Real-time estimation of peroxides and acidity level of extra-virgin olive oil: an integrated approach

Rocco Furferi, Monica Carfagni and Marco Daou

Abstract— This work provides a combined method, based on Artificial Neural Networks (ANNs) and Machine Vision (MV) systems, with the aim of assess a real-time estimation of acidity level and of peroxides number of olive oil extracted by a continuous extraction process. These parameters may be accurately measured by means of a chemical analysis (CEE Rule no. 2568/91, G.U. CEE no. L 248, 1991). This analysis has to be performed in an equipped laboratory and does not permit to the operators (working in the oil mill) to have a real-time control of the quality of the extracted oil. The present work allows a straightforward approach for an accurate estimation of the qualitative parameters directly during the oil extraction process, thus allowing a quality control of the oil quality without the requirement of a time-expensive chemical analysis. The estimation is achieved both through the measurement of several agronomical and technological parameters commonly measured by the technicians working at the oil mills and by means of machine vision systems. Some of the parameters correlated to the sanitary condition of olives and to ripeness are evaluated by means of image processing algorithms. An ANN based algorithm is able to process the agronomical, technological and image data and gives, as output, a reliable estimation of peroxides and acidity. The results of the estimation achieved by the ANN based system have been compared with the results of the chemical analyses carried out by Florence Commerce Chamber "Laboratorio Chimico Merceologico—Azienda Speciale CCIAA di Firenze" according in force to European Union Rules standards. The system has been developed and tested on the oil mill "TEM Toscana Enologica Mori" of Florence, Italy where is actually running. The work has been financed by the Tuscany Regional Agricultural Development and Innovation Office (ARSIA: Azienda Regionale per lo Sviluppo e l'Innovazione dell'Agricoltura) and is a part of a 3-year project whose objective is to create an entirely software + hardware controlled oil mill.

Keywords— Acidity, ANNs, Machine Vision, Peroxides.

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I. Introduction

Current extra virgin olive oil market performance requires daily updating of quality standards whilst maintaining prices. With this in mind, many specialists have aimed at improving critical working procedures at specific or general levels. Moreover Mediterranean and Italian olive oil production sector introduced a series of new production lines based on new technological mixers, on the uncoupling of the crushers and on the implementation of new centrifugal speeds extractors, allows a continuous and continuously controlled process. The olive oil chain is supported by legislation (EEC Regulation No. 2081/1992 on D.O.P. and I.G.P.) and it is focusing on production of high quality (oil from organic farming, oils monocultivar) closely related to the typicality of the territory which is an "added value" unlikely preservable using the classification of "extra-virgin" (EEC Regulation No. 2568/91). This new approach determines a transition from a massive production of olive oil to a lower production characterized by an higher quality marketable product. Accordingly many specialists and scientists have aimed at improving critical working procedures at specific or general levels, as shown in specialized publications [1] – [2]. This improved oil production quality can be optimized with automatic controlling systems on the mechanical extraction lines, capable of numerous quality procedural improvements [3]. A method for controlling the continuous extraction cycle is to measure several technical parameters during the olive oil extraction and to determine the influence of these parameters on the quality of olive oil. Some of the controlled, and measured, parameters are, for instance, are the oil temperature into the kneader, the mixing time and the oil temperature out of centrifugal extractor. Some recent publications have explored the possibility of devising a specific software system able to control the extraction process and to manage the involved parameters. In particular in [4] and in [5] an ANN approach has been implemented in order to estimate some olive oil parameters during the extraction phase in real-time. A predictive strategy has been used to optimize oil yield while keeping quality standards in [6]. An on-line quality control and characterization of virgin olive oil has been performed in [7]. Moreover some image processing based systems have been devised in last five years in order to perform a real-time control and automation of the inspection operations by means of instrumentations like cameras and spectrophotometers that allow the detection of features of the fruit and, with interposition of suitable filters, to push the analysis of areas not visible coming to understand characteristics of the products are not always visually detectable by operators. Numerous researches have shown the ability to sort fruits on the basis of their colour [8] –[9]. Several studies are related to the correlation between the image and the degree of ripeness of the fruit [10] – [11]. Some significant correlations between data on the shape and color and the trend of aging for apples and dates [12] are in literature.

