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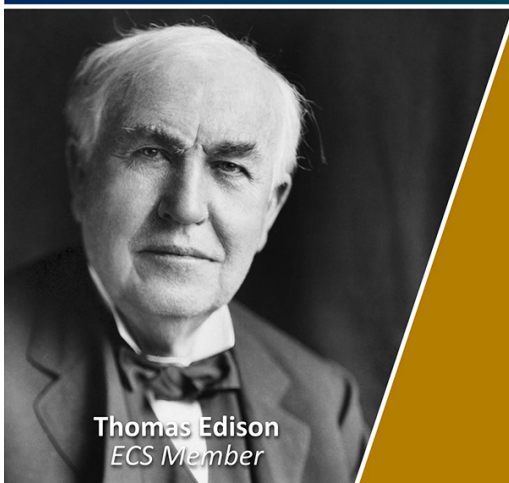
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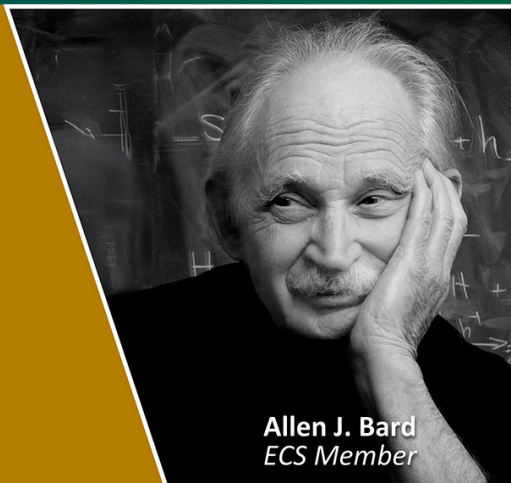
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# Knowing the maturity of fruits using Electrical Impedance Tomography through RCL-meters

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**Abstract.** This work describes a method for knowing the maturity state of a fruit using the EIT and an RLC meter. A mango was used to probe the measurement method and was obtained an EIT where are observed different conductivity levels for pulp, peel and seed. Finally, it has been found that it measures the maturity of the fruit.

## 1 Introduction

The measurement of fruit quality is nowadays a necessary procedure for the selection or quality control of fruits, whether for marketing or even for export. One of the main characteristics that a quality fruit must have is an optimal degree of ripeness [1]. There are some methods for measuring the quality of maturity, for example, measuring the pulp properties such as sugars, amount of sugar dissolved in a liquid, or visual inspection, however, they are destructive methods where the fruit is destroyed. In recent years, some methods such as electrical impedance was proposed to know some properties of the interior of the fruits as banana [2], strawberry [1] and avocado [3], but these methods only measure the properties in one direction, not as an effective conductivity in several directions as in Electrical Impedance Tomography (EIT) [4].

Electrical impedance is generally a complex quantity, composed of a real component (resistive) and a imaginary (reactive) [5], but it is frequently considered that the reactive component is small concerning the conductive part, allowing the medium to be shaped only with the real part of the conductivity [6], this allows make simpler implementations for measuring conductivity. Since currents are typically injected and potentials are measured in EIT, the first thing to consider is the injection of electric current, which in the case of a fruit is possible to take a very small value, given the low impedance due to the water content inside the fruit, this current can be direct if only is required to measure the real part or alternating current if it is required to measure both real and complex (impedance) [7].

This work describes the method for obtaining the impedance (conductivity or permittivity distribution) of the cross section of a fruit using the Electrical Impedance Tomography (EIT) technique. EIT images the internal conductivity distribution of a fruit that shows some internal composition, for example: seed, pulp, and pericarp. This method is used to know the maturity of the fruit and then to know the pulp distribution of a fruit without destroying it. The measurements are obtained using an RCL meter (Hioky HiTester model 3532-50), especially useful when there is no commercial tomograph or prototype to make the measurements.



