Abstract: Controlled atmosphere storage is a technology that reduces the metabolic reactions of fruits and, when properly applied, helps to maintain their freshness and quality. This work describes the development and implementation of a system used to regulate four atmosphere controlled chambers for conservation of cherries, variety Saco. The data acquisition and control system uses a personal computer and a data acquisition card connected to sensors and actuators installed in the chambers. The software was developed using LabVIEW version 8.5 from National Instruments. The software has a friendly interface to input and/or access data, such as: set the sampling interval and set-points, among other variables. The user can specify different set-points for temperature and gas concentrations as programmable events along time. The actuating signals for cooling and gas concentration control are computed using incremental PID algorithms.

Keywords: Computer Controlled Systems, Data Acquisition, Temperature Control, PID control, Models.

1. INTRODUCTION

The cherry variety known as Saco is a regional variety produced and highly appreciated in the region of Alto Douro, Portugal, namely in Cova da Beira, Resende and Vila Real. It is a perishable product whose behaviour when stored in cold normal atmosphere chambers (CNAC) is well known. Cherries cold Storage is a special kind of conservation in chambers, where the temperature (T) is kept between −1°C and 1°C, extending the postharvest cherry life in 2 to 3 weeks. In order to increase the cherry storage life it is necessary to employ fully controlled atmosphere storage chambers (CASC), i.e., chambers that allow, not only the control of the temperature, but also of the humidity and the concentration of gases. Controlled atmosphere storage is a technology that reduces the metabolic reactions of the fruit and when properly applied, helps to maintain its freshness and quality along time. Technical information about the optimal gas composition in cherries is wide and diverse and dependent on both the soil and climate conditions of the production site and of the cherry varieties. According to Remón S., et al. (2000, 2004) cherries "Sweetheart" tolerates a broad band of gas composition CO₂:O₂. The optimal concentration, evaluated by a panel of consumers after 3 weeks of storage, was CO₂:O₂ - 5%:2% at a temperature (T) of 1°C and a relative humidity (RH) of 95%.

This work presents the development and implementation of four controlled atmosphere storage chambers for conservation of cherries, variety Saco. The data acquisition and control system employ a personal computer with a data acquisition card, model USB-6229 from National Instruments, where are connected the sensors and the actuators...
installed in the chambers. The software was developed using LabVIEW version 8.5 from National Instruments. The software has a friendly interface to input and/or access data, such as: set the sampling interval and set-points (SP), among other variables. The user can specify different SP for temperature and gas concentrations as programmable events along time. The actuating signals for cooling and gas concentration control are computed using incremental Proportional-Integral-Derivative (PID) algorithms.

In addition to this introductory section, this document is organized in three more sections. In section two are presented the materials and methods employed. Section three presents functionalities of the control software developed and some results. In the last section are drawn the conclusions and pointed future work.

2. MATERIALS AND METHODS

This work was realized as a part of a project to build up facilities that allow to perform experiments and to study the influence of various controlled atmospheres over the conservation of fruits, namely cherries, after harvesting. In this way, four prototypes of atmosphere controlled chambers, Fig. 1, were developed in collaboration between the Engineering and the Plant Science Departments of UTAD University. These chambers are equipped with several sensors and actuating equipments in order to control the inside air temperature and relative humidity and the carbon dioxide (CO\textsubscript{2}) and oxygen (O\textsubscript{2}) concentrations.

To monitor and control the chambers atmospheres it was implemented the system showed in the block diagram of figure 2. The system comprises a control and data storage unit (personal computer) which is connected to a data acquisition board USB-6229 from National Instruments, being its relevant technical characteristics the following:

- 32 analogue input channels (16-bit, 250 kSample/s maximum sample rate);
- 4 analogue outputs (16 bit, 833 kSample/s);
- 48 digital I/O (32 up to 1MHz), and 32-bit counters;
- NI signal flow to support streams of data at high speed through USB;
- Compatible with LabVIEW, LabWindows / CVI and Measurement Studio for Visual Studio.NET

The physical variables of the chambers atmospheres were measured using a set of sensors connected to the data acquisition board. The sensors provide standard output signals in the range from 0 to 10 V (T and RH sensors) and 4 to 20mA (O\textsubscript{2} and CO\textsubscript{2} gas concentration sensors). The signals from the transducers are filtered with a low-pass filter, i.e., a mean filter implemented by software.

The sampling time and the data storage/control time intervals can be defined in the range from 1ms to 600s. In this case it was used a time interval of 60s to store the data and control the atmosphere in the chambers. Every 60s are taken 10 readings at a rate of 10KSample/s for each of the installed sensors, being recorded their mean values. The following table presents the sensors installed in each of the CASC chambers and their main electrical characteristics.