II. Problem formulation

The interest surrounding the previously mentioned researches, led the Tuscan Regional Agricultural Development and Innovation Office (ARSIA: Azienda Regionale per lo Sviluppo e l'Innovazione dell'Agricoltura) to fund a three-year research project with the intent of creating an entirely software+hardware controlled oil mill. The main aim of this project, called "MAESTRO", is to develop an integrated modelling system based on the combination of Artificial Neural Networks (ANN) based approaches and Machine Vision (MV) design. More in detail, the project concerns the development of innovative predictive techniques based on artificial intelligence and monitoring tools for real-time modelling processes in a plant with reduced oxidative impact. Accordingly the main objective of the present work is to present some of the innovative results of this project and in particular the results obtained by applying the devised techniques in the novel oil mill "TEM Toscana Enologica Mori", located near Florence, in Tuscany (Italy). The devised system is able to estimate the peroxides number and the acidity level of extracted olive oil, directly during the extraction phase by means of the combination of some agronomical and technological parameters and by using a Machine Vision system. The system is suitable for the estimation of mono-cultivar like for instance the one called Frantoio. This estimation is a crucial step for guiding the optimization of the oil extraction. The oil mill allows the setting of a lot of technical parameters. By knowing in real-time the objective quality of the olive oil (i.e. the peroxides and the acidity level) it will be feasible an immediate regulation of the parameters influencing this quality. In order to understand the devised methodology, it is crucial to describe the oil mill lay-out (comprising the Machine Vision system) and the parameters used for the model. It have to be noticed that the devised system is based on the author's approach cited in [4] with some very relevant differences:

- A novel MV design for real time analysis of the olive lots have been devised.
- A new image processing algorithm for ripeness level and sanitation condition has been developed.
- The ANN based approach described in [4] has been updated with new parameters.

A. *Oil mill lay-out*

The software+hardware system devised in order to model the olive oil extraction has been developed in an innovative, experimental, oil mill. The oil mill is installed in "Torre Bianca" farm, located in Province of Florence (Italy); it is representative for small and medium size farm plants (working capacity of about 500 kg/h of olives), concerning working process, layout plant, installed electric power, working capacity, quality level of the extracted olive oil.

The oil mill has the target to reduce the oxidation of olive paste, ensuring a high quality of product and allowing the online monitoring and regulation of process parameters (flow, time, speed, flow, size) using developed sensors.

In order to optimize the extraction process, the oil mill has implemented the following innovative techniques.

- High-speed "knife crusher" able to provide an uniform sized paste;
- Vertical kneading machine which reduces paste oxidation;
- Replacement of final centrifugal separator with carton;
- High power decanter to minimize the processing time.

The olive mill monitored processes olives conferred within 24 hours since collection and its layout comprises the following steps:

- Olive defoliating-washing of olives;
- Olive crushing, obtaining an uniform sized paste;
- Olive paste kneading in order to ease the coalescence of oil micro-drops;
- Oil extraction through stratification centrifuge;
- Oil carton filtration to eliminate suspended elements.

Some oil mill technical features are shown in Table I; In Fig. 1 the whole scheme of the oil mill is showed.

Table I – some oil mill technical features.

DEFOLIATING-WASHING	N°	kW
Feeding screw conveyor motor-gear reducer	1	0,37
Leave fan motor	1	0,85
Washing water pump motor	1	0,55
TOTAL WASHING POWER		1,77
CRUSHING	N°	kW
Feeding screw conveyor motor	1	0,37
Crushing hopper screw conveyor	1	0,37
Crushing motor	1	5,50
Crushing grid scraper motor	1	0,37
Loading pump for kneading machine	1	0,75
TOTAL CRUSHING POWER		7,36
KNEADING	N°	kW
Heating and washing water pump	1	0,55
Kneading shaft motor	3	1,10
Decanter loading pump motor	3	0,37
TOTAL KNEADING POWER		4,96
EXTRACTION	N°	kW
Decanter	1	15,00
Pomace unloading pump motor	1	0,75
Filter oil pump motor	1	0,75
TOTAL EXTRACTION POWER		16,50
FILTRATION	N°	kW
Oil filtration pump	1	0,75
TOTAL FILTRATION POWER		0,75

TOTAL MILL POWER		31,34

Process data collection was conducted during 2006 and 2007 olive oil campaign. In these two testing periods the mill remained substantially unmodified. This experimental campaigns allow the measurement of a number of parameters during the extraction process and comprise the acquisition of the images of the olive lot to be processed by means of the algorithm previously described.

