a 3D distribution or performing the quantification of large volumetric datasets derived from computed tomography images. With limited tomography datasets, the information that describes the content of moisture in the silo could be truncated. To provide better quantification of moisture content in the silo, a 3D moisture distribution is proposed. This could be achieved by reinforcing machine learning to provide a better solution with a limited number of training datasets. Using Deep Artificial

Neural Network algorithm, this could effectively predict the 3D moisture distribution and perform the quantification of large volumetric datasets derived from computed tomography images.
In the Radio frequency impedance tomography in the reconstruction of the image, the so-called Generalized Tikhonov regularization [20] is very often used. In a generalized form, this method also represents the Gauss-Newton algorithm.

The application of the least squares method originated from the Gauss-Newton method wherein the matrix $Z^{(l)}$ fulfills the role of matrix X (first partial derivatives relative to fixed approximations $\beta^{(l)}$ and observed values of independent variables), and the role of the vector y (observation of the dependent variable) vector $e^{(l)}$. Hence, the empirical values between the dependent variable and the lth of its approximations that represents the vector of differences.

$$ƒ(X_t,\beta^{(l)}) \tag{1}$$

The study employed Gauss-Newton algorithm to evaluate the structural parameters of non-linear models. The non-linear function in its general form is illustrated below:

$$y_t = ƒ\ (x_t, b) + \varepsilon_t \tag{2}$$

Also, the artificial neural networks and the electrical tomography method was also used. Thus far, there have not been wide assessment of the silos by using the tomographic and neural networks methods. The low accuracy of mappings and the low resolution of the reconstructed image have been the major reason [21]. Where:

$y_t$—observations of the explanatory variable,
$x_t = [x_t]$—P vector of observations for explanatory variables,
$\beta_t = [\beta_j]$—K vector of structural parameters,
$\varepsilon_t$—implementations of random elements (we assume that random components are uncorrelated, have an average of zero and equal, positive and finite variance).

The reform of the internal image of the investigated sample is associated with the determination of the global minimum of the fitness function in the Gauss-Newton method. In order to carry out quantitative considerations, we assume that the tested sample is polarized with an alternating low-frequency current. Then, a function with real values describes the electrical material properties. But then, in the generalized Laplace equation, the word relative to the frequency is neglected, and this function can be equated with the electrical conductivity (real isotropic admittivity case).

### *4.1. Humidity Testing by the Neural Imaging*

In solving the moist grain imaging problem, the artificial neural networks as well as the electrical tomography method was also examined. And thus far, there have not been a wide dissemination in the assessment of the grain with regards to tomographic and neural networks methods. Reason been that of low accuracy of mappings and the low resolution of the reconstructed [21]. A set of new method was developed centered on a set of many separately trained neural networks to increase the resolution of tomographic reconstructions depicting the degree of internal humidity of silos. The number of neural networks corresponds to the 3D resolution of the lattice dividing the inside of the silos into individual pixels, which was divided into 8099 points. In a short intervals, by making use of a device termed multiplexer, 192 value of voltage drops were generated by the tomographic system which reads between different electrode pairs. These are the input data for the neural network system. The neural networks are designed in such a way that on the basis of an input vector containing 192 elements, each of the 8099 neural networks generates the value of a single pixel of the output image. Fig. 2 illustrates the neural model employed during the simulations experiments in mathematical form.

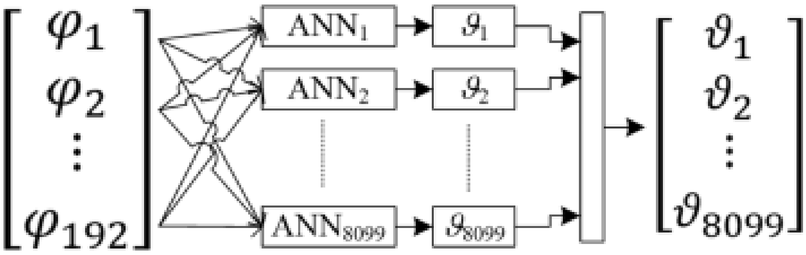



**Figure 2.** The scheme of converting electrical signals into the image pixels[22].

## 5. Conclusions

The main goal of this review was to find the best solution of localization of moisture distributions sensing in agricultural silos. Non-destructive methods and algorithms have been studied, which allow estimation of moisture distributions sensing in agricultural silos. A new concept of a non-destructive system based on Radio Frequency (RF) based volume tomography was reviewed. Then, tomographic imaging as well as computational intelligence approaches such as ANN are also have been studied to investigate the efficiency and accuracy of localization of moisture distributions sensing in agricultural silo. The correlation between multiple RF sensor network attenuation information can be gathered and analysed using tomography method to locate the moisture distribution in the silo. From the literatures that have done, it can be concluded that these three approaches have very effective for measuring the moisture content of grain and should be adaptable for fast, accurate, nondestructive moisture measurements on grain.

