transformation towards the fourth industrial revolution or industry 4.0 (Oio et al., 2017; Efendioglu and Woitsch, 2017; Ruohomaa et al., 2018).

In this sense, Cloud Manufacturing (CM) is an essential technology to achieve the monitoring tools for food companies. CM supports in transforming the industry from a traditional business model to a more collaborative, distributed and global business model. More speci cally, CM will allow cooperation and manufacturing activities at different places, departments or organizations (Mourtzis and Vlachou, 2016). Consecuently, the industry will be more ef cient and competitive and products quality improves, which implies an increase of the consumer satisfaction and, therefore, of the sales (Oio et al., 2017). By the hand of the CM, Big Data (BD) appears as a technology which allows to analyse the large amount of data that a company can have and use it intelligently to increase its global competitiveness. Proper use of BD and mathematical models can help notably to the ef ciency increment in the productivity and quality. The application of advanced sensor systems and PAT paradigm in combination with mathematical modelling techniques of BD offer enhanced process understanding, allow on-line prediction of critical quality attributes and subsequently real-time product quality control (Sommeregger et al., 2017).

In this paper is presented ICatador, a software platform based on Cloud Manufacturing with which is possible to monitor the quality control process of Iberian ham and shoulders. The platform allows, on the one hand, to keep the traditional control methods (tasters panel) increasing the ef ciency and allowing the cooperation and the information exchange in a distributed way. As an instrumental measurement, is used Near InfraRed Spectroscopy (NIRS) on the samples, which is based on the electromagnetic radiation absorption in the band from 780 to 2500 nm. NIRS is well-known in material sensing, and its major bene t is that it doesn't need any sample preparation, furthermore, it can yield a response on-line. Applications of NIRS can be found in medical and biomedical studies, food science, forestry, and the pharmaceutical and petroleum industries (Balabin and Sa eva, 2011). On the other hand, the platform incorporates Arti cial Neural Networks (ANNs), as a computational intelligent technique (Big Data), to reproduce/predict the tasters valuations about the food sensory attributes. ANNs are computational techniques perfectly adapted to discover non-linear trends between variables (Boccorh and Paterson, 2002; Cancilla et al., 2014), as is in our case the Near InfraRed spectrum and the sensory attributes.

2 DEFINING THE QUALITY CONTROL MONITORING STRATEGY

The design goal in our strategy of the quality control monitoring is to transfer the estimation of food organolectic properties from a tasting room to the production chain and to tend towards at-line quality model.

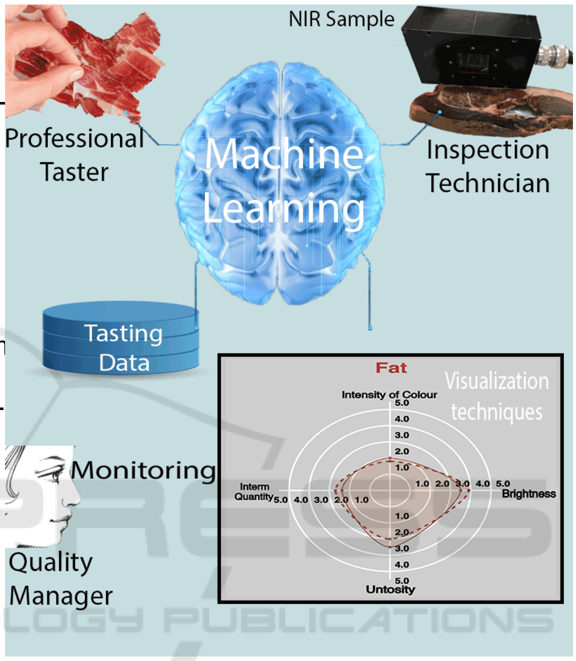

Figure 1: Conceptual scheme of the monitoring of the tasting process.

The core of quality control monitoring is a set of algorithms based on machine learning techniques using a supervised learning set of functions that will allow to predict the valuations of a professional taster, having as input data a measurement provided by an instrument, such as can be a NIR spectrometer (Fig. 1). The ultimate aim is not to replace the tasters panel, but to accelerate the tasting process by means of alternative and objective valuation sources.