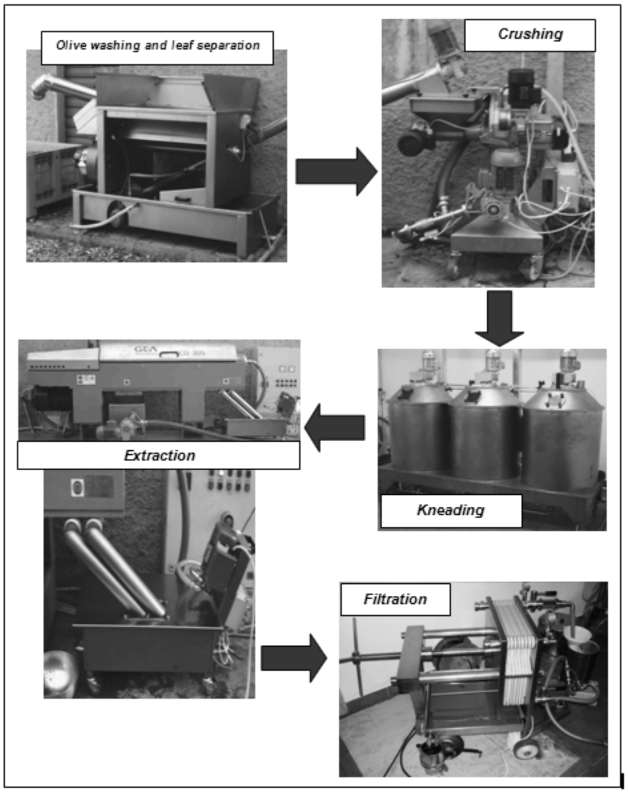

Fig. 1 – Whole scheme of the oil mill where the system has been tested and implemented.

The data collected have been stored in a database with the intent of developing the ANN based software. In Table II some of the data collected are showed. The chemical analysis were carried out by Florence Commerce Chamber “Laboratorio Chimico Merceologico—Azienda Speciale CCIAA di Firenze” according in force to European Union Rules standards.

Table II – Some of the parameters measured during the experimental campaign

Olive lot	T0 (°C)	Mass flow (l/h)	Kneading time tk (s)	Kneading Temp. (°C)	DC%	Oil temp. leaving centrifugal decanter (°C)
60009	23.3	162.7	3600	15.7	4.00%	23.3
60025	23	252.6	2400	19.1	5.00%	25
60053	30	122.6	2600	22.1	3.00%	23.5
60060	28	197.3	3000	20.2	5.00%	25
60070	26	145.8	2400	20.5	4.00%	27.5
60084	22.7	152.9	3000	21.1	5.00%	28

III. Development of the MV-ANN sisyem

As stated before, the main purpose of this work is to devise a system able to estimate peroxides number and acidity level of olive oil during the continuous centrifugal extraction by measuring the agronomical and the technological parameters and by image processing of the olives during the referring phase. As a consequence the problem solution is divided into the following basic tasks:

(A) Agronomical and technological data acquisition.

(B) Machine Vision system design; a vision system able to perform real-time image processing has been developed in order to measure (by means of image processing algorithms) some of the characteristics of the olives.

(C) ANN based software development; a predictive, intelligent, software able to perform a real-time estimation of peroxides and acidity of olive oil has been developed.

(D) Simulation of the oil mill process by means of the MV – ANN devised system.

A. Agronomical and technological data acquisition.

Prior to the definition of the integrated system (ANN - MV system) for the control of the oil mill, is important to assess the parameters that have been used for the model. In several previous works it has been demonstrated that every production phase of the extraction process influences the qualitative characteristics of the extracted olive oil in different ways; the qualitative characteristics of olive oil are mainly influenced by the agronomic parameters (80%) rather than by the technological parameters related to the extraction process (15%). Moreover, as widely known, a strong influence on the quality grade of the olive oil is given by the working time of oil extraction. Therefore the parameters used for modelling the oil mill are split into two main categories (Table III): agronomical parameters and technological parameters. Each parameter influences the main oil quality characteristics (acidity, peroxide number) according to some process parameters and the corresponding influence weight [13]. Moreover the ripeness level and the sanitation condition are parameters strongly related to the physical aspect of the olives (colour and number of defects on the fruit). For this reason these two parameters can be detected in real-time by means of a MV system. In particular it is possible to acquire some high resolution images of the olives and, by means of image processing algorithms, to define some a ripeness and a sanitation parameter correlated to the average ripeness of olives and to average sanitation condition respectively.

The experimental tests on which this work is based have been carried out in the course of various periods i.e. during the olive picking campaign. Accordingly a homogenization of data was necessary for the work period database. The experimental values of acidity and peroxide number have been multiplied for valid influence factors eliminating processing period influence (see Table IV) using the method described in [5]. The influence factors are determined by means of experimental tests.

Table III - Parameters used in modeling process.

	Process phase	Involved parameters
Agronomic parameters	Olive handling	Processing period
		Ripeness level
		Sanitation condition
	Olive storing	Storing condition
		Input olive temperature
Technological parameters	Olive milling	Crusher-mill type
	Olive paste kneading	Kneading-machine type
		Kneading temperature
		Kneading time
	Oil extraction	Diluted water percent
		Oil extraction temperature

Table IV: Processing period influence factor on oil quality parameters.

PROCESSING PERIOD		Oil peroxide number [meq O_2/kg]	Oil acidity [% oleic acid]
1	before November the 6 th	1,00	1,00
2	from November the 7 th to the 16 th	1,30	0,93
3	from November the 17 th to the 27 th	1,75	0,93
4	from November the 28 th to the December 5	2,50	1,00
5	from December the 6th to the 14 th	3,50	1,12
6	After December the 15 th	4,65	1,25

The processing period influence factor for each extracted oil quality parameter (acidity and peroxide number), is the ratio between parameter average value related to the considered processing period and the reference one (beginning olive handling), considering the yearly average crop samples.

