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Reconfigurable instrument for measuring variations of capacitor's dielectric: an application to olive oil quality monitoring

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ABSTRACT

The current method for the extraction of olive oil consists on the use of a decanter to split it by centrifugation. During this process, different olive oil samples are analyzed in a chemical laboratory in order to determine moisture levels in the oil, which is a decisive factor in olive oil quality. However, these analyses are usually both costly and slow. The developed prototype is the foundation of an instrument for real-time monitoring of moisture in olive oil. Using the olive oil as the dielectric of a parallel-plate capacitor, a model to relate the moisture in olive oil and capacitance has been created. One of the challenges for this application is the moisture range, which is usually between 1 and 2%, thus requiring the detection of pF-order variations in capacitance. This capacitance also depends on plate size and the distance between plates. The presented prototype, which is based on a PSoC (Programmable System-on-Chip), includes a reconfigurable digital and analog subsystem, which makes the determination of moisture independent of the capacitor. Finally, the measure is also sent to a smartphone via Bluetooth.

Keywords: olive oil, moisture, capacitor, capacitance, dielectric, PSoC, reconfigurable.

1. INTRODUCTION

Moisture is present in almost all the food we eat. The trade standard specifies a maximum content limit which depends on each product. In the case of olive oil, it is considered as a contaminant, so even a slight deviation from the defined standard adversely affects its quality [1]. Thus, moisture content is one of the parameters analyzed to evaluate olive oil quality. However, the current traditional process is subject to chemical analyses, delaying the time-to-market and increasing production costs. Therefore, a real-time *in situ* monitoring of the moisture in olive oil would reduce both time delays and costs.

One of the advantages of the chemical method is its accuracy, which is also independent of the oil type, so the real-time monitoring should be flexible enough to be a real competitive alternative to this traditional process. This versality can be achieved thanks to PSoC (Programmable System-on-Chip) devices, whose reconfigurability capabilities allow the development of sensor-based systems that are adaptable to the inherent variability in the output from one sensor to another. The developed sensing system relates capacitance variations in a parallel-plate capacitor, which uses different olive oil samples as dielectric, with the sample's moisture concentration.

In the following sections this method is detailed and validated, and the final instrument is presented; finally, the main conclusions are drawn in Section 4.

2. OLIVE OIL AS DIELECTRIC

A parallel plate capacitor is quite simple, as it stores certain level of charge which is directly proportional to the potential difference between its two plates (Eq. 1). The proportionality factor, C, is known as capacitance and depends on the geometry of the capacitor's plates and the permittivity of the dielectric material between them. Eq. 2 shows this dependence, where ε_o and ε_r are the permittivity of the vacumm and the dielectric material respectively, A is the conductive plates' area and d is the dielectric width (spacing between the conductive plates).

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$$Q = C \cdot \Delta V \tag{1}$$