In our monitoring strategy, materialized in a cloud platform, different actors have been de ned, each with a different role. All of them collaborate in the quality control process of the food product, from different places of the company or the other companies. The monitoring strategy is supported in a cloud platform, which has been called ICatador, whereby the collaborative process is established.

One of the main actors is the professional taster (Fig. 1). The tasters will value the product following a traditional methodology. They will introduce their scores directly through mobile devices, laptop or desktop computers. Initially, this information provided to the system will be used to train the prediction algorithm (Fig. 1). In successive phases this information will be used to optimize the algorithms of supervised learning.

The organizer of taste panel will define the sensory profile according to the product type. The sensory profile contains the organoleptic attributes to be evaluated by professional tasters, such as flavour, odour, texture, etc. Different profiles can be defined for each product type and, even, several profiles for the same product type, if the quality standards are modified. Automatically, tasters will have, through the platform, the sensory attributes to be scored. The procedure, the related legislation, the description of the attributes, and in general any documentation can be included by the organizer, and used as help by the tasters

The quality inspection technician (Fig. 1) will be the responsible of making the instrumental measures of each ham sample. This task can be carried out manually in the laboratory or at the line production through a portable instrument and, in the best case, automatically at line. Configuring the particular type of product, the instrumental measures will be registered in the platform. Automatically, the sensory attributes of this product will be predicted through the obtained functions via supervised learning. These functions, one for each attribute, are embedded in the cloud platform.

Another actor involved in the monitoring strategy is the responsible of supervising the products quality from the tasting data (Fig. 1). The cloud platform makes easier the work of this user, because it allows him to add, delete or modify products, and it is possible to update the complete information concerning them, such as the feeding of the animal of provenance, the quality and the origin of this animals, date of ripening start, ... The most remarkable feature of plataform is that quality manager can check and visualize immediately (Fig. 1), the values predicted by the machine learning algorithm (artificial tasting) and the valuations that tasters make over the time. He can compare the human scores with predictions, so that it can feedback the ratings and tune prediction functions to correct deviations.

3 SENSORY AND INSTRUMENTAL MEASUREMENTS

To perform a predictive evaluation of the Iberian ham and shoulder organoleptic characteristics, such as visual appearance of lean, fat streaks, rancidity of fat, characteristic odour, texture and flavour, is needed sensory and instrumental measures of food samples.

The Iberian ham and shoulders with known racial percentages and different feeding varying from acorn, meadow feed and normal feed, were elaborated by the partners of Guijuelo Protected Designation of Origin (Spain). The sensory and instrumental tests have been performed on 62 ham and shoulder samples, elaborated by different partners. At the end of the ripening process, tests were made for both products in laboratory (NIR spectroscopy) and sensory room.

In our work, the sensory evaluations were performed by a panel of 4 members trained in the use of the QDA (Quantitative Descriptive Analysis) methodology. The tasting panel was trained at the ITACYL Meat Technology Station. As instrumental measures have been used the data of NIR spectroscopy of the ham and shoulder samples, which is based on the electromagnetic radiation absorption in the band from 780 to 2500 nm. The NIRS measurements were obtained in the Analytical Chemistry laboratory of the University of Salamanca.

3.1 Sensory Measures

The sensory profile of the ham and shoulder were carried out by a panel formed by 4 members trained in the use of the QDA methodology (Murray et al., 2001), which provides an objective description of the products in terms of perceived sensory attributes.