B. *Machine Vision System design*

In order to develop a reliable estimation of the oil acidity level and of the peroxides number it is necessary to consider other two important parameters: the olives ripeness level and the olives sanitation condition, also called "integrity grade". These parameters proved to affect the quality of the olive oil and to have a significant influence on the peroxides number and on the acidity level. As wide know, if olives have an high ripeness the number of peroxides and the acidity level tend to increase and vice versa. The same occurs if the olives are defective. These parameters are mostly important also because the oil mill works in strictly controlled condition. Accordingly the olive quality affects in a stronger manner the quality of extracted oil. In order to assess the ripeness level and the integrity grade of olives a MV system has been developed. It consists of an high resolution uEye UI-1480 camera QSXGA (2560x1920 pixel^2) provided with a ½ inches CMOS sensor and with a frame rate of 6 fps. The camera is rigidly attached to a support and positioned upright to the leaf remover – washing machine. The used optical is a Tuss Vision LV0814 with Focal Length of 8mm, opening between 1 and 1.4 mm and angular openings equal to 56.5 ° (horizontal) and 43.9 ° (vertical). The camera is connected to a PC by means of a USB 2.0 connection. During the olive washing, the CMOS camera is able to acquire 6 fps. For this work it is sufficient to perform a quasi-static acquisition of the scene i.e.1 frame every 5 seconds. The images are acquired in RGB format in full resolution. In Fig. 2 it is possible to see an acquired grayscale image of an olive lot (acquired in November 2007) of "Frantoio" cultivar.

Fig. 2 – One of the acquired images (in grayscale) of an olive lot, acquired in November 2007.

In Fig. 3 the positioning of the camera upright to the leaf remover is showed.

Fig. 3 – Positioning of the CMOS camera.

In Fig. 4 the camera model and the spectral response are showed.

The camera is positioned on a distance of about 80 cm from the olive lot. With the aim of acquire and process the images of the olives, an ActiveX GUI in Matlab® environment has been developed.

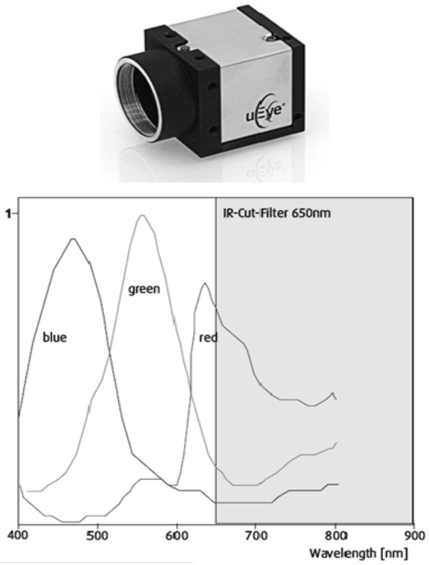

Fig. 4 – Camera model and CMOS spectral response.

C. Ripeness Parameter

Once acquired and transferred to the PC, the images can be processed in order to define a parameter related to the ripeness grade. The aim of the image processing algorithm developed for determining the ripening grade is to segment the green olives in the image from the blackish-purple olives. The first simple image processing algorithm is a threshold of the R channel of the acquired image. This operation allows the segmentation of the leaves in the image as showed in Fig. 5 by means of a local thresholding.

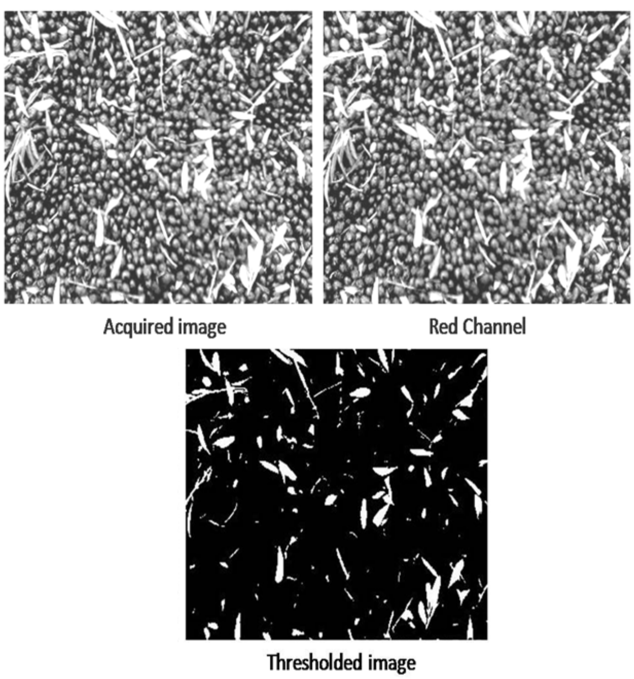

Fig. 5 – Acquired image, its Red Channel and Thresholded image.