$$C = \frac{\varepsilon_r \cdot \varepsilon_o \cdot A}{d} \tag{2}$$

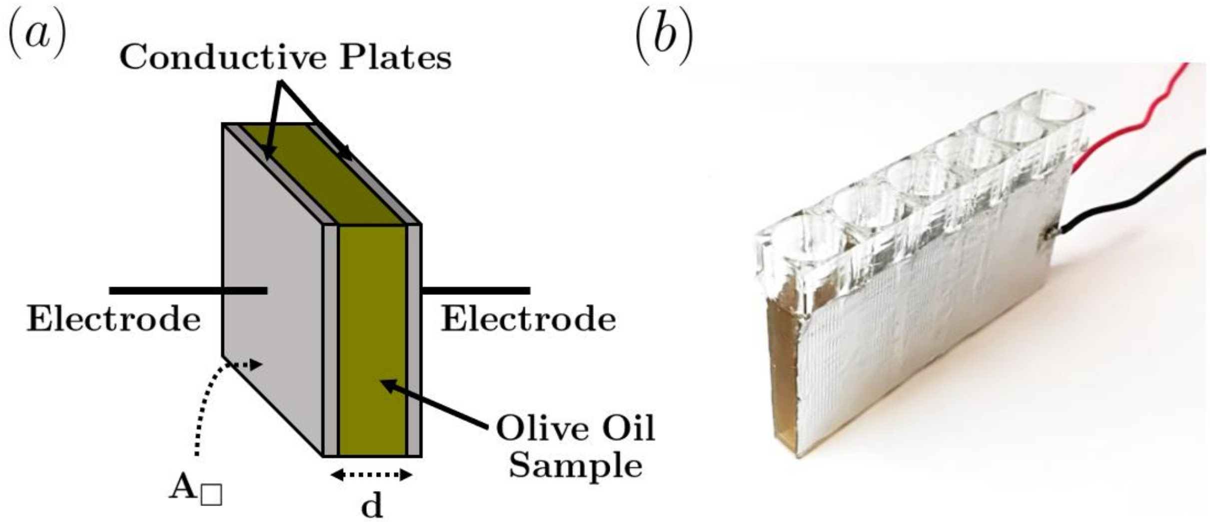

Figure 1. (a) Model of a parallel plate capacitor. (b) Experimental setup.

The implementation of this model is shown in Figure 1b. The capacitor consists of two conductive plates comprising $25cm^2$ rectangles of aluminum placed 5mm apart, which gives a volume of 12.5 cm^3. The characterization of the olive oil sample is made through the variation in the capacitor's capacitance. This capacitance, as Eq. 3 indicates, only depends on the variation of the dielectric constant of the olive oil sample. Therefore, the capacitor's capacitance when using olive oil as dielectric and the capacitance obtained without it can be easily related.

$$\frac{C_{Oil}}{C_{Air}} = \frac{\varepsilon_{r_{sample}} \cdot \varepsilon_o \cdot \frac{A}{d}}{\varepsilon_o \cdot \frac{A}{d}} = \varepsilon_{r_{sample}} \tag{3}$$

3. INSTRUMENT DESIGN AND IMPLEMENTATION

During the last years, the use of reconfigurable technologies, such as Field-Programmable Gate Array (FPGAs), Field-Programmable Analog Array (FPAAs) and System-on-Chip (SOCs), has consolidated in the development of portable instrumentation for biomedical and chemical applications [2-4]. The great advantage of this technology is that it offers much more versatility than full-custom devices. The developed instrument includes a PSoC 5LP (Low-Power Programmable System-on-Chip [5]) by Cypress. This device, thanks to its reconfigurable analog and digital domains, makes the instrument independent of the physical characteristics of the capacitive sensor, as well as of the olive oil type.

3.1 Reconfigurable capacitance measuring circuit

The key aspect in this application is measuring very small capacitance changes in relatively large capacitance values. For this purpose, different circuits can be suitable; one of them is the AC-based circuit [6]. Using this topology, shown in Figure 2, the value of the capacitor C_X can be measured with high accuracy, since its transfer function is stray-immune, as Eq. 4 indicates.

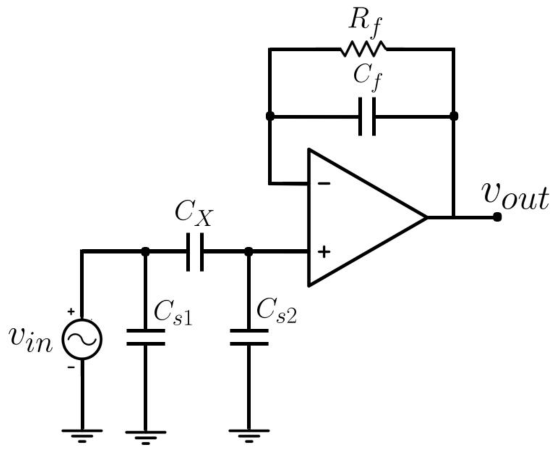

Figure 2. C_X measuring circuit. *Cs1* and *Cs2* represent the stray capacitances.

$$A_v = \frac{sC_X R_f}{1 + sC_f R_f} \approx \frac{C_X}{C_f} \tag{4}$$

This approximation is valid when the value of the feedback resistor is high enough to consider $|sC_f R_f| >> 1$.

