RESEARCH ARTICLE OPEN ACCESS

Innovation in coffee post-harvest: development of an automation system for the drying process.

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ABSTRACT
Innovation is one of themost important elements in order to obtain success in any business. In this paper, firstly we will show the importance of innovation and then its application with technological development, based on a mechatronic system for automation in the drying step of thecoffee post-harvest process. This implements a design methodology in real environments with real coffee producers, in order to generate innovation and help to obtain quality in the final product. Every step of the methodology applied is explained including designs, implementation and validation phases.

Keywords: Agriculture Innovation, Coffee Automation, Coffee drying, Specialty coffee, Technological Development.

I. INTRODUCTION

"One of the stages in generation of innovation is development, where a discovery moves from laboratory to field and is scaled up, commercialized and integrated with other elements of the production process"[1]. This concept may be called application. To be able to include an application piece in a technological development, it is appropriate to study its needs, which vary depending on specific geographical situations. With the afore-mentioned item we seek to add innovation to processes which aim to improve production systems. Analysis of social networks indicates that they are an example of how to suggest linear detail in search of the information existing in farmer's networks and service extensions. In the same way, it is recommended that the agricultural innovation catalyzation programs should consider interaction and know how to exist among farmers [2].

As an example we want to discuss an experience from the Mexican agricultural sector. In an association for coffee producers, a social project has been developed concerning problems which occur during the production process. In this project, organic fertilizer and fuel production based on waste recycling with farmer participation have been provided [3].

In addition to the innovation processes in agricultural production, after-harvesting processes should also be analyzed. In the specific case of coffee culture it is necessary to understand the changes the coffee bean is subject to until it has achieved its taste characteristics, to develop technological alternatives that allow the coffee's tasting characteristics to improve, bearing in mind the afore-mentioned and other aspects such as the metabolic activity that occurs during the drying process, and the potential of some proteins to be highlighted as taste makers and drink aromas, the quality control which is necessary for after-harvesting processes and the abundance of protein in the bean after drying [4]. The present article seeks to be understood as an innovation suggestion and consists of the development of an automatic system for monitoring and control of the coffee drying process.

To develop such a system, we took drying experiences from agricultural products such as coffee, tea, tobacco, fruits, cocoa, rice, walnut and wood, which all require a consistent but relatively low heat exposure while drying. This process traditionally is done by wood fire or fossil fuels in ovens which have the disadvantage of causing environmental pollution; another current method is free air drying under sunlight which is sensitive to climatic changes [5], requires extensive open spaces, and leaves the product susceptible to becoming infested with polluting elements such as dust and garbage, as well asto exposure to fungi, birds, insects and rodents [6].

Another common technique is sun drying, for which various designs have been developed, for example the use of environmental air heated by sun collectors through drying air recycling [7]; sun dryers which include a sun collector, a drying chamber and a centrifugal blower, enclosed in polystyrene laminate where the hot air is driven to the drying tunnel by a conductor pipe in U-form [8]; in the same way the solar dryer is used; the sun drying approach is based on heat recovery, a mode which works following the principle of a hothouse catching the energy by condensation. For the latter a mathematical model has been built which is based on heat and mass transfer, fluid flow and maximum working achievement by limit analysis [9].

In order to apply innovation components to the after-harvesting process of coffee, we suggest a monitoring and control approach for coffee drying, consisting of a mechatronic system that supports the final product's quality improvement.

Mechatronic systems integrate mechanical systems with electronics and information technologies [10], most new products for different fields of application: industrial, business or home, are designed as mechatronic systems. Agriculture also includes mechatronic devices for optimizing resources and increasing efficiency.

A mechatronics system design requires multidisciplinary collaboration equipment; in order to organize this collaboration, there are several design methodologies such as waterfall model, spiral model or V-model, all of them applied in systems engineering to establish the steps to transform customer needs into a product or prototype [11]. Those methodologies help engineers from different disciplines to enable their collaboration for complex tasks in design engineering. However there is not a design methodology specially adapted for mechatronic projects; they are approach-based or derived from methods such as traditional sequential design, concurrent engineering or recent lean product development [12].