The removal of the leaves in the acquired images is crucial for the following algorithm. Unfortunately G and B channels are not suitable for a reliable segmentation of the green olives from the blackish-purple ones. As a consequence an algorithm that performs a colour-based segmentation using the L*a*b* colour space [14] have been developed in order to count up the global area occupied by the green and the blackish-purple olives. This wide known algorithm performs a conversion from RGB and LAB colour spaces (by means of a first conversion from RGB to tristimulus values XYZ and a second conversion from XYZ to CIE L*a*b*).

The results is a Lab three channels image. Afterwards, by means of a Nearest Neighbor Classification [15] combined with a CMC tolerance method [16] the LAB image is "clustered" in three channels (Fig. 6) separated by colours. The image clustering allows to count up how many olives in the image are green and how many are blackish-purple. The image processing task requires less than 5s to measure the olive ripening grade. This computational time is coherent with the fps settings described in paragraph III.A.

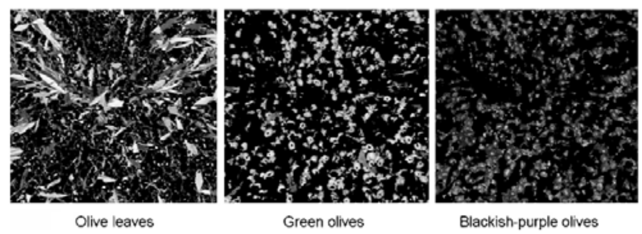

Fig. 6 – Clustering of LAB image in three channels: leaves, blackish-purple objects and green objects.

Moreover it is possible to measure some geometrical properties of the olives like the area distribution (in pixel) and the equivalent diameter distribution of the In Fig. 7 the area and the equivalent diameter of the olives of lot 60084 are showed.

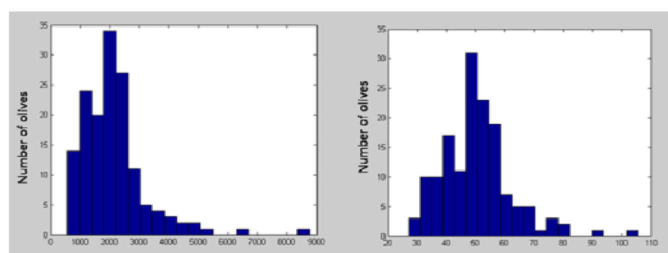

Fig. 7 - Area and equivalent diameter of the olives of lot 60084.

Once evaluated the areas occupied by green and blackish-purple olives, it is possible to define a parameter, called Ripeness Parameter RP as the ratio between the area (in pixel) occupied in the image by the blackish-purple olives A_{bp}, and the sum of the same area with the area occupied by the green olives A_G (in pixel):

$$R_P = \frac{A_{BP}}{A_{BP} + A_G} \tag{1}$$

It is evident that this definition is suitable only for cultivars that changes their colour when mature; this is due to the fact that some cultivar maintain a green colour even when ripen. In order to assess a more extensive definition of the Ripeness

Parameter it is required to understand the difference in green colour between the mature and the immature conditions.

D. Sanitation Parameter

Another task of the present work is the determination the sanitation conditions of each lot of olives. This condition depends on some factors, like for example the presence of olive fly (bactrocera oleae), that are not visible without a mechanical crush of the olive. Accordingly this factor can be related only to the presence of bruises, surface defects or advanced aging. Furthermore, these defects are more evident if a local analysis of the olive lot is performed (i.e. a number of olives are extracted from the lot and are disposed into a grid for analysis). In Fig. 4 a selection of olives (lot 060013), positioned on a 20 cm x 20 cm grid, is showed. In order to evaluate a parameter correlated to the sanitation condition of the olive lot, an image processing based algorithm has been developed. This algorithm performs the following tasks:

- A segmentation of the Red Channel of acquired image (an example is showed in Fig. 8) by means of a LTM method [17]; this operation allows the detection of the surface defects as black spot onto each olive, represented by white pixels.