<table>
<thead>
<tr>
<th>sensor</th>
<th>physical variable</th>
<th>model</th>
<th>output</th>
<th>range</th>
<th>precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hygro-Thermo sensor</td>
<td>T (°C) + RH (%)</td>
<td>Thies</td>
<td>dual</td>
<td>-30 to 70°C</td>
<td>±0.1°C</td>
</tr>
<tr>
<td>carbon dioxide sensor</td>
<td>(CO\textsubscript{2} gas concentration)</td>
<td>Oldham</td>
<td>4 to 20mA</td>
<td>0 to 50% CO\textsubscript{2}</td>
<td>±0.02%</td>
</tr>
<tr>
<td>oxygen sensor</td>
<td>(O\textsubscript{2} gas concentration)</td>
<td>Oldham</td>
<td>4 to 20mA</td>
<td>0 to 30% O\textsubscript{2}</td>
<td>&lt;0.02%</td>
</tr>
</tbody>
</table>

The sensors employed to measure the O\textsubscript{2} and CO\textsubscript{2} gases concentrations where connected to the input channels of the data acquisition board with terminal precision resistors of 250Ω. In this way the analogue current output signals of these sensors are converted to voltage signals 1 to 5V for the ranges 0-50% of CO\textsubscript{2} and 0-30% of O\textsubscript{2} concentrations.
In order to regulate the atmosphere of the CASC chambers, it were installed in each chamber a heat pump for cooling the air, a dehumidifier to reduce the relative humidity, a ventilator/air pump to promote the circulation of gases through the chamber and gas filtration and solenoid valves to inject pure carbon dioxide.

2.1 Atmosphere control of the CASC chambers

The temperature, the relative humidity and the CO$_2$ and O$_2$ gases concentrations of the air inside the CASC chambers, were regulated using digital PID controllers.

The actuating signals are computed using a discrete version of the analogue PID control showed in eq. 1. Since in this algorithm the derivative term is performed over the output variable the derivative kick is avoided whenever the set-point is changed.

$$u(t) = K_p e(t) + \frac{1}{T_i} \int_0^t e(t) dt - T_d \frac{dy(t)}{dt}$$  \hspace{1cm} (1)$$

where: $u(t)$ is the controller output signal, $y(t)$ is the process output, $e(t) = y(t) - SP(t)$ is the error signal, and $K_p$, $T_i$ and $T_d$ are the proportional gain, the integrative time and the derivative time, respectively.

The digital version of the absolute PID algorithm that was implemented is showed in eq. 2, resulting from the approximation of the integral and derivative functions of eq. 1 to a sum and a first order difference term.

$$u(kT_s) = K_p e(kT_s) + \sum_{i=0}^{k-1} \frac{T_s}{T_i} e(iT_s) - \frac{T_s}{T_d} \Delta y(kT_s)$$  \hspace{1cm} (2)$$

where: $u(kT_s)$, $e(kT_s) = SP(kT_s)-y(kT_s)$ denote the controller output and the error signals at time instants $kT_s$ with $k = \{0,1,2,...\}$, $T_s$ is the sampling time and $\Delta y(kT_s) = y(kT_s) - y((k-1)T_s)$.

There are several methods referenced in the literature to tune the parameters $K_p$, $T_i$ and $T_d$ of the PID controller (Kinney, 1983; Leigh, 1992; Iserman, 1989; De Moura Oliveira et al., 2002a, 2002b). In this work, the parameters of first order linear ARX models for the temperature, humidity and gas concentration processes were previously identified off-line. It was found that the interaction between these processes control loops are low and that the linear ARX models describe well the processes dynamics since the operating set-points do not change along the time period of fruits conservation, typically 2 to 3 weeks. In this way the parameters where tuned, for each of the control processes, using an optimization algorithm to reduce the performance index ISE-Integral of squared errors, based on the identification of the parametric ARX models described by,

$$y(k) = a.y(k-1) + b.u(k-d) + \varepsilon(k)$$  \hspace{1cm} (3)$$

where $u(k-d)$ is the delayed actuator signal applied to the process, $d$ is the delay between the process output and input signals, $a$ and $b$ are the ARX model parameters and $\varepsilon(k)$ is the model error output, i.e. the difference between the real and the simulated process outputs. The models parameters were computed off-line using estimation techniques based on the least squares method (Ljung, 1987; Söderström and Stoica, 1997). Several experiments were realized in order to acquire enough data in turn of the operating region required for the relevant atmosphere variables. The data acquired was splitted in two data matrixes, one used to estimate the model parameters and other to validate the models.