Therefore, the capacitance C_X can be obtained from the circuit voltage-gain. Following this principle, this circuit was implemented in the PSoC development tool (PSoC Creator), with its block-diagram shown in Figure 3. The analog subsystem of the PSoC allows the internal generation of the input sinusoidal signal using a DAC (Digital-to-Analog Converter) as well as the current-voltage conversion. Finally, the output signal is converted again to the digital domain for its processing. In this particular example, the selected values are *Rf = 1MΩ*, *Cf = 4.7 pF* and *f = 100kHz* in order to satisfy the condition imposed by Eq. 5. This, along with the capacitor C_X that, according to its physical dimensions and the volume of dielectric used, takes values in the range 4.7-20pF, provides a voltage-gain in the range 1-4.5. On this basis, the amplitude of the input signal was set to 500 mV to take advantage of the whole dynamic-range of the ADC.

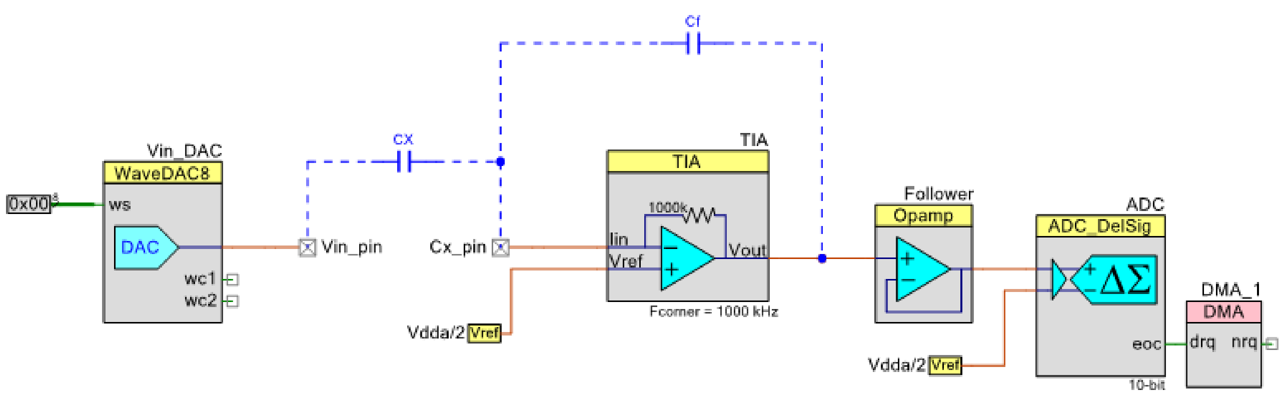

Figure 3. C_X measuring circuit implementation for PSoC 5LP. The external components are represented in blue.

The advantage of this implementation is its reconfigurability, since the parameters of the input signal (frequency, amplitude, waveform, etc.) can be modified, as well as both current-voltage conversion and DAC stages.

3.2 Moisture in olive-oil determination

Once the amplitude of both input and output signal are known, the dielectric constant of the olive oil sample can be calculated combining Eq. 3 and Eq. 4, which yields:

$$\varepsilon_{r_{sample}} = \frac{C_f}{C_{ref}} \cdot \frac{\sqrt{\sum_{n=1}^{N} V_o^2(n)}}{\sqrt{\sum_{n=1}^{N} V_{in}^2(n)}} \tag{5}$$

being C_{ref} the value of the two-parallel capacitor obtained when it is empty (air as dielectric) and N the number of samples.

The next-step is defining a calibration curve to relate the dielectric constant of the olive-oil sample with its moisture content. For that purpose, different samples of olive-oil with a controlled moisture content between 0% and 10% were prepared using a centrifuge tube rotator (shown in the inset of Figure 4). As seen in Figure 4, the dielectric constant of the samples is directly proportional to its moisture content, which facilities the definition of a calibration curve.

