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(Communication)

Monitoring Moisture Content for Various Kind of Tea Leaves in Drying Processes Using RF Reflectometer-Sensor System

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Abstract: This paper presents tea leaves moisture monitoring system based on RF reflectometry techniques. The system was divided into two parts which are the sensor and reflectometer parts. The large coaxial probe was used as a sensor of the system. The reflectometer part plays a role as signal generator and also data acquisition. The reflectometer-sensor system was operated with a graphical user interface at 1.529 GHz at room temperature. The system was able to measure the moisture content of tea leaves ranging 0% *m.c* to 50% *m.c* on a wet basis. In this study, up to five kinds of tea leaves bulk were tested. The mean of absolute errors in the moisture measurement for tea leaves was ±2.

Keywords: tea leaves; microcontroller-based RF reflectometer; large open-ended coaxial probe; reflected voltage; moisture content

1. Introduction

Generally, the production line of tea is mainly depending on the moisture content, *m.c* to decide how long the tea leaves should be dried in every drying step (Figure 1). Traditionally the *m.c* of tea leaves was estimated by the skilled workers. However, the percentage of measurement errors which caused by the workers were in the range of about 3% to 30% [1]. In fact, there are some accurate chemical methods (water extracted from tea sample) that were used to determine the moisture of tea [2], but these kind of methods are time consuming and unsuitable for large-scale tea processing in manufacturing. In addition, most of the moisture meters only involve DC circuit by using the concept of measuring the tea leaves resistance, conductivity or capacitance [3-8]. The ionic conductivity, σ in the tea leaves interacts with the metal surface of the sensor (sample holder) to create a small amount of voltage in the meter. However, this measurement concept will cause less sensitivity to the dry tea leaves (< 30% *m.c*) measurement, due to the lack of free ionic in the dry tea leaves. Furthermore, these economical meters can only measure one type of tea leaves for a narrow measurement range of *m.c* (normally only 3% to 18% *m.c*). Besides, the sensitivity of measurement towards the water contained in the tea leaves requires extensive interaction between the sensor surface and tea bulk samples.

Recently, the near-infrared spectroscopy (NIRS) [2, 9] is the most common sensing method in biology and food processing. The *m.c* measurement using optical technique is based on the change in refractive index, *n* parameter of the tea sample (due to the change in *m.c* in the sample). On the other hand, the interaction between tea sample and microwave can be described by the parameter of relative complex permittivity, $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$. In general, the *m.c* measurement using the microwave technique is different from the optical technique in terms of sensitivity, since the relationship between *n* and ε_r is given as $n^2 = \varepsilon_r$. Over the past until now, there were two types of microwave sensors which have been reported and used in the monitoring of tea drying process. The first type of sensors is one pair of horn antennas and its moisture measurement is based on the free-space transmission techniques [10-11]. The second type is a microstrip line sensor which is used for near field measurement [12-13]. Both methods have advantages and disadvantages, respectively. The first method is suitable for high temperatures tea leaves bulk measurement due to the horn antennas sensor which does not come into direct contact with the tea leaves sample, thus, the RF circuit is safe from heat damage. Nevertheless, this method provides a less precise measurement due to the sensing field is highly dispersed. Furthermore, the distance between the tea leaves sample and the horn aperture is difficult to gauge precisely. The second method has a small sensor and portable feature which is capable to measure wider *m.c* range containing in the tea leaves sample. However, the microstrip line sensor has a thin sensing area above the microstrip line. Normally, the sensing area = (width of microstrip line)^2. Thus, the *m.c* is mainly measured only for the tea leaves which are overlaid on the surface of the microstrip line. This situation led to high uncertainty in the moisture measurement since the tea leaves are inhomogeneous sample.