Panel members were trained (ISO, 1994; ISO, 2003) on the sensory profile of ham during 18 sessions. During the training was encouraged that the group developed a common vocabulary for the evaluation of the sensory characteristics, which contained simple and specific terms that made easier the description of products. In the QDA methodology, reference scales are used to evaluate the texture intensity (Piggot and Mowat, 1991), olfactory-taste parameters, and also some foods are proposed as standards to stablish the scale (Bárcenas et al., 2003). Specifically, the organiser had set the sensory profile with 23 sensory attributes, framed within of: visual appearance of lean (intensity, homogeneity and brightness), fat (intensity of colour, brightness, untosity, intermuscular quantity), fat streaks (quantity, homogeneity, thickness and uniformity), characteristic odour, texture (stickiness, hardness, crumbling, fibrousness, pastiness and juiciness), flavour (intensity of sweetness and saltiness), characteristic flavour (intensity and persistence) and, finally, rancidity of fat. During the panel training, the evaluators along with the organizer agreed the established reference standards, the terminology definitions and the evaluation techniques. For quantification the intensity of each attribute, 6 point scales are used, where "0" is the lack of parameter, "1" is the minimal intensity and "5" is the maximum intensity for each of the parameters (Bárcenas et al., 2003).

In the product evaluation phase, the hams and shoulders were scored by panelists according to the description list defined during the training. The sensory measures on which our work is based correspond to different tasting sessions of the ham and shoulders.

This sensory information constitutes the training data and the neural networks validation.

3.2 Instrumental Measures

Spectroscopic sensors are optimal instruments for real time analysis during manufacturing, being rapid, non-invasive, very flexible, and rugged. NIRS, in particular, with its ability to fingerprint food materials and to simultaneously analyze different phenomena, is one of the predominant e-sensing technologies used in PAT (Grassi and Alamprese, 2017). The NIR technology is based on the electromagnetic radiation absorption in the band from 780 to 2500 nm and provides a spectrum represented as values of $\log\left(\frac{1}{R}\right)$ where R is the reflectance against the wavelength. The NIR spectra were obtained with an analyser Foss NIR 5000 in the band of 1100-2000 nm with a spectral resolution of 2 nm. The recording of NIR spectra (Fig. 2) was performed applying the carbon fiber probe directly on the ham or shoulder sample, at room temperature (20-23 ^{o}C). Previously to each record, the probe window was cleaned to minimize the cross-contamination.

The recorded information constitutes the instrumental measures which are used for neural network

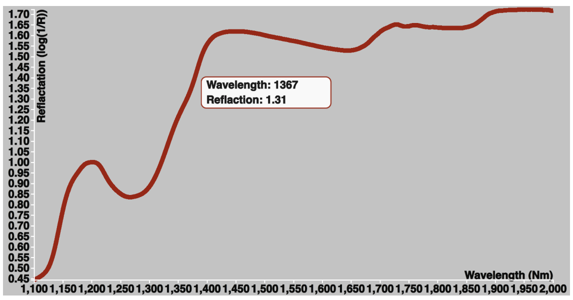

Figure 2: NIR spectra corresponding to a ham sample.

off-line training and validation. When working on-line, the NIR records of each ham or shoulder sample constitute the instrumental measures for the sensory attributes prediction through ANN. The quality manager can observe the NIR spectra of each sample to detect possible errors.

4 PREDICTION MODEL BASED ON ARTIFICIAL NEURAL NETWORKS

The mathematical model used to estimate the sensory characteristics of the ham and shoulder samples is based on ANNs, which are framed within no-lineal (Della-Lucia and Minim, 2010) statistical data modeling tools. Specifically, a Multi-Layer Perceptron (MLP) ANN was used, where the processing elements (PE) are structured in three layers: an input layer where the instrumental measures will be entered, an intermediate or hidden and an output layer where the sensory attribute to be evaluated is obtained.

The software application JavaNNS (Java Neural Network Simulator) has been used as design, training and validation tool of the ANN. The ANN model used is implemented within the application as a "multi layer perceptron network". After several trials, the network model is constituted as follows:

- An input layer with three processing elements (PE), whose inputs are the principal components (PCA) of the NIR spectra. The NIR spectra that has been recorded ranges from 1100 to 2000 nm with a spectral resolution of 2 nm. With 3 values of Principal Components from NIR spectrum, the 99.98% of the spectral variability is expressed. In this way the spectral information is compressed and the number of input values is reduced from 451 to 3.
- A hidden layer with 5 PE
- A output layer with 1 PE which corresponds to the modelled sensory characteristic.

