NEURO-FUZZY ANALYSIS OF THE *IBERICO* HAM DRYING PROCESS

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BACKGROUND

The Engineering Department of the Instituto del Frío is studying since 1996, the drying process of *Ibérico* ham. The first activities in this topic consisted of the acquisition of real data from four selected Spanish ham factories and the theoretical study of these data complemented with the analysis of water and salt diffusion by image processing in computerised tomographies. All the selected factories are located in Guijuelo, a Spanish village famous for their high quality hams. These activities have been realised in a cofinanced project by the Junta de Castilla y León.

An Analysis Tool for Drying process has been designed, trained and tested recently by the mentioned Engineering Department. This tool will be retrained with specific real data generated in fully automated ham dryers, covering all the possible conditions (humidity, temperature air circulation, ...) that are not reached in the industrial process.

The use of Artificial Neural Networks (ANNs) and Fuzzy Logic in the analysis of Drying process is complementary to the theoretical studies. It is very useful in complex systems, where theoretical analysis is difficult. The internal structure of the *Ibérico* ham and the possible great differences between different hams, makes the election of this product ideal for the development of an "empirical" Analysis Tool for Drying process.

The Analysis Tool provides an estimation of the weight reduction of an *Ibérico* ham. The weight estimation is the output of various artificial neural networks combined with the use of fuzzy logic. Each drying phase is modelled, during the tool training, with a dedicated network.

The Analysis Tool incorporates an auto reliability calculus, so it can answer "I do not know" if the test data (input and output of the tool) is quite different from the training data. It is not a "black box". The mentioned reliability calculation is made with a possibilistic clustering algorithm.

OBJECTIVES

This study has been planned with the intention of exploiting empirical data (collected from industrial process) in order to complement theoretical studies in the analysis of the Drying process of *Ibérico* ham.

The main objective of this study is the application of Neuro-Fuzzy modelling techniques in the study of the Drying process of *Ibérico* ham. The use of these techniques merges the learning and the generalisation capability of artificial neural networks with the approximate reasoning embedded in the fuzzy logic theory.

The mentioned objective is implemented in the design, construction and test of a Drying Analysis Tool. All this activities have been focused to the elaboration of a general purpose Analysis Tool for studying all kind of Drying process.

METHODS

The materials considered in this study can be resumed as data acquisition systems, automated dryers and a Drying Analysis Tool.

Independent data acquisition systems have been installed in four selected ham factories at Guijuelo. All data (historic and real-time) are available in Madrid via a modem connection. All these data are used in the development, training and test of the Drying Analysis Tool. An example of the collected data is shown in Figure 1.

Associated to this study, various fully automated dryers have been designed and constructed for obtaining complementary data to the obtained in the industrial process in order to modify the external conditions during the process.

The Drying Analysis Tool has been designed in a PC platform, using standard tool oriented programs in addition to Matlab Program in which the neuro-fuzzy algorithns have been programmed.

The Drying Analysis Tool consists of a Fuzzy Clustering algorithm that classifies the Drying process in different phases. Each of the phases (the clusters resulting of classification) has a dedicated neural network that provides an estimation of the weight reduction in one hour of the process. In the fuzzy partition problem the Gustafson and Keller (GK) algorithm is used, because clusters with different shapes and sizes are expected.

In order to get information about the process dynamics, data that correspond to different periods of time are used as inputs. The structure of the ANNs used in each cluster is feedforward (with three hidden layers). They have been trained using the backpropagation algorithm. The selection of the number of input signals and the number and separation between considered periods will be studied with data obtained in specific dryers in the next phase of the study. In the presented tests input data are temperature, humidity, already reduced weight and an estimation of the total quantity of water that still remains in the ham, during five periods of time.

The output of the tool is a fuzzy combination of different neural networks outputs, so the transitions between different phases (clusters) are not crisp.

In parallel to the described structure a possibilistic algorithm is used to provide a reliability indication of the estimation. In other words, the system checks automatically if the system status corresponds with the drying areas in which the tool has been trained. The basic structure of the Drying Analysis Tool is shown in Figure 2.

RESULTS AND DISCUSSIONS

In this paper, the answer of a Drying Analysis Tool to external conditions in the Drying process of *Ibérico* ham is presented.