Hence, this paper attempts to introduce a simple and relatively low cost portable microcontroller-based frequency domain microwave reflectometer for tea leaves moisture monitoring. A large open-ended coaxial probe was used as a moisture sensor, which is directly connected to the reflectometer. The applied system is based on a frequency domain reflectometer (FDR) method which is based on the dielectric property changes in the wet tea leaves. The obtained measurements are calibrated using the oven drying method. Up to five kinds of manufactured tea leaves were tested, namely Boh tea, Pu Erh tea, Green tea, Sabah tea, and Oolong tea. The study system has several advantages:

1. Able to determine a wider range of *m.c* (0% to 50% on a wet basis) in tea leaves bulk.
2. Provide a significant sensing volume (5 cm diameter × 2.5 cm depth), thus, the uncertainty in the moisture measurement due to inhomogeneous properties of the tea leaves bulk can be reduced.
3. The probe aperture is directly contacted with tea leaves, thus irregularity of the surface of the tea leaves can be tolerated.

Normally, the making process of tea in factory is divided into at least six sub-processes (Figure 1) [8]. However, this study is only interested in the moisture determination starting at 2nd drying step until final drying step.

Steaming fresh leaves (Less than 1 minutes)
↓
1st drying (70 → 50 % *m.c*); (40 – 45 minutes)
↓
Tea rolling by hand or drum stirrer machines (15 – 20 minutes)
↓
2nd drying (50 → 30 % *m.c*); (30 – 40 minutes)
↓
3rd drying (30 → 13 % *m.c*); (30 – 40 minutes)
↓
Final drying (13 → 5 % *m.c*); (10 – 20 minutes)

} Interest drying stages for this study

Figure 1. Tea manufacturing processing.

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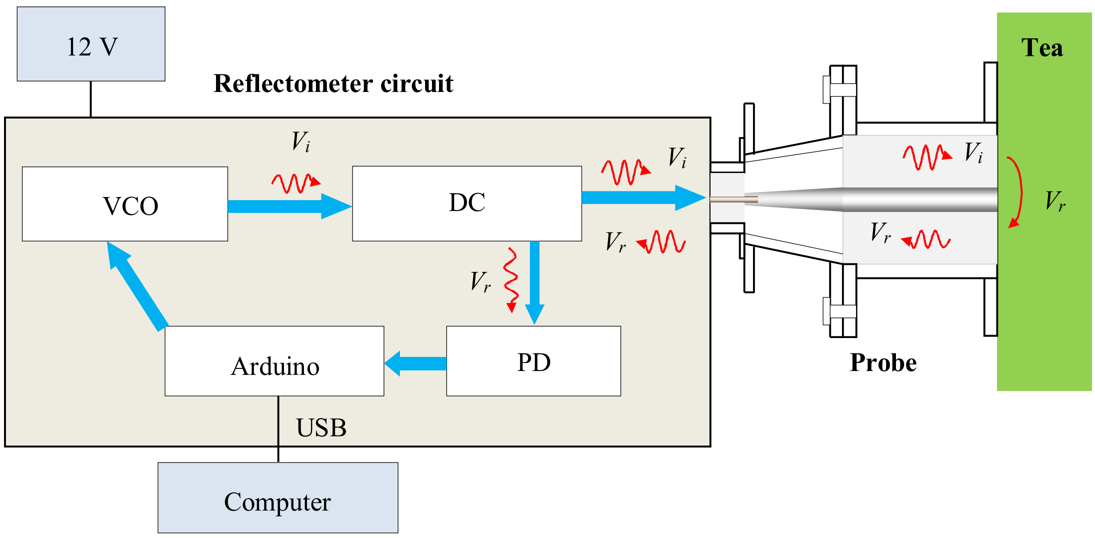
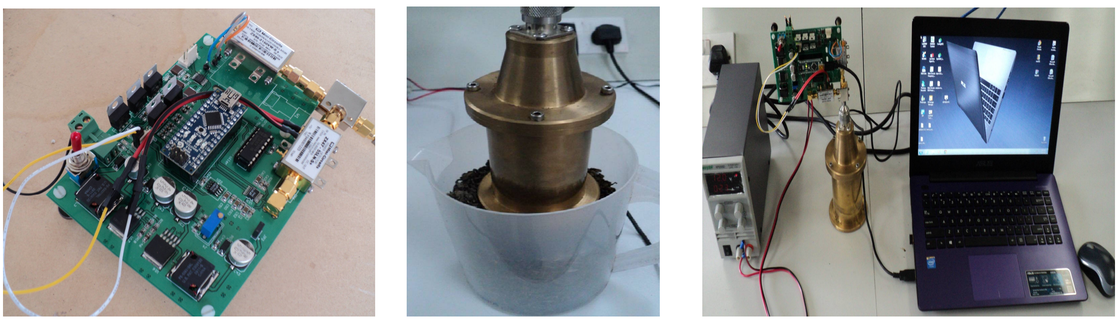
2. Materials and Methods