**Acknowledgement**

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

IOP Conf. Series: Materials Science and Engineering **705** (2019) 012054 doi:10.1088/1757-899X/705/1/012054

**References**


[1] Wilson J, Patwari N 2010 *Radio tomographic imaging with wireless networks*. IEEE Transactions on Mobile Computing, 9:621-632

[2] Kraszewski A, Trabelsi S, Nelson S 2000 *Density-independent and Temperature-compensated Moisture Content Determination in Shelled Corn by Microwave Sensing*. Sensors update, 7:51-64

[3] Nelson S, Soderholm L, Yung F 1953 *Determining the dielectric properties of grain* Agricultural Engineering, 34:608-610

[4] Knipper N 1959 *Use of high-frequency currents for grain drying*

[5] Corcoran PT, Nelson SO, Stetson LE, Schlaphoff CW 1970 *Determining dielectric properties of grain and seed in the audiofrequency range* Transactions of the ASAE, 13:348-0351

[6] Stetson LE, Nelson SO 1972 *Audiofrequency dielectric properties of grain and seed*. Transactions of the ASAE, 15:180-0184

[7] Nelson SO 1973 *Microwave dielectric properties of grain and seed*. Transactions of the ASAE, 16:902-0905

[8] Chugh RK 1973 *Dielectric properties of wheat at microwave frequencies*.

[9] Nelson SO 1987 *Models for the dielectric constants of cereal grains and soybeans*. Journal of Microwave Power and Electromagnetic Energy, 22:35-39

[10] Kraszewski A, Nelson S 1989 *Composite model of the complex permittivity of cereal grain* Journal of Agricultural Engineering Research, 43:211-219

[11] Lawrence K, Nelson S, Kraszewski A 1990 *Temperature dependence of the dielectric properties of wheat*. Transactions of the ASAE, 33:535-0540

[12] Nelson S, Trabelsi S, Kraszewski A 1998 *Advances in sensing grain moisture content by microwave measurements*. Transactions of the ASAE, 41:483

[13] Lawrence K, Nelson S 1998 *Sensing moisture content of cereal grains with radio-freequency measurements-a review* In Papers and Abstracts from the Third International Symposium on Humidty and Moisture: 195-203

[14] Kraszewski A 1980 *Microwave aquametry—a review* Journal of Microwave Power, 15:209-220

[15] Kim K-B, Park S, Noh SH, Kim MS, Choi MY 2005 *Moisture measurement in grain by free-space microwave transmission at 10.5 GHz* In 2005 ASAE Annual Meeting. American Society of Agricultural and Biological Engineers;: 1

[16] Kraszewski A, Trabelsi S, Nelson S 1996 *Wheat permittivity measurements in free space* Journal of microwave power and electromagnetic energy, 31:135-141

[17] Kim K-B, Kim J-H, Lee SS, Noh SH 2002 *Measurement of grain moisture content using microwave attenuation at 10.5 GHz and moisture density* IEEE Transactions on Instrumentation and Measurement, 51:72-77

[18] Karhunen K, Seppänen A, Lehikoinen A, Monteiro PJ, Kaipio JP 2010 *Electrical resistance tomography imaging of concrete* Cement and Concrete Research, 40:137-145

[19] Daily W, Ramirez A, Binley A, Henry-Poulter S 1993 *Electrical resistance tomography of concrete structures. Lawrence Livermore National Lab., CA (United States);*

[20] Lechleiter A, Rieder A 2008 *Newton regularizations for impedance tomography convergence by local injectivity* Inverse Problems, 24:065009

[21] Rymarczyk T, Kłosowski G 2018 *Application of neural reconstruction of tomographic images in the problem of reliability of flood protection facilities.* Eksploatacja i Niezawodność, 20

[22] Rymarczyk T, Kłosowski G, Kozłowski E 2018 *A Non-Destructive System Based on Electrical Tomography and Machine Learning to Analyze the Moisture of Buildings*. Sensors, 18:2285