Monitoring Health Status and Quality Assessment of Leaves Using Terahertz Frequency

Adnan Zahid[1]
[1]School of Electronics and Nanoscale Engineering, Glasgow University of Glasgow, G12 8QQ
[1]Email: a.zahid.1@research.gla.ac.uk
Hasan T. Abbas[2]
[2]Department of Electrical and Computer Engineering, Qatar Texas A&M University, Qatar
[2]Email: hasan.abbas@qatar.tamu.edu

Fawad Sheikh[3], Thomas Kaiser[3]
[3]Institut für Digitale Signalverarbeitung, Universität Duisburg-Essen (UDE), Campus Duisburg, NRW, Germany.
[3]Email: {fawad. sheikh, thomas.kaiser}@uni-due.de
Ahmed Zoha[1], Muhammad Imran[1], and Qammer H. Abbasi[1]
[1]Email: {Ahmed.Zoha, Muhammad.Imran, Qammer.Abbasi} @glasgow.ac.uk

***Abstract* – This paper presents a new and non-invasive electromagnetic technique that utilizes the terahertz frequency waves to monitor the plant health. To do so, the water content of a plant leaf is obtained using the measured scattering response in the frequency range of 0.75 to 1.1 THz. Leaves of three commonly used herbs were observed for four consecutive days and the electromagnetic material parameters such as the permittivity were extracted using a material characterization algorithm. The decreasing moisture level and in turn the plant health can therefore be directly inferred from the leaf permittivity which approaches to that of free space with the passage of days.**

***Index Terms* – terahertz (THz), sensing, material characterization.**

I. INTRODUCTION

The increasing demand on endorsing fruits and vegetables quality has led to a quest for viable techniques [1] and, practical approaches to provide better symptoms of plants drought stresses at an early stage [1], while effectively utilizing water consumption in the field of plant biology. In this regard, many techniques [2-5] have been evolved by scientists, horticulturists, and researchers to develop feasible strategies for non-destructive and timely detection of the water content (WC) in plant leaves and environmental stresses. The availability of such systems enable the cultivators and farmers to take efficient and appropriate measures by timely monitoring WC and nutrients in leaves to maintain a healthy physiology and lessening the early inception of age dependant disease [2-5].

Considering the physiological characteristics of plant leaves' spectral properties, researchers are interested in exploring further understanding about the electromagnetic parameters of various leaves and their correlation with plant response to different stresses [4]. In this context, significant contributions and techniques have been attempted in [5-8] including chlorophyll fluorescence analysis, hyperspectral imaging, thermal imaging, infrared transmissions/reflections methods, which have addressed the plant leaves' MC in detail and their strong connections with electromagnetic properties such as permittivity, refractive index, and absorption coefficient [8]. These aforesaid techniques [5-8] have offered a detail spectral analysis of WC in leaves and have a major impact in plant physiology research. However, these methods experience some major drawbacks, such as; time-consuming, low-resolution, sensitivity issues, and chief among them, unable to provide information of WC in the leaves at cellular level [8]. Moreover, some of them are considered as inappropriate for enduring studies due to their destructive nature [8].

Consequently, this has led researchers to focus on non-destructive and non-invasive techniques and have considered the Terahertz Spectroscopy (THz-TDS) to determine internal morphology of leaves, relating to WC in leaves due to its strong absorption feature [8]. Though, this method is proven to be reliable and has higher resolution to detect diminutive variations in leaves. However, this too is considered a high-cost technique and is not portable [8]. In this paper, a simple and non-invasive technique is presented to characterize and estimate the WC of three fresh leaves including baby-leaf, pea-shoot, and spinach employing a THz material characterization kit (MCK), Swiss*to*12 in the frequency range of 0.75 to 1.1 THz [2]. This paper also illustrates a significant correlation between electromagnetic parameters i.e. permittivity with the WC in leaves over the course of four consecutive days measurements.

II. MATERIALS AND METHODS

The THz Swiss*to*12 MCK [2] system is configured from 0.75 to 1.1 THz to perform measurements as shown in Fig. 1. Prior to measurements, the system is calibrated using a fully two port short-open-load-thru (SOLT) technique to lessen any measurement and transmission losses. The structural integrity and configuration of leaves are also considered by employing two Polytetrafluoroethylene (PTFE) caps which are fitted internally to the waveguide. The weight of all three leaves are continuously monitored during an evaporation of WC for consecutive four days using a digital scale. All three leaves are placed and observed in a laboratory temperature which is set to 18°C ± 0.2°C. All leaves are measured at three various locations and at each location, the behaviour and surface anomalies of all three leaves are monitored. The permittivity is extractred from the scattering measurements using NRW Method [9].

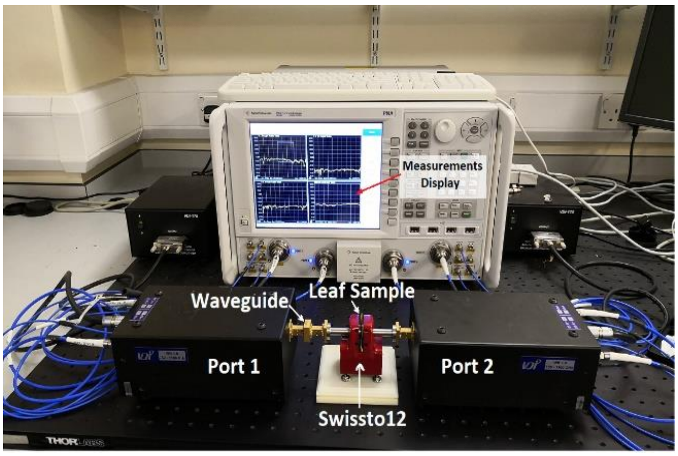

Fig 1. System setup with a frequency range from 0.75 to 1.1 THz.