For each sensory characteristic, a network, with the previously topology commented, is built. These ANNs were trained using the 80% of the dataset, randomly selected for each ANN. Once each ANN was trained, its accuracy were evaluated on the test dataset formed by the remaining 20%. These data were not shown during the training and were selected randomly for each ANN.

5 CLOUD PLATFORM IMPLEMENTATION

ICatador system is developed to be used in cloud from any computing device (PCs, tablets, smartphones...) so that it can be accessible from any place and any moment.

ICatador has a MVC (Model-View-Controller) architecture. Views are developed in HTML, the controllers in Javascript using the open source framework AngularJS. Finally, data model is developed in a MySQL database. Model has functionalities which allow selecting automatically the sensory profile to which a product belongs, making that this fact fully transparent to users who only have to introduce or consult data. For the communication between the database and the controllers is used a DAO (Data Access Object) pattern, which is developed in PHP, making easier maintenance works.

To make easier the ICatador adaptation to new sensory profiles or to changes in existing ones, a template system has been implemented which will allow to add, modify or delete sensory profiles according to the needs of the users. All of it is transparent for them with a dynamic adaptation.

Graphics and visual representations have been developed using the D3.js library which allows the graphic representation from the data. Therefore, thanks to this library, the system can create different graphical visualizations (histograms, parallel coordinates, radars) to represent the sensory attributes information, either from human or artificial scores.

6 RESULTS: SENSORY ATTRIBUTES PREDICTION IN ICatador

As main result, ICatador is the cloud platform that can be used by ham producers and quality regulatory agencies for on-line quality control of their products, following the PAT guidelines to monitoring the product sensory parameters. The quality manager, tasters, tasting panel organizer and the production line inspection technician collaborate (Fig. 1), from different places, on the quality control tasks. The contributions of each agent are combined to increase the efficiency and to fulfil demands of the food industry.

In ICatador, the quality manager introduces the products (Fig. 3) which will be evaluated, with all the data concerning them (racial percentages, animal feeding, elaboration date, ...).

The organizer of the panel draws up the sensory

Figure 3: New product entry in ICatador.

Figure 4: “Odour/Flavour” and “Texture” of sensory profile used by the tasters.

profile (Fig. 4) with the attributes (fully configurable), identifies the products to be tasted, selects the tasters according to their characteristics stored in the Database, chooses the help regulation and documentation and, once the tasting is done, scores the tasters. Through forms (Fig. 4), the tasting panel members will enter their evaluations directly into the platform, once they are identified, using mobile devices such as tablets or smartphones. By the product identifier, ICatador recovers the sensory profile which the product belongs. Automatically, the sensory attributes, that tasters have to enter, will be showed together with the working procedure and the help descriptions.

The quality manager can visualize the attribute scores completed by tasters, individually or on average, through graphs as a histogram (Fig. 5).

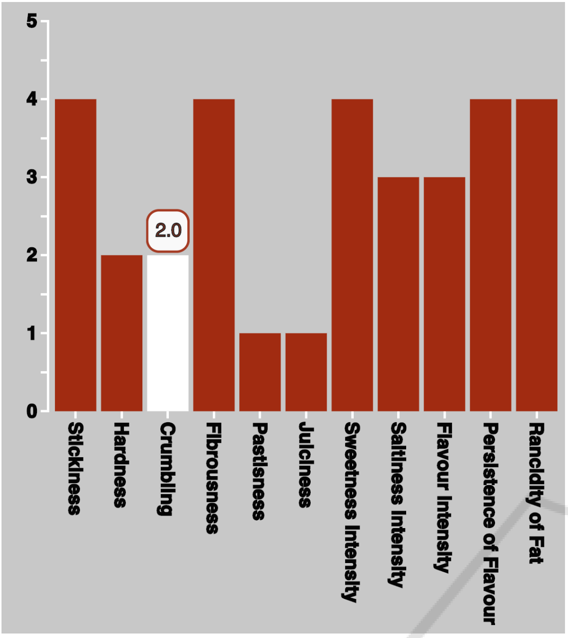

Figure 5: Histogram of the panel scores of a determinate sample.