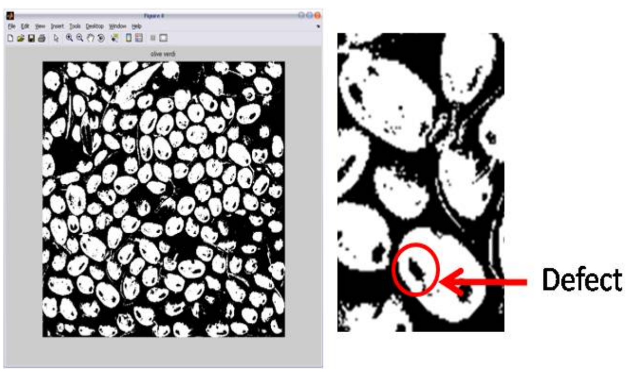

Fig. 8 - Segmentation of the Red Channel of an image acquired for lot 060013 and detection of a defect

- A labeling of the binary image obtained with the previous task.
- A blob analysis of the labeled image; this task allows the measurement of some geometrical properties of the defects and in particular of the area of defects for each olive.

Once evaluated the area of each defect, it is possible to define the Sanitation Parameter as the ratio between the sum of all the areas occupied by the defects A_D (in pixel) and the sum of all the areas occupied by the olives (in pixel) A_O:

$$S_P = \frac{A_D}{A_o} \quad (2)$$

IV. ANN SOFTWARE DEVELOPMENT

As widely known [18] ANNs are computational systems that simulate the microstructure of a biological nervous system. Inspired by biological neurons, ANNs are composed of simple elements operating in parallel, i.e. ANNs are the simple clustering of the primitive artificial neurons. ANNs can be trained to perform a particular function either from the information from outside the network or by the neurons themselves in response to the input. Knowledge is acquired by the network from its environment through a learning process and inter-neuron connection strengths, known as synaptic weights, are used to store the acquired knowledge. In order to devise a software able to estimate peroxides number and acidity level of olive oil during the continuous centrifugal extraction some basic steps have to be carried out:

1. Data acquiring (measurement of the agronomical and technological parameters, image processing results).
2. ANN development in order to estimate the desired output parameters.
3. Refining of the estimation.

A. Data acquiring

The data acquired for training the ANN are described in section 2.1. Moreover, for each olive lot it is possible to automatically evaluate (by means of the previously described image processing algorithms) the Ripeness and the Sanitation Parameter. In Tab.V some values of the two mentioned parameters are showed.

Tab. V –RP and SP for some olive lots

Olive lot	RP	SP
60009	0.32	0.12
60025	0.34	0.14
60053	0.42	0.17
60060	0.25	0.09
60070	0.41	0.21

B. ANN architecture

The devised ANN consists of a Feed-Forward Back Propagation network with 8 sigmoidal activation functions as input layer, 18 hidden neurons and 2 outputs (sigmoidal). The training was carried out using a training rule based on the Levemberg–Marquardt algorithm [19] that is an effective method for training moderate-sized FFBP [20]. As known, during the training, the weights and the biases of the network are iteratively adjusted to minimize the network error function. The network error used in this work, provided by the Matlab® environment, is the mean square error (M.S.E.).

The training set was achieved with 80 samples, each containing the following 8 inputs:

- Initial olive temperature T_O. This parameter depends on the environmental conditions (temperature).
- Kneading temperature T_M. This parameter normally varies in the range (18–35 ◦C).
- Kneading time t_M. This parameter varies in the range (20–120 min).
- Dilution water percent $D_{C\%}$ at spin decanter entry (% H20). Range: 0% – 50%.
- Oil temperature leaving centrifugal decanter T_C (22–35 ◦C).
- Oil temperature leaving water–oil separator T_{out} (22–35 ◦C).
- Ripeness parameter of the olives RP, stated by means of the previously mentioned image processing algorithm.

- Sanitation parameter SP of the olives, also stated by means of the Machine Vision system.

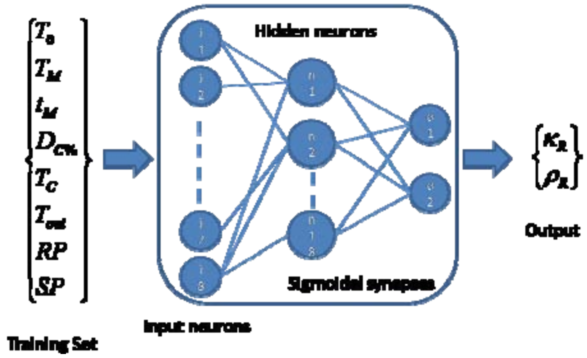

Fig. 9 - Architecture of the devised ANN.

In Fig. 10 the range for T_M, t_M and $D_{C\%}$ is showed in a 3D domain. The most common olive oil extraction mills, in the Tuscany Region, work with parameters varying in the following range: T_M = [27–35 ◦C], t_M = [30–60 min], $D_{C\%}$ = [18–40%]. These values are showed, in Fig. 4, into the blue block inside the entire range variation (red block).