Based on the v-model, a methodology is defined that includes integrated design process and concurrent engineering that implement a life cycle project as shown in Figure 1.

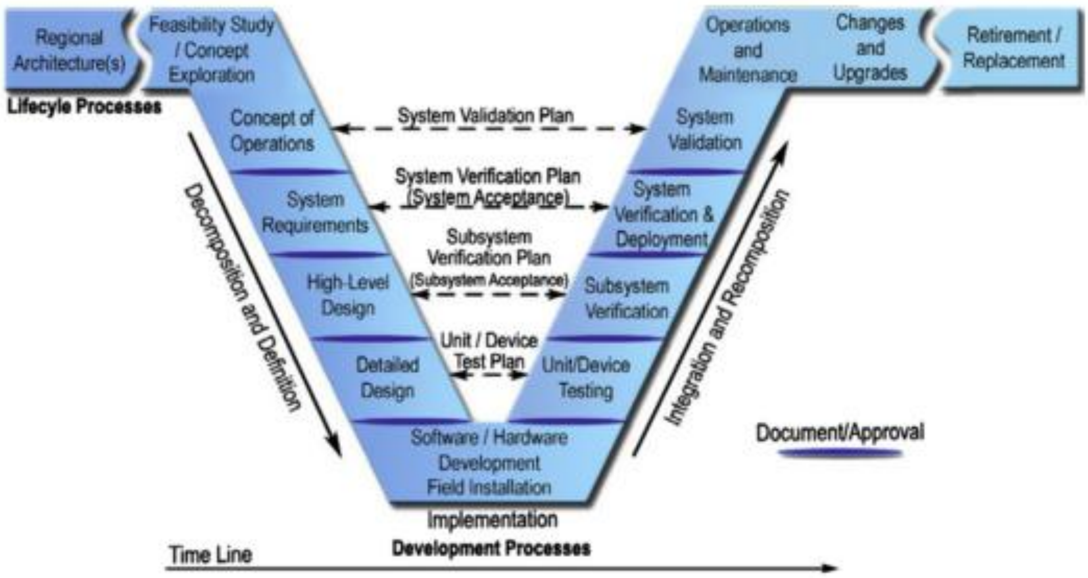

Fig. 1. V-Model for a mechatronic system develop [12].

II. DEVELOPMENT OF AN AUTOMATION SYSTEM FOR COFFEE DRYING PROCESS

The V-Model was implemented as a methodology to develop a coffee drying process control and monitoring system.

2.1 Concept of operations

In the concept of operation phase, the advice from the Coffee National Research Center CENICAFÉ about a drying process using solar parabolic dryer method was taken into account. This method includes a drying time of 7 to 15 days to obtain humidity about 12% or 10%, using a 35 mm coffee layer, and layer mixing 3 or 4 times per day [13].

2.2 System requirements

Requirements were taken from three principal sources: coffee growers, a coffee quality specialist tester, and designers of specialty coffee trade support software, who all seek to integrate their own subsystem into the system information. Functional and non-functional requirements were described and documented, including:

- Easy access and operation for coffee growers.
- Temperature (T), and Relative Humidity (RH) measurement.
- Capacity to store up to 1 million samples.

ISSN: 2456-2764, Vol. 2, Issue 4, September 2017, pp.01-09

- Real time capabilities.
- Power: rechargeable batteries.
- T and RH displayed on screen.
- Outputs for air extractor control.

2.3 High level design

Block diagram shown in Figure 2 represents high-level design of main components comprising the Temperature (T), and Relative Humidity (RH), measuring and control system. The T and RH Sensor detects these variables in the coffee dryer, the real time clock takes a time stamp (time and date) for measurements, the storing unit saves data for subsequent analysis, and the visualization block allows users to know variables' status inside the drier. Actuators for temperature controlling (air extractors) are connected to relay output, battery charge allows uninterrupted power for the whole system, and a microcontroller component controls all other block functionality.

