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# Construction of an experimental pilot-scale electric oven using wireless sensor instrumentation for baked food evaluation

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ABSTRACT

This work aims at the development of a pilot-scale electric oven to test the possibility of evaluating baked food propriety by using a wireless sensor network. The experiment was realized in the Faculty of Animal Science and Food Engineering where the technologies will enable new possibilities to analyze baked food improvements. To test the oven developed, an experimental setup with traditional Brazilian baked food was investigated. The food investigated was biphasic; it consisted of a filler surrounded by flour-based dough. An image of the biphasic food was acquired to control the oven temperature and belt velocity during the baking process and then to check whether the baking had been carried out correctly. In addition, the temperature inside the filler was monitored using an encapsulated wireless system. The experimental setup developed was able to demonstrate how digital images and filler temperatures could be used to control the oven temperature and belt velocity within the pilot-scale oven.



## 1. Introduction

To add technology to Brazilian food manufacturing, it will be necessary to invest in interdisciplinary scientific research in order to understand factors that affects the quality of baked products. The economic value of the products produced is associated with their acceptance in the market. Thus, it is necessary to understand the factors that affect the quality of a baked product such as food color that is directly related to the heat transfer and convection occurring in the oven (Shibukawa et al., 1989), firmness that is related to the oven temperature profile, structure (Patel et al., 2005), airflow (Therdthai et al., 2002) and moisture content (Zareifard et al., 2009) that can affect the dynamics of convection and radiation heat transfer and hence the way in which oven characteristic act on the baked food proprieties.

The international standardization, with respect to food products increasingly focuses on control of quality even before

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the ingredients enter the production line. Within this is the monitoring of ingredients, as well as close monitoring of food during its production (Ning et al., 2006).

Pilot-scale oven implementation has been shown to be effective in developing phenomenological hypotheses for the baking of bread and biscuits (Fahloul et al., 1994; Sablani et al., 1998) and a number of mathematical models have been evaluated by comparing simulated and experimental results obtained in a pilot-scale oven (Fahloul et al., 1995; Therdthai et al., 2003; Sommier et al., 2005).

Most systems to monitoring and control in the food industry use cables to carry data in order to ensure its reliability and safety as well as to meet the requirements of economic cost. In this kind of environment, there is a need for monitoring and controlling the many variables that directly determine the quality and desirable characteristics of the food product (Sommier et al., 2005).

Wireless sensors, suitable for remote monitoring of food properties, are currently a challenge for industry application. There is a lack of scientific information about wireless systems monitoring equipment like ovens. Some articles in the literature show possible solutions of wireless sensor network in the field of food transport supervision (Zou et al., 2014). Recently, Shih and Wang (2016) described the effectiveness of a wireless sensor network to cold chain management in the food industry.

Wireless sensors networks allow the monitoring and control of various types of environments (Silva et al., 2005); their use has been widely studied for various application areas, including food process monitoring (Ning et al., 2006). Their viability in industrial environments is justified by the characteristics of ubiquitous and processing node mobility (Manes et al., 2007). Thus, data collection conducted by several sensors at the same time guarantee the accuracy of the synthesized information (Asada et al., 2000).

Measurements are important for understanding different aspects of the food, such as texture (Szczesniak, 1988; Chen et al., 2005), crispness (Maruyama et al., 2008) and production factors (oven temperature, flour quality, conveyors speed) (Heidenreich et al., 2004). This suggests using a pilot-scale oven to modify oven characteristics and baking profiles to improve food characteristics without having to engage in high-cost experiments and process losses on the production line (Zareifard et al., 2009). Also, the determination as to whether baked food has been cooked correctly, especially while baking, is an important aspect to be considered in oven tunnels and this information can be acquired by digital image of baked food (Iyota et al., 2010; Paquet-Duranda et al., 2012).

This work aims the development of a pilot-scale electric oven with a computerized system powered by a wireless sensor network to monitoring the oven variables. To test the effectiveness of the system, a traditional Brazilian baked food characterized by having a filler surrounded by flour-based dough (forming a biphasic food) was used as a trial application. The biphasic food was baked and the process was monitored to check that the food had been cooked correctly.

## 2. Materials and methods

This work was carried out at the Faculty of Animal Science and Food Engineering, University of São Paulo, by employing techniques of electronic instrumentation, embedded computing and wireless communication.

As an overview, the system developed can be described as an oven with an upper and lower chamber with a metal chain conveyor belt moving between the chambers. A computer system connected to the oven via wireless network to collect and send data through sensors and actuators dispersed inside the oven. The system could thereby monitor and control in real time the oven components such as heating elements, belt velocity and temperature sensors.

### 2.1. Oven details

The pilot-scale electric oven was designed and built having three zones: Preheating, Baking and Cooling. Each consisted essentially of:

- Internal area with a useful volume of $0.4 \times 0.4 \times 2.0\,m^3$ where the product is heated.
- Six electric heating elements of 1.2 kW, three positioned 0.2 m above the product surface and three below in the lower chamber.
- Electronic system for belt velocity control and monitoring sensors.
- Thermal insulation.

The heaters were separated in two sectors per zone, one above and another below the conveyor belt. The oven construction is shown in Fig. 1. A computer control system was set up to act in each oven sector by mean of actuators linked to heaters and temperature sensors.

### 2.2. Sensor nodes and communication protocol

The sensor nodes were developed to: perform temperature measurement that represent the actual temperature of the oven and inside the food during the baking process; monitor belt speed and the mixer by using the methodology described by Pereira et al. (2013) and then to produce the dough properties in real time. Fig. 1 illustrates the placement of the sensor nodes.

Temperature sensors should meets specific limits of error tolerance and frequency response adequately in order to obtain real time measurements of oven and food temperature. This could be achieved by using k-type thermocouples to measure the oven temperature and j-type thermocouples to monitor temperature inside the food. The thermocouple signal conditioning was made using the AD595 integrated circuit (IC) conditioner from Analog Device® (USA). This device connects the thermocouple to an amplifier that is contained in a loop that uses the ambient temperature as its reference. The AD595 IC at ambient temperature has an ice point compensation circuit that develops a voltage equal to the deficiency in the locally reference thermocouple loop.

This system could produce a temperature proportional to $10\,mV/^{\circ}C$. The analog output of the AD595 was digitalized by using a 12-bit analog-to-digital converter provided by a PIC 16F877A Microship® (USA) microcontroller. With all electronics requirements well established, the system was calibrated by using a controlled temperature chamber with a digital thermometer from Minipa® (BRA). The temperature sensor was placed in the oven sectors as shown in Fig. 1.

The temperature of food during the baking process was measured by using an insulated cylindrical-shaped system with a cavity measuring $0.01\,m^3$ as illustrated in Fig. 2. The main components in the developed sensor nodes are a low