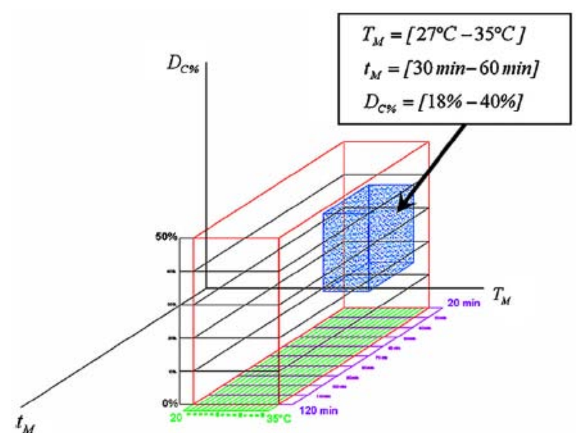

Fig. 10 - Typical domain of some parameters for Tuscany oil mills.

The ripeness and the sanitation parameters are used as an input for the ANN; this allows the overcoming of the approach described in [5] where these parameters were used as an influence factor for acidity level and peroxides number.

The ANN target is composed by two parameters:

- peroxide number (κ_R);
- acidity level (ρ_R).

This system can be regarded as a transfer function $R^8 \rightarrow R^2$: for each 8-elements input it computes an output couple.

The training was carried out using an adaptive learning rate, which is the variation in the weights values between two epochs, until the Mean Square Error reached a value less than $1 \cdot 10^{-5}$. This goal was obtained in approximately 450 epochs.

Training completed, an estimation of acidity κ_{RE} and of peroxide number ρ_{RE} can be assessed comparing new inputs. The comparison between ANN response (κ_{Rnet} and ρ_{Rnet}) and effective (κ_R and ρ_R) values has shown a average error of 6%. This shift is linked to two parameter evaluation using just the 8 parameters, without considering other technical extractive cycle parameters: the outcome achieved is thus considered of "medium" accuracy level. A finer estimation of the two targets is performed in the next paragraph using the new data collected during experimental campaign.

C. *Refining of the ANN outputs*

In order to refine the estimation of the two target parameters a series of influence parameters are defined. In particular the estimation of the quality parameters can be refined by means of the following influence factors:

- The weighed oil temperature influence factors for peroxides number $C\kappa$ at centrifugal decanter exit is defined as follows:

$$C\kappa = \begin{cases} 1 \ \text{if} \ T_C \le 300K \\ \delta(T_C)^2 - \varepsilon(T_C) + \varsigma \\ \qquad \text{if} \ T_C \ge 300K \end{cases} \tag{3}$$

Where δ=0.005, ε=0.3 and ζ=5 are coefficients stated experimentally.

- The weighed oil temperature influence factor for Acidity number $C\rho$ at spinner decanter exit is defined as follows:

$$C\rho = \begin{cases} 1 \ \text{if} \ T_C \le 302K \\ \theta \cdot (T_C)^2 - \lambda \cdot (T_C) + \mu \\ \qquad \text{if} \ T_{ol\_us} \ge 302K \end{cases} \tag{4}$$

using θ=0.002, λ=0.1 and μ=2.3.

These parameters, deterministically obtained, are multiplied by the ANN output in order to refine the initial estimation performed by the ANN itself. Accordingly, the combination of ANN simulation and the refining operation allows an accurate estimation of the peroxide number (κ_{RE}) and of the acidity level (ρ_{RE}) stated by the followings equations:

$$\begin{aligned} \kappa_{RE} &= C\kappa \cdot \kappa_{Rnet} \\ \rho_{RE} &= C\rho \cdot \rho_{Rnet} \end{aligned} \tag{5}$$

V. Validation of the Software

Exceptional climatic conditions during the 2007 Tuscan oil production brought olive production down by 60-80%, even by 90% in some areas. This has made the choice of adequate production areas and oil mill model testing difficult. To overcome these difficulties, programme procedure validation has been divided into two distinct phases:

- The first phase verified that when the software inputs were database samples, not used in artificial neural network system training, the outputs (peroxide number and acidity) presented a sufficient precision level.
- With a positive outcome of verification, validation phase has been conducted using olive oil samples. In

Table VI a comparison between the chemical analysis and the software results (ANN + Refining) is showed.

Table VI – comparison between chemically stated parameters and software results (ANN + Refining).