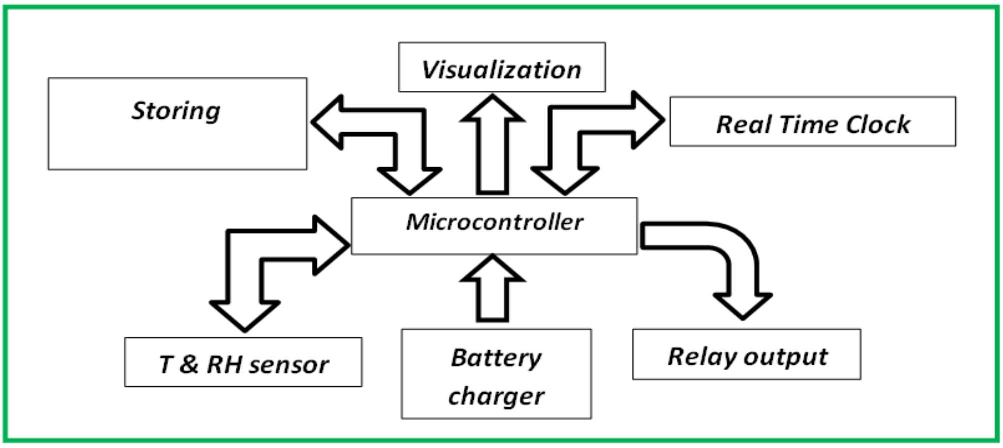

Fig 2. Block system diagram.

2.4Detailed design

In detailed design each block of the high level design is explained in terms of parts, components and their integration for a single functionality.

2.4.1 Real time clock

Real Time Clock (RTC), provides time stamps for T and RH data storing. A Maxim Integrated DS3234 is used, this component is a high precision SPI (Serial Peripheral Interface), communicated with integrated temperature-compensated crystal oscillator (TCXO); a 12mm coin-cell battery backup is also included.

2.4.2 Data storing

T and RH data obtained by sensors is stored in a microSD card connected to microcontroller trough SPI. Data is stored in a plain text file as comma separated valued (*.csv) in order to integrate with other information systems and subsequent analysis in a spreadsheet; Figure 3 shows a fraction of a "Software for helping specialty coffee trade" design diagram and its integration with the data storing subsystem.

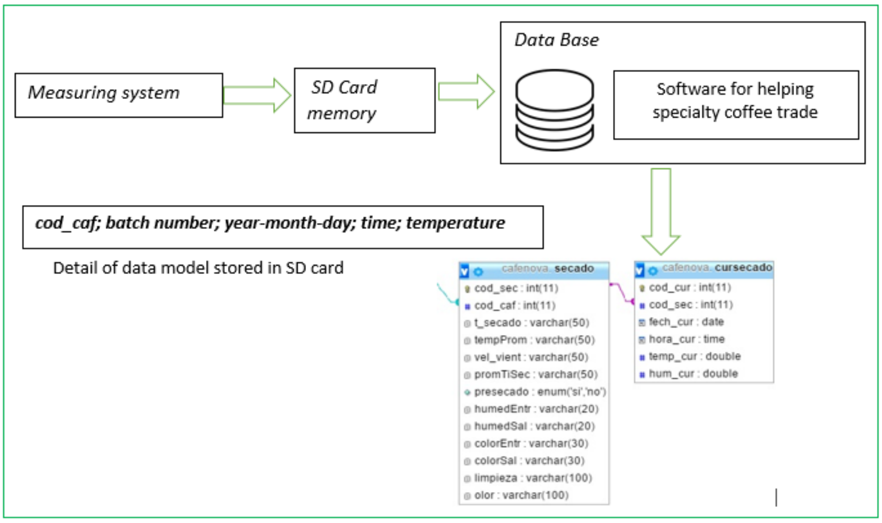

Fig. 3, Data storing explained, and its integration with systems information software.