The spectral analyser generates a file with the data of the NIR spectroscopy of the sample. The inspection technician, in production, incorporates the file in the ICatador Database, selecting the date and the product identification. Actually, in our monitoring platform this task is performed manually from the laboratory, or from any place of the manufacturing plant, but, thanks to actual technological innovation, this information can be incorporated automatically. The quality manager can observe the NIR spectra of each sample (Fig. 2) to detect possible errors.

After the training and validation of each neural network (which is performed off-line) with Deep-Learning techniques, the quality manager, in his daily work, can use ICatador to predict the sensory attributes of a product. An artificial tasting (tasting based on ANN) is extraordinarily simple and it can be performed anywhere in which a NIR analyser is available. The starting point is the NIR record that is performed of a product sample and, then it is enter to ICatador through a file. After its loading, when the option “Artificial tasting” is clicked, the platform ICatador calculates the organoleptic attribute predictions which have been configured for this product by the quality manager.

Using advanced visualization techniques, the results, grouped by categories, are displayed through

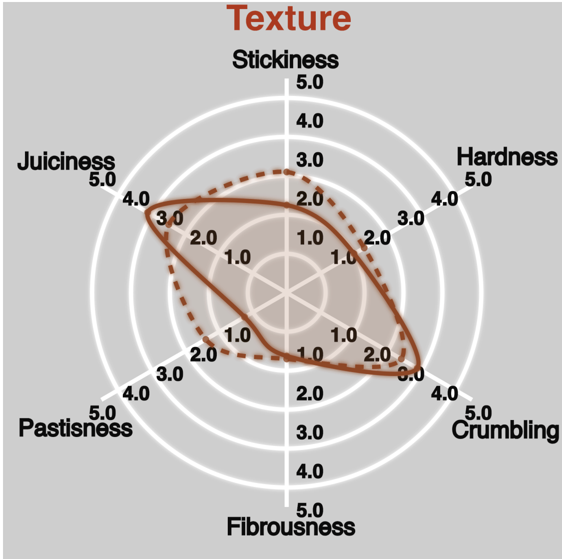

Figure 6: Artificial tasting (discontinuous line) of the attributes of “texture” against the average of professional tasters (continuous line).

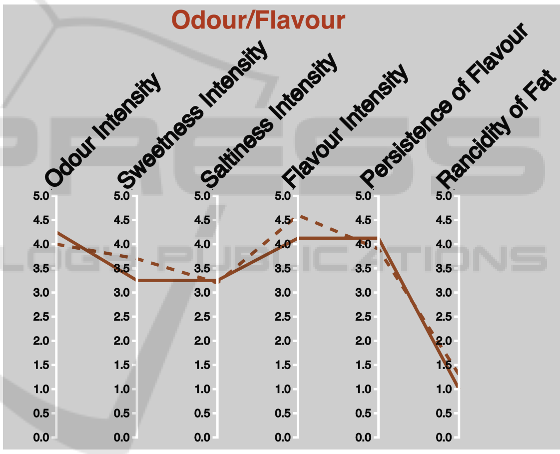

Figure 7: Artificial tasting (discontinuous line) of the attributes of “Odour/Flavour” against the average of professional tasters (continuous line).

graphs of parallel coordinates (Fig. 7) or radars. The quality manager, at a glance, can have the “merit figure” of the considered sample (Fig. 6) to detect the deviations from the expected quality. The merit figures are grouped according to the attribute typologies. The result will be stored in the Database for subsequent analysis for the system participants (quality managers, production managers, etc.).

7 CONCLUSIONS

In food industry, the quality control operations based on the sensory analysis are restricted to the availability of the experts, which implies relatively high economic costs, a certain degree of subjectivity associated with the sensory fatigue, and, in addition of the arduous organisational task. This restrictions impose that the quality control are reduced to certain lots.

As an alternative approach, the machine learning techniques along with instrumental measures appear as an intelligent solution to obtain a reliable estimate of the sensory parameters of the food products.

In this work, a monitoring tool supported on a cloud platform, has been presented. The core of the ICatador tool is a suite of intelligent algorithms (ANNs) which calculate organoleptic attributes estimates using NIR spectrometry data from samples as input.