The reflectometer part is mainly consist of ZX95-2150VW-S+ voltage controlled oscillator (VCO), ZX30-17-5-S+ directional coupler (DC), ZX47-55LN-S+ power detector (PD), Arduino Nano Microcontroller 3.0, control circuit board, and 12 V DC power supply as shown in Figure 2. The large coaxial probe sensor has operating bandwidth covered from DC to 2 GHz and its dimensions are shown in Figure 3. The moisture measurement is based on the principle of reflectometry and the probe aperture was firmly contacted with the tea leaves bulk. Arduino microcontroller is used to control the VCO in order to generate incident voltage signal, V_i to the wet tea leaves bulk via the probe aperture. The incident signal will partially reflect and travel back due to the discontinuity impedance at the probe aperture. The reflected signal will obtain the desired information about the volume of water in the wet tea leaves bulk. The reflected voltage, V_r signal from the probe aperture is detected by the power detector in the system.



(a)



(b) (c) (d)

Figure 2. Reflectometer system diagram. (b) Reflectometer's circuit. (c) Coaxial probe for tea leaves bulk measurements. (c) Overall measurement system.

The moisture content, *m.c* of the tea leaves bulk are measured at various operating frequencies. The used VCO is capable of generating a wide range of frequencies signal based on input tuning

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voltage, in which the frequency values of the signal are measured using UFC-6000 RF frequency counter. The signal control and acquisition algorithms are created using Python software in order to extract the measured V_r, as well as to process raw measured V_r and tea moisture level display. The correlation formula between V_r and $m.c$ is described in Section 4.

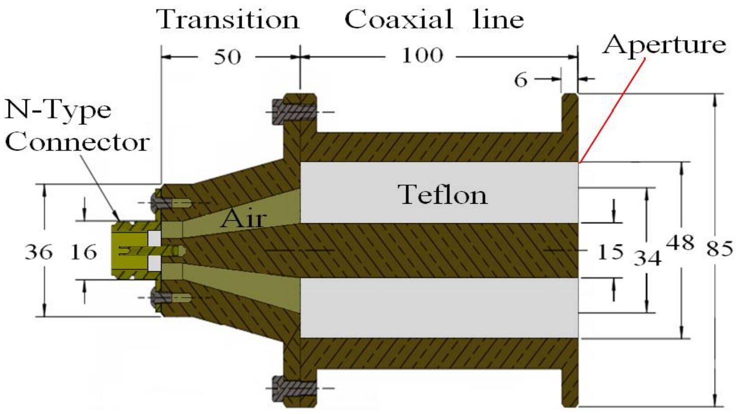

Figure 3. Cross-sectional view and dimensions (in millimeter) of the probe.

3. Moisture Measurements

The gravimetric moisture content, $m.c$ of the five kind of manufactured tea leaves was obtained by the wet basic oven-drying method, respectively. Up to 250 g of each tea leave was mixed with an amount of water so that the total mass, m_{total} of the wet tea leaves bulk reaches approximately 500 g. Then, the wet tea leaves bulk was left for 1 day in order to reach equilibrium water absorption (water distribution uniformity). After one day, the tea leaves sample in the initial condition was weighed at room temperature using digital balance, the initial mass, m_{total} (mass of tea leaves, m_{tea} + mass of water, m_{water}) of the tea sample was recorded. The corresponding reflected voltage, V_r of the tea sample was measured using the reflectometer-probe system. The tea sample was dried in an oven at 105˚C for 3-5 minutes to reduce the moisture containing in the sample. After oven drying, the mass, m_{total} of the tea sample was re-weighed and recorded as soon as it has cooled to room temperature. The corresponding V_r for reduced mass, m_{total} of tea sample was measured. The above experimental steps were repeated until the tea sample stops losing weight when after oven drying. The final constant weight is the mass of dry tea leaves, m_{tea}. The actual $m.c$ of the tea sample for each time after the drying process was carried out, and calculated as:

$$m.c = \frac{m_{total} - m_{tea}}{m_{total}} \times 100\% \tag{1}$$

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

4. Results and Discussion

The wet tea leaves bulk is a composition of water (ε_r = ~80), dry tea leaves (ε_r = ~2.7), and air (ε_r = 1). The dielectric of water is much greater than these elements. Thus, the microwave energy can be easily absorbed by water and cause the polarization of water molecules present in the leaves bulk. For this reason, the proposed system is expected to exhibit more sensitivity towards changing *m.c* in the wet tea bulk.

The variations in reflected voltage, V_r of tea leaves bulk with the percentage of *m.c* at various operating frequencies, respectively, are plotted in Figures 4 (a)-(e). As expected, the reflected voltage, V_r of tea leaves increases exponentially with *m.c*, since relative permittivity, ε_r of agricultural product normally increases exponentially with its *m.c* [14] at higher operating frequencies. From Figure 4, we found that the measurement frequency at 1.529 GHz is able to provide stable and sensitive measurement respect to *m.c* of the all tea leaves. In this study, the simple relationship between the V_r and *m.c* is achieved using a empirical semi-log expression as:

$$\ln\left(V_r\right) = \alpha\left(m.c\right)^{\gamma} + \beta \tag{2}$$

where α, β and γ are the fitting parameters. The solid line of reflected voltage, V_r in Figure 4 was the calculation of the V_r using Equation (2). The values of α, β, and γ for operating frequency of 1.529 GHz are obtained using regression method as listed in Table 1. The maximum deviation between the calculated and measured V_r are within ±0.04 V.

The reflected voltage changes, ΔV_r resulting from a change of 1% *m.c* in the five tea leaves bulk samples at 1.529 GHz, is shown in Figure 4 (f). Overall, tea leaves bulk containing high water content has high sensitivity of reflected voltage, V_r measurement. From (1) and parameter values in Table 1, the *m.c* (%) of the tea leaves bulk can be predicted as:

$$m.c\left(\%\right) = \left(\frac{\ln\left(V_r\right) - \beta}{\alpha}\right)^{\frac{1}{\gamma}} \tag{3}$$

The mean deviation between the predicted and actual *m.c* are within value of ±2. The deviation may be mainly caused by inhomogeneous form of tea leaves bulk in which most of the tea products are in roll or crush form as shown in Figure 5. Different kinds of teas are manufactured by various techniques. Boh tea and Sabah tea are crushed into small pieces. On the other hand, the green tea, Oolong tea and Pu Erh tea are rolled into round shape by hand or machinery.

