# C-97.1

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

Carrasco, J.A.; Mingoarranz, F.J.; Elvira, C.de; Sanz, P.D. Instituto del Frío C.S.I.C. Ciudad Universitaria. 28040 MADRID Spain. Tfno: 915445607 e-mail: atanasio@if.csic.es

#### 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 algorithms 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

Gustafson, E.E., Kessel, W.C. "Fuzzy clustering with a fuzzy covariance matrix", Proceedings of IEEE CDC, San Diego, Calif., jan 10-12, (1979).

Jason, A.C., Peters, G.R. "Analysis of bimodal difusión of water in fish muscle". J.Phys.D: Appl. Phys. Vol 6, 512-523, (1973) Palmia,F. Et al. "Salt and water distribution in typical Italian hams". Revista Esp.Ciencia y Tecn. Alimentos 32 (1), 71-83, (1992) Tsoukalas, L.H., Uhrig, R.E. "Fuzzy and Neuronal Approaches in Engineering". John Wiley & Sons, Inc. New York (1997).



## NOTES

The mover of a Unying Analysis 1 ool to external conditions in the Unying process of *Derived* hards a presented. The mover of the system to one of the barns included in the matching of the tool, if they are a process in the presented of the tool of tool of

In Figure 5 the estimated weight reduction variats the real weight reduction in a hum 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 acclificititititit of each hour estimated reduction in the Drone process.

The Engineering Department of the Institute del Frio is studying since 1996, the drying process of *Derice* ham. The dry activities in this topic consisted of the acquisition of real data from four selected Spanish ham foctories and the theoretical against diffusion by image processing in computerised tomographies. All the selected factoring complemented with the analysis of water and self diffusion by image processing in computerised tomographies. All the selected factoring for their static sectoring in the selected factoring by image processing in computerised tomographies. All the selected factoring for their static sectoring in the selected factoring by the factoring sectoring and the factoring sectoring by the factoring sectoring the factoring by the factoring sectoring the factoring sectoring and the factoring sectoring sectoring the sectoring sectoring the sectoring sectoring sectoring the sectoring sector

Interceptif and non-section watched the mine watched to be affected to be and the winter of the day of a light of the one of a trainer is to the configuration of the test Tasse the statement of the property of a market the day of the day of a distributed to an process. The answer of this tool, training it is new processed with different the market the distributed to an an attributed to the test of the statement of the stateme

Design of a maintaine upper of and only in to nereation they all to normalize at to normalize a serving bot aryan bet Distributed. Entry Cases W. Oversity estaticing where many sowirely is minory providings of their one and an any sowirely is normal. (1979).

Raser an Orferent) GRE "Analysis of braden definition of water for her influence VI Privity April 1978, 217 (975) Diffusion and the and water the interface in Space for the State 15 (2001) and 15 are set with the 12 YE with the State of the set of the s

#### **OBJECTIVES**

This study has been planned with the intention of exploring empirical data (collected 6 art had see and and a solution of the Drying process of Revice had. The main objective of this study is the application of regionanty no felling testing arts in the study of the Drying process of Revice had. The main objective of this study is the application of regionanty no felling testing arts in the study of the Drying process of Revice had. The main objective of this study is the application of regionanty for felling testing arts in the study of the Drying process of Revice had. The main objective of this study is the application of regionanty for felling testing arts in the study of the Drying process of the process of the study of the Drying process of the process of the study of the Study of the Drying process of the process of the process of the study of the Study of the Drying process of the process of the study of the Study of the Drying process of the process of the study of the S

#### METHODS

The materials manufaced in this study can be resurted and at the fight of the second dryers and a Discrete and the resurted and the fight of I and I and the resurt of the fight of I and I and the resurt of the result of the re

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 DC putting having standard hool oriented oriented with the neuro-fluzzy eigendust have been programmed.

The Drying Analysis Tool consists of a Filzy Cliptering argonithm that classifies the Drying process in different space. Filzy for the phases the Drying process in different space. Filzy cliptering neural neural

In order to get information about [1] process dynamics, data that contraction of the even periods of time of used is inputs structure of the AADIa used in cach during a feedforward (with three bladen bytes). They have been trainburners the backhood with the structure of the about the backhood of the backhood with the structure of the number of input signals and the number and even the periods when the structure in the next place of the back of the backhood of the structure of the structure of the number of input signals and the number and even that are trained as pecific dryers in the next place of the back of the backhood of the structure of the structure of the back of the backhood of the structure of the backhood of the structure of the backhood of the

The setting restriction and the set of a structure should be appreciated in the setting the set of the set of

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