To make possible that the ICatador monitoring tool had all the ham and shoulders quality data available, the main agents (quality manager, tasters, tasting organizer, quality inspector) collaborate and exchange information from different points and, in addition, instrumental data are systematically incorporated. This collaborative model based on the data, will allow to have a wide range of data coming from the production process itself. In this way, the intelligent algorithm suite can be tuned and adapted to the process itself to avoid deviations.

Through the proposed approach, iberian ham manufacturing companies can carry out an intelligent production based on the data, they can get that final product gathers the same sensory characteristics fixed in the production goals.

The Icatador platform that has been presented in this paper combines the use of Information and Communication Technologies with Artificial Intelligence techniques such as ANNS. Therefore, it can be included within the concept of Industry 4.0, and contributes to the digitization of the industry. Its goals are to improve efficiency, quality control times, flexibility and enables a distributed responsibilities within of the industrial sector.

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REFERENCES

(1994). ISO 11035: 1994:sensory analysis – identification and selection of descriptors for establishing a sensory profile by a multidimensional approach.

(2003). ISO 4121: 2003: Sensory analysis – guidelines for the use of quantitative response scales.

(2014). Real decreto 4/2014, de 10 de enero, por el que se aprueba la norma de calidad para la carne, el jamón, la paleta y la caña de lomo ibérico.

Balabin, R. M. and Safieva, R. Z. (2011). Biodiesel classification by base stock type (vegetable oil) using near infrared spectroscopy data. *Analytica Chimica Acta*, 689(2):190–197.

Boccorh, R. K. and Paterson, A. (2002). An artificial neural network model for predicting flavour intensity in blackcurrant concentrates. *Food Quality and Preference*.

Bárcenas, P., Elortondo, F. P., and Albisu, M. (2003). Sensory changes during ripening of raw ewes' milk cheese manufactured with and without the addition of a starter culture. *Food Science*.

Cancilla, J. C., Wang, S. C., Díaz-Rodríguez, P., Matute, G., Cancilla, J. D., Flynn, D., and Torrecilla, J. S. (2014). Linking chemical parameters to sensory panel results through neural networks to distinguish olive oil quality. *Journal of Agricultural and Food Chemistry*.

Della-Lucia, S. M. and Minim, L. A. (2010). Redes neurais artificiais: fundamentos e aplicações. In UFV, V. E., editor, *Análise sensorial: estudos com consumidores*, chapter 9, pages 258–279. Springer-Verlag New York, Inc.

Efendioglu, N. and Woitsch, R. (2017). A modelling method for digital service design and intellectual property management towards Industry 4.0 caxman case. *International Conference on Serviceology*.

Grassi, S. and Alamprese, C. (2017). Advances in NIR spectroscopy applied to process analytical technology in food industries. *Current Opinion in Food Science*.

Mourtzis, D. and Vlachou, E. (2016). Cloud-based cyber-physical systems and quality of services. *The TQM Journal*.

Murray, J. M., Delahunty, C., and Baxter, I. A. (2001). Descriptive sensory analysis: past, present and future. *Food Research International*.

Oio, K.-B., Lee, V.-H., Tan, G. W.-H., Hew, T.-S., and Hew, J.-J. (2017). Cloud computing in manufacturing: The next industrial revolution in malaysia? *Expert Systems with Applications*.

Piggot, J. R. and Mowat, R. G. (1991). Sensory aspects of maturation of cheddar cheese by descriptive analysis. *Journal of Sensory Studies*.

Rathore, A. S. and Kapoor, G. (2017). Implementation of quality by design towards processing of food products. *Preparative Biochemistry and Biotechnology*.

Ruohomaa, H., Kantola, J., and Salminen, V. (2018). Value network development in Industry 4.0 environment. *Advances in Intelligent Systems and Computing*.

Siegrist, M. and Cousin, M.-E. (2009). Expectations influence sensory experience in a wine tasting. *Appetite*.

Sommeregger, W., Sissolak, B., Kandra, K., von Stosch, M., Mayer, M., and Striedner, G. (2017). Quality by control: Towards model predictive control of mammalian cell culture bioprocesses. *Biotechnology Journal*.