III. MEASUREMENT RESULTS

Likewise, electromagnetic parameters i.e. both real and imaginary parts of permittivity are extracted from a measured s-parameters, as shown in Fig. 2. On day 1, permittivity was

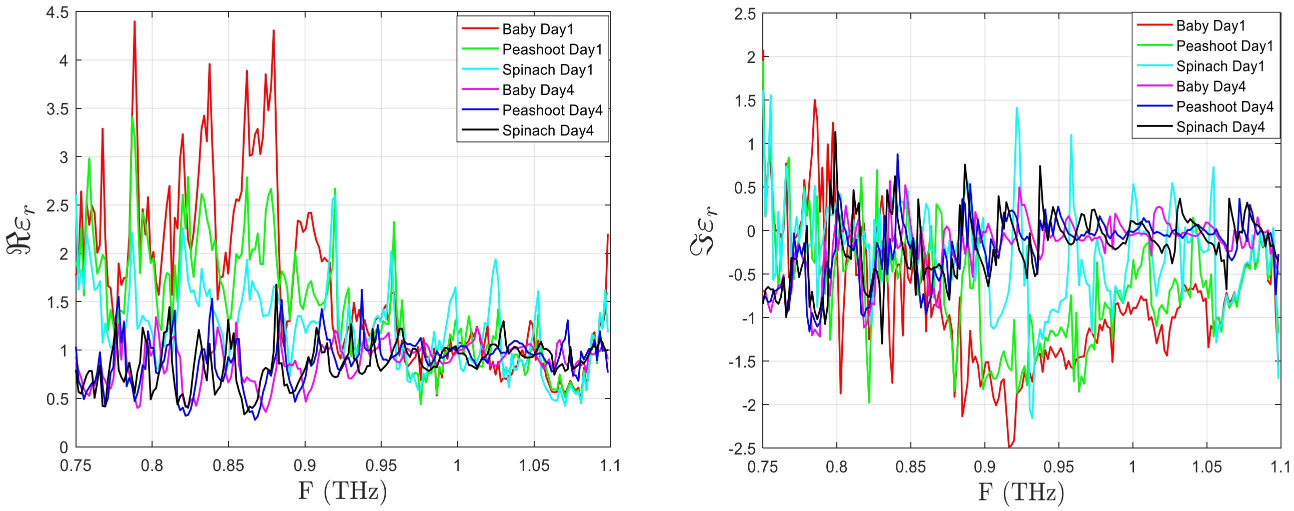

Fig 2. Permittivity (Real and Imaginary) response of all three leaves from day 1 to 4 using a frequency range from 0.75 to 1.1 THz.

considerably high due to the presence of high WC in leaves and decrement is obtained as leaves became water stressed with passing days. Fig. 3 illustrates the loss of WC observed in all three leaves for four days' measurements using [10].

$$WC = \frac{W_{time} - W_{dry}}{W_{fresh}} \times 100\% \qquad (1)$$

In Fig 3, WC loss is observed in baby-leaf, pea shoot, and spinach leaves from day 1 to 4 are 88%, 93% and 91% respectively. On day 1, leaves exhibit a high WC and a decaying trend with every passing day, reflecting a change occurs in morphological structure of leaves at cellular level. From Fig 2, it is observed that various leaves have shown distinct decaying responses which indicate that the internal characteristics and process of growth of leaves differ from each other. The measurement results illustrate a strong correlation of permittivity with WC of leaves, i.e. fresh leaves display high permittivity, whereas, water stressed leaves reveal low values due to the evaporation of WC in leaves as shown in Fig.

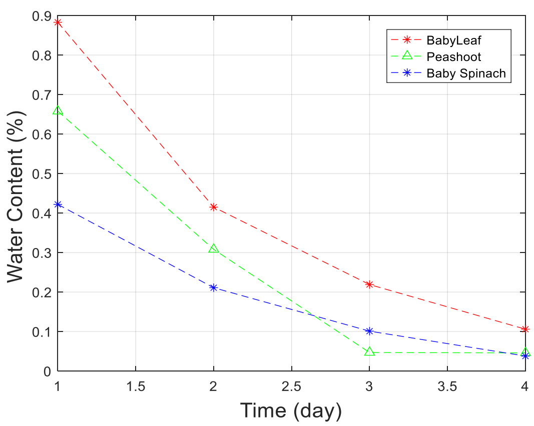

Fig 3. Water content of the leaves from day 1 to day 4

IV. CONCLUSION

In this paper, a novel and non-invasive method is presented using THz frequency for the characterisation of the plants' leaves utilizing the electromagnetic parameters. Subsequently, the complex valued permittivity of three types of commonly used edible leaves is extracted for four consecutive days through the s-parameters. Moreover, the loss of WC is also monitored for four days consecutively. It is observed that the WC in leaves show a strong correlation with the permittivity. The average decaying response observed from day 1 to 4 in permittivity is attributed to the loss of WC in leaves. The results have shown that the proposed method can be effective for monitoring the health status of leaves and precision agriculture applications.

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