## 2 Methods

### 2.1 Data collecting for EIT of fruits

In this work, a commercial RCL meter was used. This measurement tool can measure impedance in LCR circuits or even any material, this RCL meter obtains the magnitude and phase of the impedance using the four-probes method. In this case it will be used as a potential meter and current source separately. The current source must be configured with the value of the injection current that is required, and the voltage meter must simply be placed where measurement is required.  $H_{cur}$  corresponds to the part of the current source where the signal goes out, while  $L_{cur}$  corresponds to the source part of the current where the circuit is closed. For its part,  $H_{pot}$  is the tip for voltage measurement and  $L_{pot}$  is the tip for reference for voltage measurement. In this way, if it is required to measure the voltage with the method of four-probes with the RCL meter, you have to connect the configuration of Figure 1(right). In this case the proposed current injection is in the range of 0.01 and 1 mA to prevent the saturation device. Two typical current injection methods are: polar and adjacent injection [4]. In this work, adjacent injections are used.

In this work, the measured material will be a fruit,  $n$  current injections and  $m$  potential measurements must be made around the surface of the fruit. To perform an EIT with a  $n$  number of electrodes in the adjacent method [4],  $N_m = Ne(Ne - 3)$  must be made. That is, if you have 16 electrodes ( $Ne = 16$ ) and an adjacent current injection, you need a total of  $Nm = 208$  measurements to obtain an EIT; suppose you have 8 electrodes to measure EIR at some fruit, so  $Ne = 8$ , they will need a total of  $N_m = 8(8 - 3) = 40$  measurements. A diagram of the connection of the fruit and the measurement is shown in Figure 1.

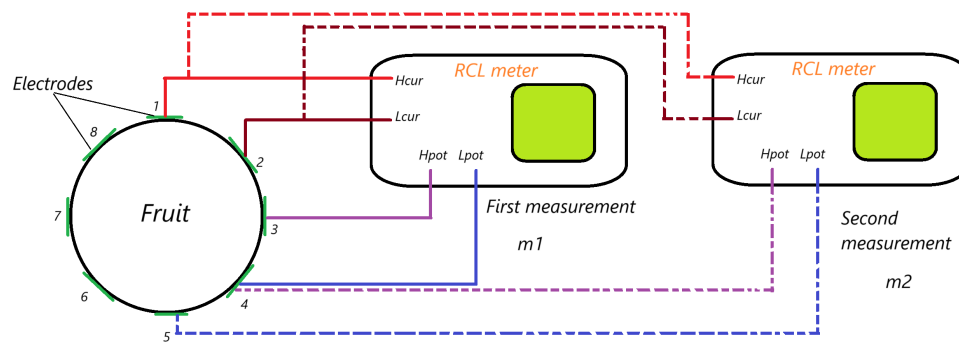


Figure 1: Connection of the fruit to RCL meter. First measurement injects current at the first pair of electrodes while the potential measurement is made between the other pairs of electrodes.

The potential can be registered using the magnitude and phase of the impedance ( $Z.\theta$ ) or directly using the  $V_{moni}$  data given by the impedance measurement. Both real and imaginary components of potential can be obtained using the equation (1).

$$|Z| = e^{j\theta} = \frac{|V_{meas}|}{|I_{meas}|} e^{(\theta_V - \theta_I)} \quad (1)$$

Where  $V_{meas}$  and  $I_{meas}$  are the measured potential and current respectively, and  $\theta_V$  and  $\theta_I$  are the phase for potential and current measured at the output signals respectively. For better management of measured data, you can create Table 1. In this table we have the potential  $V_{ij}$  with  $i$  the number of electrode pairs, and  $j$  the number of current injections. Note that in cases where the measure was not taken because this pair has contact with one of the electrodes where current is being injected, the table contains the symbol '-'. The connection of the system is shown in Figure ???. For this work the measurements were taken one by one using the four-probes measurement technique, but the RLC meter has the GPIB interface, so it can be automated using a programming language to get the measurements automatically.

Once you have taken the  $N_m$  voltage data measurements, the next thing is to process the data. For this case, the tomography was obtained using a software called EIDORS (Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software) [6] is used for obtaining EIT. The  $V_{ij}$  values are placed all together in an array as follows:  $V_m = [0.086 \ 0.147 \ \dots \ 0.276 \ 0.273]'$ ; all the information on the conductivity change calculation can be consulted in the workspace, particularly the values of conductivity calculated with the model used in the *elem\_data* variable.