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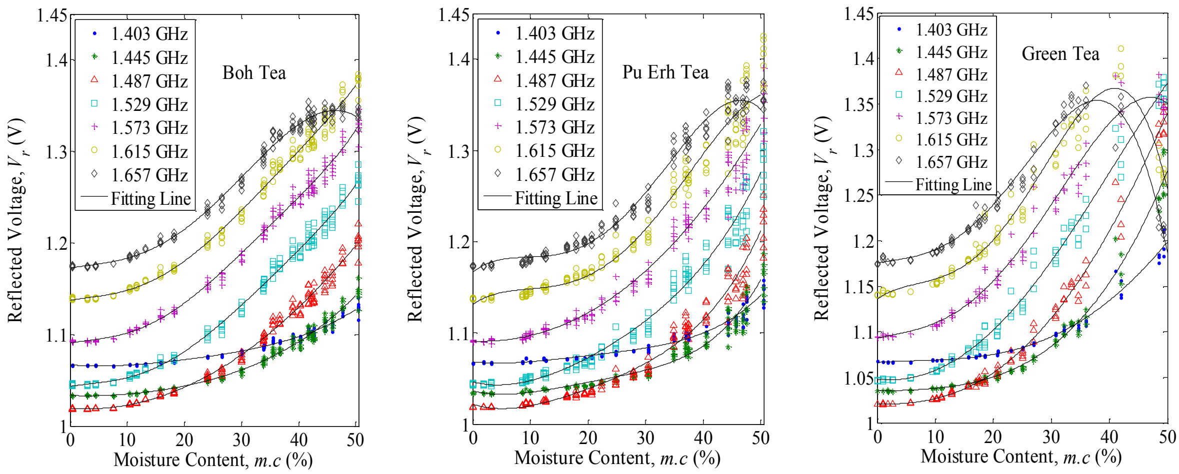
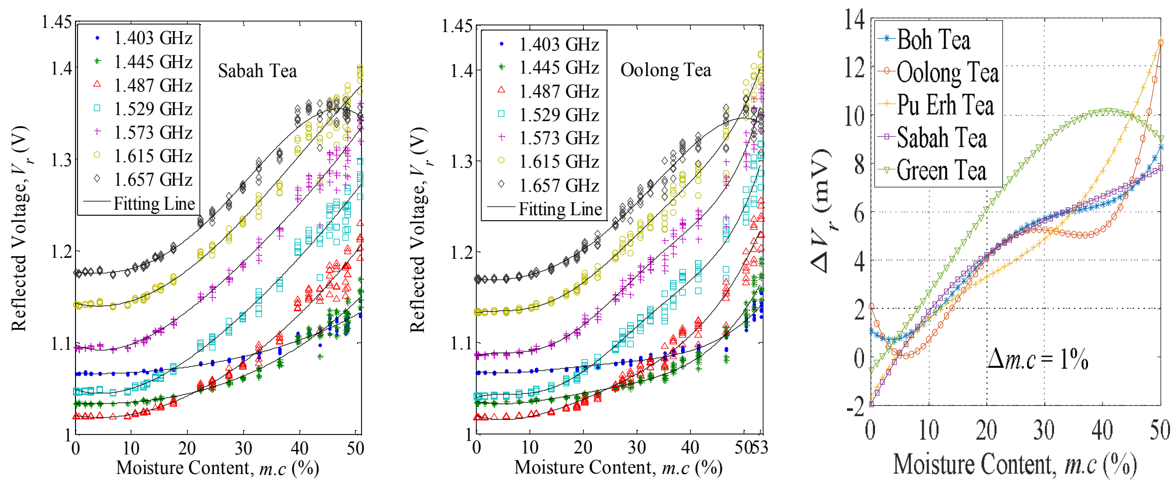


(a) (b) (c)



(c) (d) (e)

Figure 4. (a), (b), (c), (d), (e) Variations in V_r and $m.c$ (%) at (25 ± 1) °C. (f) Sensitivity of measured V_r respect to $m.c$.

(a) (b) (c) (d) (e)

Figure 5. Roll form (a) green tea, (b) Pu Erh tea, and (c) Oolong tea leaves. Crush form (d) Sabah tea and (e) Boh tea.

Table 1. Parameter Values of Equation (2).

	Boh Tea	Pu Erh Tea	Green Tea	Sabah Tea	Oolong Tea
α	2.5342×10^{-4}	1.672×10^{-5}	2.498×10^{-4}	2.5253×10^{-4}	7.5581×10^{-5}
β	0.040257	0.045046	0.038454	0.039706	0.043778
γ	1.7	2.4	1.8	1.7	2.0
r^2	0.99219	0.97845	0.98639	0.98691	0.98494

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5. Conclusion

The tea moisture reflectometer-sensor system is developed successfully in which is suitable for large scale tea processing manufacturer. The reflectometer has conceptualized a commercially viable product and this measurement system has several features including data storing capability and various types of tea measurement capability, namely Oolong tea, Boh tea, Sabah tea, green tea, and Pu Erh tea. Furthermore, in future, the applied system can also be used in other agricultural products and industries, such as moisture content monitoring for wood board industry.

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