2.4.3 Visualization

The T and RH state inside the coffee dryer and time and date information are published in a 2 X 16 Liquid Cristal Display (LCD), that can be consulted by growers at any moment, allowing decisions like whether or not air flow should be allowed in order to obtain an optimum grain humidity.

2.4.4 Relay output interface

Relay output allows the connection of optional controllers to change the state of variables inside the dryer, for example heat extractors that increment cold air flow and reduce T and RH.

2.4.5 Microcontroller

The microcontroller manages other sub-systems mentioned, requesting sensor and RTC for T, RH data and date and time respectively, storing data onto an SD card and making an on/off control in relay output; information managing is explained with a flow diagram show in Figure 8; An ATMEL AVR ATMEGA 328® microcontroller was used, some characteristic of this device are 16K flash memory and 2 SPI ports as shown in Figure 4 block diagram.

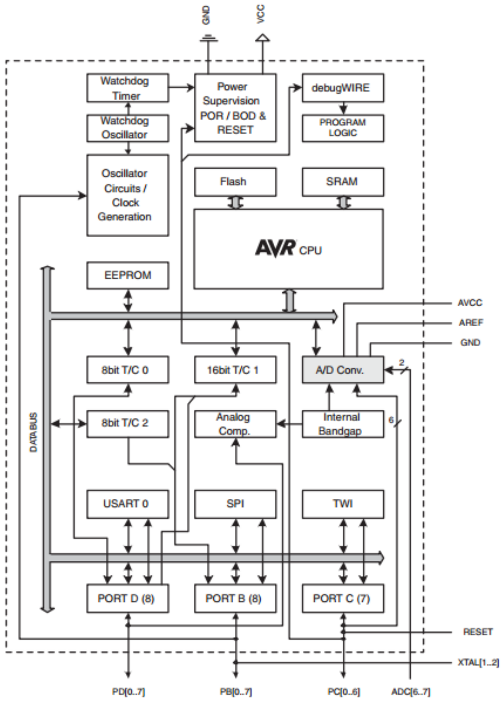

Fig. 4. Atmel AVR ATMEGA 328P block diagram [14].

2.4.6 Battery charger system

A battery charging system and a long life Li-Ion battery pack are integrated in order to power the whole system; it is needed because dryers are often far from AC electricity sources and a 15 day power autonomy is needed. A MCP73833 Li-Ion / Li – Polymer charger manager from Microchip Technology Inc®. Company was used.

2.5 System integration

Based on a fast prototyping approach and detailed design, it was established that an ARDUINO 1 development board would be used as a strategy to integrate components, with quick validating and adjusting to obtain a final product. Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino 1 is one of the more basics boards in the family, it is based on an Atmel Atmega 328 microcontroller, it has 14 digital I/O ports, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It also has the option to use shields; boards that can be plugged in on top of the Arduino PCB extending its capabilities; a micro-SD card in the Ethernet Arduino shield V1 was used to store T and RH data; also based on Arduino modularity it was designed as a proprietary compatible shield used to attach T and HR sensor and the real time clock with its backup battery as shown in Figure 6.

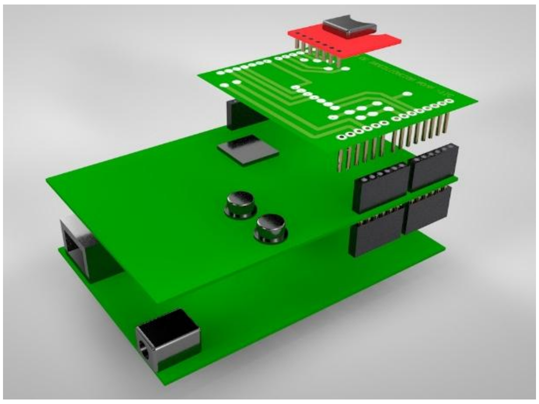

Fig. 6. Arduino 1, Ethernet shield and custom shield for sensor and RTC integration.