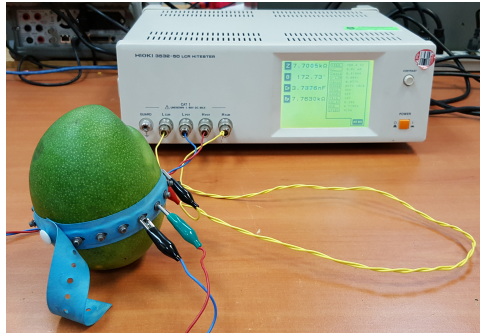


Figure 2: Electrical impedance measurement of a mango. The electrodes are placed at the surface of the fruit without destroying it.

Table 1: Example of potential measurement for an 8 electrode configuration. The 40 measurements are stored at each current injection.

$V_{i1}$	$V_{i2}$	$V_{i3}$	$V_{i4}$	$V_{i5}$	$V_{i6}$	$V_{i7}$	$V_{i8}$
-	-	0.213	0.187	0.161	0.187	0.137	-
-	-	-	0.372	0.291	0.304	0.185	0.135
0.086	-	-	-	0.147	0.178	0.132	0.208
0.147	0.088	-	-	-	0.201	0.150	0.224
0.232	0.108	0.275	-	-	-	0.196	0.276
0.176	0.095	0.255	0.257	-	-	-	0.273
0.221	0.105	0.282	0.287	0.248	-	-	-
-	0.086	0.225	0.200	0.191	0.211	-	-

For this work, the measurement of the potentials was performed manually, one by one, rotating the measurement setup.

### 3 Results

#### 3.1 Maturity of a mango fruit

A measurement was done using a mango to obtain its EIT. The mango was connected to 16 electrodes of Ag/AgCl, this is due to stability and reproducibility in the measurements. The applied current is  $I = 0.01mA$  at a frequency of  $700Hz$  in both cases, non-mature and mature fruit. This configuration is only an example, but you can configure the current and frequency as you desire in the apparatus, if the RCL meter saturates, the current must be lower as you configure for injection. As a first step, the electrodes are connected as shown in Figure 2. The current injection was carried out using adjacent injection, and the connection to the RCL meter for measurement of potential was carried out according to Figure ???. The current injection was done 16 times, and 208 potential values were recorded in a table that is entered into EIDORS. Results of the EIT are shown in Figure 3(a). After a week of letting the mango ripen, another EIT was performed on the same mango and the results were obtained as shown in Figure 3(c). For this case an EIT was used through back-projection. This represents the change that conductivity in the mango pulp suffered while it was left mature. The mango was not moved and was left to ripen naturally at room temperature.

#### 3.2 Discussion

Using RCL meters allows us to forget about building tedious electronics and achieve great precision. The results obtained qualitatively show that there is a change in the maturity of the measured fruit. Quantitatively the results in the color-bars show that are contrasting the three phases of conductivity and match with the expected, the seed is more dielectric than the pulp, but the pulp is more conductive than the peel, and the same result evolve in time with a shift in the results.

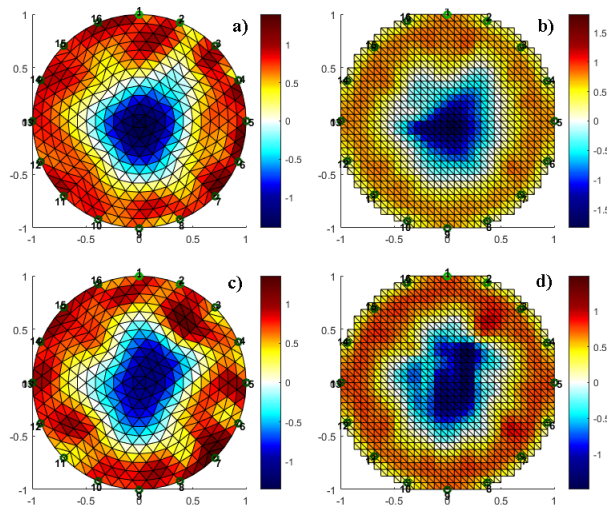


Figure 3: Impedance distribution inside a mango using EIT data. The EIT shows information of pulp (maturity), seed (quality, quantity and maturity of the pulp) and pericarp (quality).

#### 4 Conclusion

It was possible to know the maturity of a fruit using an EIT and an RCL meter, this was possible thanks to the amplitude and phase of the impedance values captured from the apparatus and the reconstruction by means of an image. The measurements were probed with a mango, and it was found that it measures the maturity without destroying the fruit. This was possible to know the interior composition too, as conductivity of the feed, peel and pulp.

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