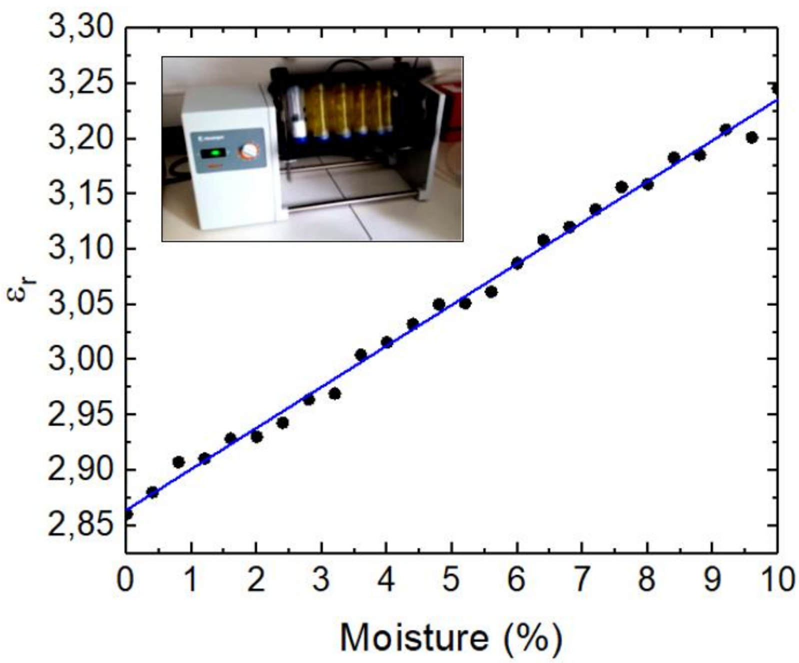

Figure 4. Dielectric constant – Olive oil Moisture (%) calibration curve for the capacitor shown in Figure 1.b. Inset shows the centrifuge tube rotator used to prepare the calibration samples.

3.3 Final prototype and mobile app

The final prototype developed is shown in Figure 5a. It includes a PSoC 5LP CY8CKIT-010A Development Kit [7], which implements the analog system described above as well as the data processing, along with an expansion shield that provides the following features:

- Power Supply (5V USB or 3.7V batteries).
- Programming interface.
- Debugging interface.
- Bluetooth communication.
- SD card storage.
- Pin headers.

Through the Bluetooth interface the measures are triggered and, once the value of the moisture is obtained, it is sent to the Android App for its visualization (Figure 4b).

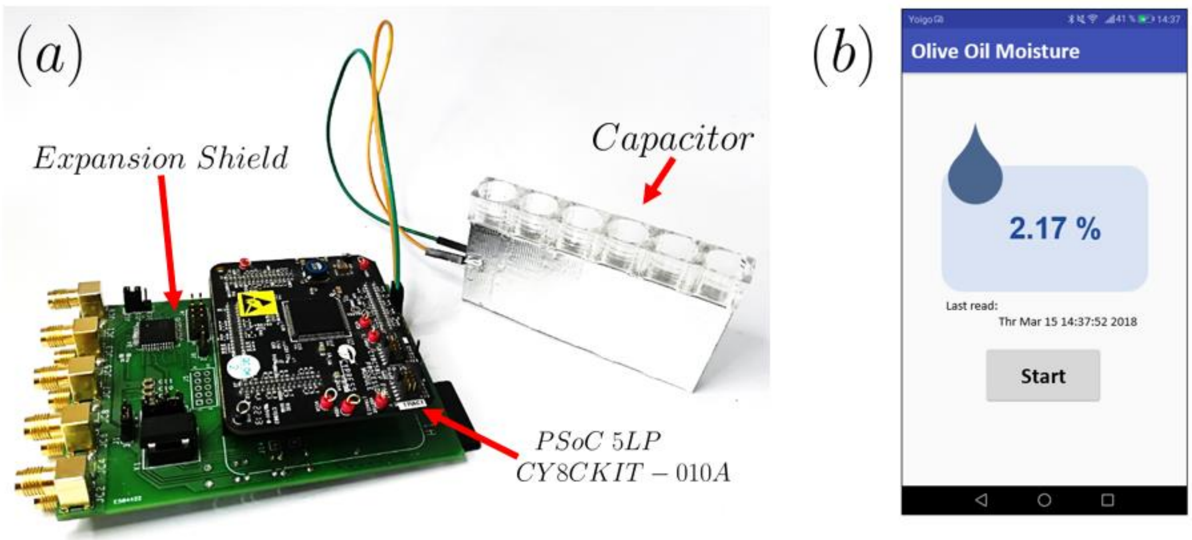

Figure 5. (a) Final view of the instrument developed. (b) Android App screenshot.

4. CONCLUSION

In this manuscript the design and validation of a reconfigurable instrument to determine the moisture in olive oil in a non-invasive way has been presented. The percentage of moisture is obtained through its relationship with the dielectric constant of the olive-oil samples, which is almost linear. This instrument is controlled by a smartphone app, in which the moisture percentage obtained is visualized and new measures can be triggered.

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