2.6 Essential consideration for temperature measuring

Solar radiation causes important temperature measuring errors [15], for this reason it is crucial to use radiation shields that minimize this effect in instruments' sensors. Although radiation shielding is most important for measuring air in the open, it also should be considered for any temperature sensor that is not completely shaded during measurement periods [15]. There are several types of radiation shields for temperature, sensors of aspirated air or fan based; in the first group we found three most commonly used types in weather stations across United States: CRS (Cotton Region Shelter), MMTS (Maximum - Minimum Temperature System) and Gill Shields [16]

2.7 Radiation shield design and construction

A home-made anti- radiation shield based on the GILL model and [Tara &Hoheisel, 2007] work, was designed and constructed using five (5) 240 mm diameter rounded white polypropylene layers, separated from each other by 20 mm and 140 mm total in height as shown in Figure 7. For ventilation, 4 mm holes were made in the layers underneath.
An RHT03 sensor was placed in the shield's second layer using a PCB coupled with a RJ45 jack to facilitate connection to datalogger using an unshielded twisted pair (UTP) cable.

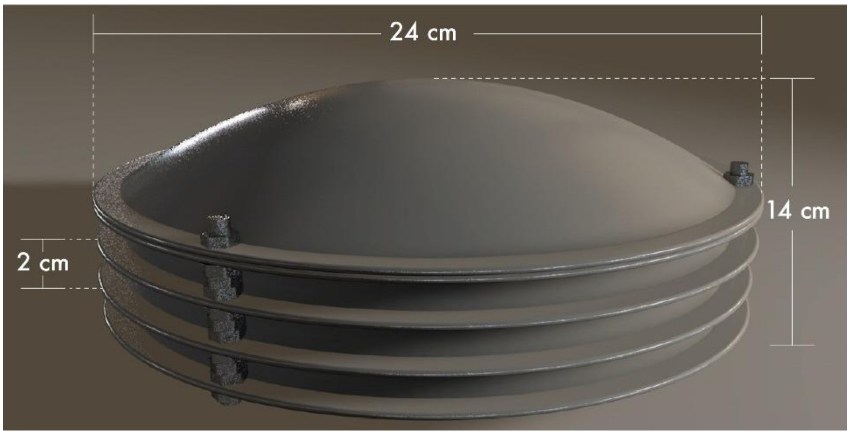

Fig. 7. Anti-Radiation Shield design and dimensions.

2.8 Firmware programming

A firmware code was designed for subsystem management; it was in charge of RHT03 data requesting, validation and displaying, and also of comparing it with maximum and minimum set points for temperature control using relay enable or disable and data storage with RTC time stamp; a flow diagram design is shown in fFigure 8.

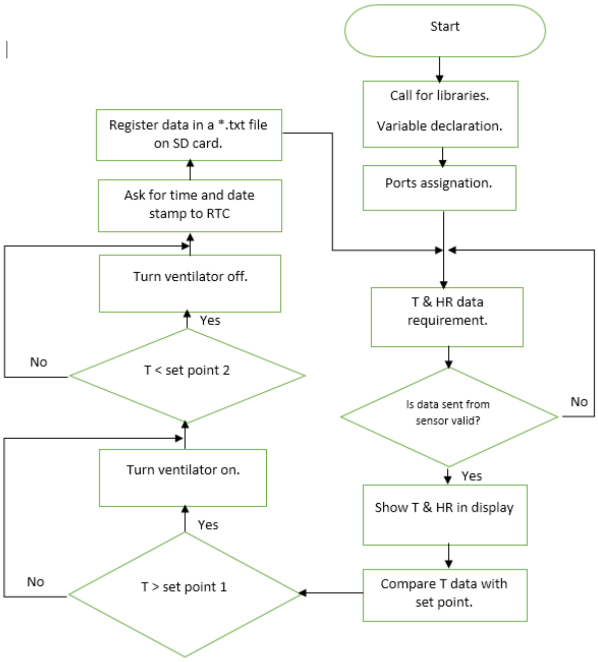

Fig. 8. Firmware design flow chart.