The answer of the system to one of the hams included in the training of the tool, is shown in Figures 3 to 5. Each Figure corresponds to one of the three drying phases (clusters), in which the Analysis Tool has divided the full drying process; units being percentage of weight reduction and hours (from the beginning of the drying process after the salt addition phase).

In Figure 6 the estimated weight reduction versus the real weight reduction in a ham not included in the training of the tool is presented. An important factor to highlight is that the estimated percentage of weight reduced has been obtained by accumulation of each hour estimated reduction in the Drying process.

CONCLUSIONS

The first successful obtained results confirm the utility of neuro-fuzzy techniques to analyse drying process. After these tests, the Drying Analysis Tool is a reality.

The election of the main variables that affect to the Drying process and how many previous data is considered are important parameters for the configuration of the tool. These parameters can not be properly optimised using the data obtained from an industrial process. The answer of this tool, training it in new process conditions different from industrial process conditions, will pursue a better understanding of the process and lead to an optimisation of the process. The new process conditions will be generated with some fully automated dryers designed by the Engineering Depatment of the Instituto del Frío for this purpose.

PERTINENT LITERATURE

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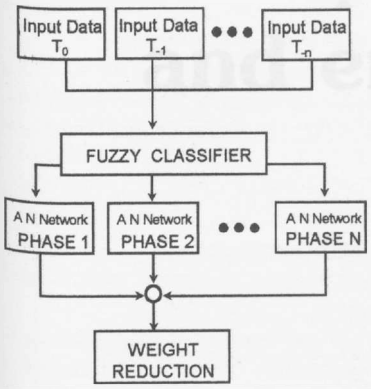

Figure 1

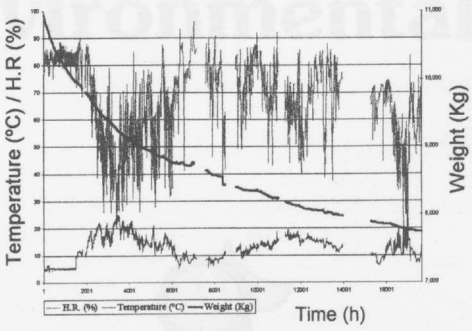

Figure 2

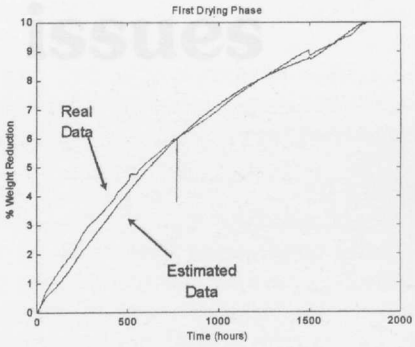

Figure 3

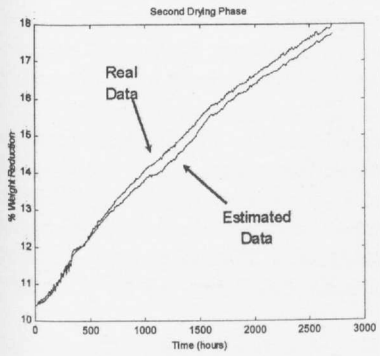

Figure 4

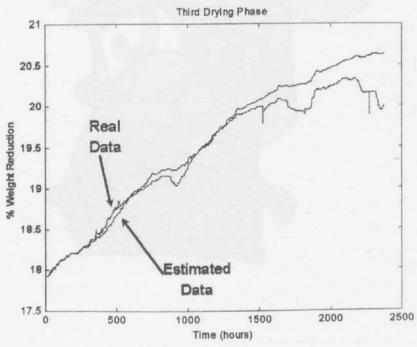

Figure 5

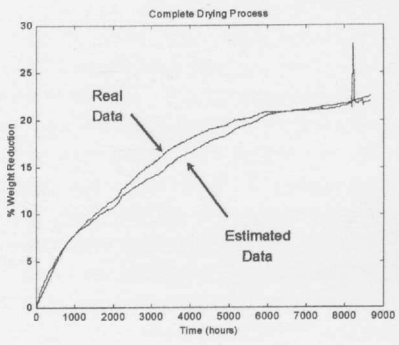

Figure 6

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