2.2 User interface

The user interface and control algorithms were developed using the graphical programming language LabVIEW version 8.5 from National Instruments. In contrast to text-based programming languages, where instructions determine program execution, this graphical programming language uses dataflow programming, where the flow of data determines execution (LabVIEW, 2008) being possible to build a user interface with a set of tools and objects. The user interface is known as the front panel and the addition of code using graphical representations of functions enables the control of the front panel objects. The block diagram contains the implemented code.

The user interface enables to define all the parameters needed to regulate the CASC chambers, such the set-points (SP), Fig. 3a), and the PID control parameters, the sampling time, the sensor calibration parameters, the switch between automatic and manual control, among others, Fig. 3b).

![Fig. 3. User interface for: a) SP setting  b) setting of control parameters.](image-url)
The data of each of the controlled atmosphere chambers is automatically recorded in daily files. Users can access data files and the time plots of the data for a day or a set of days. Next figure shows the air temperature and relative humidity during a run test conducted in chamber 1.

The actuating control signals were computed with 4 PID controllers, one for each of the four process control loops. The actuating signals are computed in the range 0 to 1, which is translated, via a power interface, to a power applied to the actuator ranging from 0 to 100% of the nominal power of the actuator. The heat-pump is controlled in a proportional mode using the analog output channels of the DAQ acquisition board.

The dehumidifiers and the gas concentration actuating equipments are also controlled in a proportional way. However, these cases use digital outputs signals, and the actuators are switched between the on-off states using a PWM technique. Figures 6a) and 6b) show the contribution to the cherries conservation when are used the chambers with controlled atmosphere (control of $T$, $RH$, and $O_2$:CO$_2$ gas concentrations), being the results compared to the ones achieved with the CNAC chamber (control of $T$). In these experiments it were regulated the concentrations of $O_2$:CO$_2$ in the ranges of 2:10%; 2:15%; 2.5:15% 2.5:20% in chambers CASC 1, 2, 3 and 4, and all chambers were regulated for air temperature and humidities set-points of 1 to 1.5°C and 90 to 95%.

The implemented system is a useful tool to study and compare the performance of different cherry conservation techniques, namely for various atmosphere conditions used in conservation. The fruit quality evaluation parameters were computed according to the commonly indexes of mass losses, calibre, hardness and sugar content, (Dever, et.al., 1996; Shewfelt, 1993).

3. RESULTS

This section presents some results achieved with the implemented system. In Fig. 5 are shown the air temperatures and relative humidities controlled in two CASC chambers over a time interval period of 30 days. The setpoints were adjusted to 1.5°C and 90% relative humidity for chamber 2 and 1°C and 94% relative humidity for chamber 1.

From these graphs it can be observed the occurrence of some large deviations from the specified SP temperatures that occur whenever a door was opened to collect cherries samples for laboratory testing to compute fruit quality evaluation parameters, such as mass losses (%), calibre (mm), hardness (N-Newton) ans sugar content (ºBrix). Also, it can be seen that during the first 14 operating days the relative humidity inside chamber 1 presents an offset of about 4% which was due to an improper function of the dehumidifier system.
From the plotted cherry quality parameters measured after a fruit conservation period of 30 days in the chambers (Fig. 6), it can be seen that the chamber CNAC, which as only temperature regulation, is the worst in conserving the fruits, since the losses are greater and the calibre is the minimum.

These results show that the cherry is better conserved in fully controlled atmosphere chambers, and in this case on the CASC2 chamber, where the cherries mass losses are smaller and the calibre higher. The results achieved for the cherries hardness (N, Newton) and sugar content (ºBrix) are similar, from the point of view of yield value, for all the conservation techniques compared and illustrated in figure 6.

4. CONCLUSIONS

In this work was presented the implementation of a controlled atmosphere storage chamber system for fruit conservation. The developed and implemented hardware and software techniques were tested for conservation of cherries, variety Saco, by regulating four atmosphere controlled chambers (CASC). The results achieved with fruit conservation using this system were compared to the ones achieved with the cherries conserved in the cooling chamber (CNAC).

The implemented user interface and the atmosphere regulation possibilities of the proposed system, proof to be relevant tools in order to study the effects of different control conservation techniques in the quality of the conserved fruits. With these hardware and software tools, which are low cost and that can be easily replicated, the Plant Science Department is now capable of conducting, simultaneously, several experiments concerning fruit conservation under different combination of the physical variables that characterizes the chamber atmosphere conditions.

REFERENCES