2.9 Deploy and test

Following V-model methodology, individual and subsystems testing was carried out for microcontroller management of the real time clock, temperature sensor, SD memory card, liquid crystal display and relay modules; all of them comply with system requirements established in earlier steps. Tests were developed using testing firmware and a checklist; a final design model is shown in Figure 9.

Fig. 9. Final design model with sensor shield detail.

System validation was applied on three coffee farms -“Mamola”, “Villa Eilyn” and “Lucitania”-, placed in rural area of the municipality of La Plata – Colombia, for testing the total operation concept according to the V-model; see Figure 10.

Fig. 10. La Plata – Colombia localization. Dark Gray shows urban and rural areas.

The mechatronic system was installed in a parabolic solar dryer of each coffee farm, as shown in Figures 11, 12 and 13; during the coffee drying process -15 days average-, T and HR data were collected and registered while temperature was controlled according to users' configurations.

Fig. 11. System installed in "Mamola" coffee farm's solar dryer.

Fig. 12. Installing the radiation shield's sensor.

Fig. 13. Installing the whole system.

In order to analyze T and RH behavior before and after the implementation of heat extractors in test dryers, data collected was plotted on graphs as shown in Figures 14 and 15.

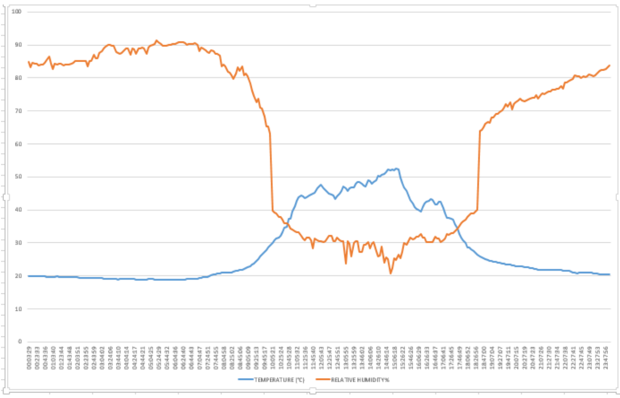

Fig. 14. Temperature and Relative Humidity behavior in parabolic solar dryers without the use of heat extractors.

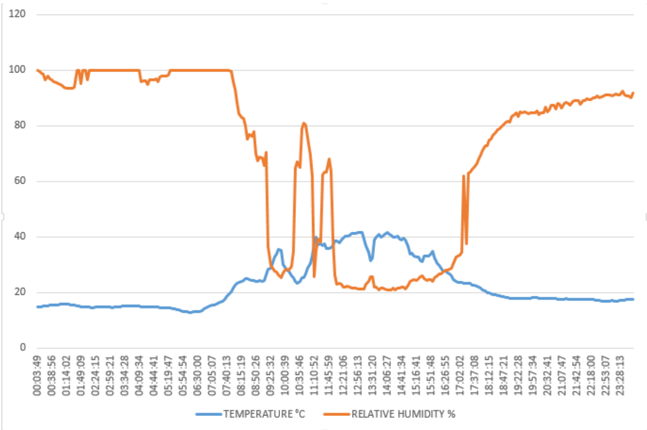

Fig. 15. Temperature and Relative Humidity behavior with heat extractors' activation at 40 °C.

III. CONCLUSION

Internal temperature in a parabolic solar dryer is higher than 50 °C and relative humidity higher than 90%. These conditions produce physical defects such as moldy or crystallized beans.

V-methodology was implemented to develop a mechatronic device to improve the drying process. All steps in the methodology were applied in order to obtain a robust product that meets all the user requirements.

The Datalogger device was installed in three coffee farms in order to validate the concept of operations and all of the requirements established; this validation was successful according to a evaluation instrument i.e. a check list.

Integration with "Software for helping specialty coffee trade", was satisfactory and information stored with the device is registered to help the traceability process to coffee producers that use this information system to promote their products to local or international buyers.

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