	Peroxide number [meq O_2/kg]		Acidity [mass % oleic acid]	
Sample label	**Analyses results [6]**	**Software results**	**Analyses results [6]**	**Software results**
12_00f04o1	6±2	6	0,18±0,01	0,18
12_00f04v1	7±2	7,5	0,21±0,01	0,22
12_00f04v2	6±2	6,2	0,23±0,01	0,24
12_00f10o1	6±2	5,4	0,17±0,01	0,16
12_00f10v1	7±2	5,7	0,19±0,01	0,2
12_00f10v2	6±2	6,8	0,21±0,01	0,23
12_00f17o1	5±2	6,4	0,17±0,01	0,19
12_00f17v1	5±2	6,6	0,21±0,01	0,27
12_00f17v2	5±2	6,2	0,22±,0,01	0,26
12_00f24o1	6±2	6,4	0,22±,0,01	0,21
12_00f24v1	6±2	6,2	0,28±,0,01	0,27
12_00f24v2	5±2	5,9	0,23±,0,01	0,24
12_01f03o1	4±2	3,6	0,17±0,01	0,15
12_01f17o1	5±2	5,1	0,14±0,01	0,11
12_01f17v1	8±2	7	0,13±0,01	0,16
12_01f24o1	2±2	1,9	0,20±0,01	0,15
12_02f09o1	4±2	4	0,18±0,01	0,18
12_02f09v1	4±2	5,1	0,25±0,01	0,25
12_02f20o1	4±2	4,3	0,15±0,01	0,19
12_02f20v1	4±2	4,8	0,28±0,01	0,26

Laboratory analyses results showed that for each sample software evaluated peroxide number fall into laboratory confidence range. Software output performed well regarding acidity. Compared to laboratory confidence range central value, software output showed an error distribution confirming approach effectiveness. In Fig. 11 the distribution of the error in acidity estimation is showed.

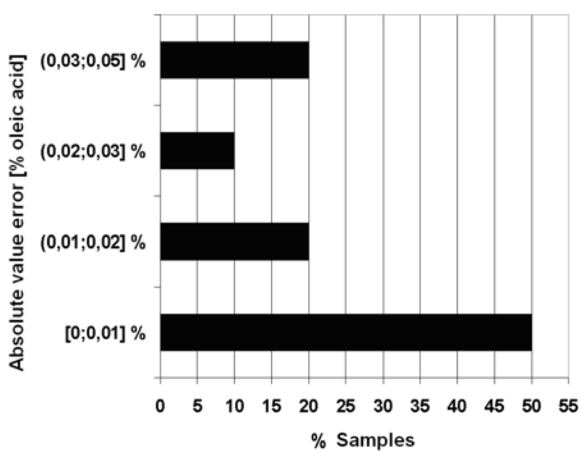

Fig. 11 - Software acidity estimation error distribution.

VI. Results

The results of the estimation achieved by the developed system are compared with the results of the chemical analyses according in force to European Union Rules standards. Table VII shows a comparison between experimental measurements of peroxide number (in Meq O2/kg) and peroxide software estimation and of Acidity (in mass % oleic acid) and the Acidity software outputs. It appears how software output is consistent with experimental data for both the target parameters.

Table VII – Comparison between some experimental measurement of peroxide number and acidity and software output.

Olive lot	Peroxide number (Meq O2/kg)		Acidity [mass % oleic acid]	
	Analysis results	**Software results**	**Analysis results**	**Software results**
60009	6±2	6.4	0.19±0.01	0.18
60025	7±2	6.7	0.21±0.01	0.22
60053	6±2	5.8	0.23±0.01	0.24
60060	6±2	6.1	0.17±0.01	0.15
60070	7±2	7.6	0.19±0.01	0.20

The software determines oil peroxide number value into laboratory confidence range for each sample, as shown by chemical analyses results (see Fig. 12).

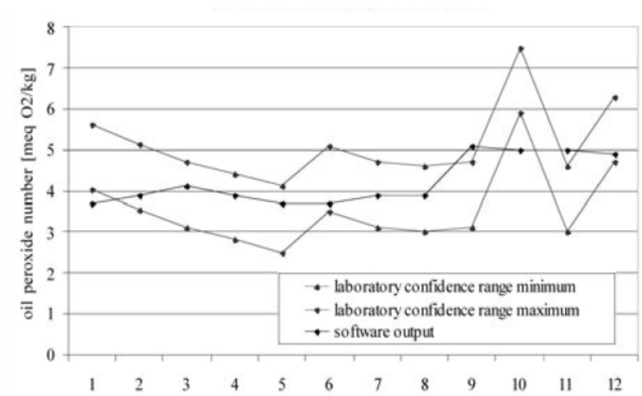

Fig. 12 - Comparison between chemical analysis and software estimation of oil peroxide number.

The mean error between the ANN output and the measured values of the two qualitative parameters is about 6% for acidity level and 5% for peroxides number. The maximum error affecting this method is about 15% for peroxides number and about 16 % for the acidity level. As wide known, the error in measurement with the standard chemical analysis is about 5% for peroxides number and of 0.01% for acidity level. Even if the results of the estimation are appreciably different from the chemical analysis the estimation of the two qualitative parameters may be considered a good chance to have a fast and reliable idea of the oil quality without performing the chemical analysis stated on the Reg. CE 2568/91 Reg. CE 1513/2001 and Reg. CE 796/2002. The results of the refining process may now be compared with the measured κ_R and ρ_R values: the mean error between the estimated κ_{RE} and the measured κ_R is about 4.5% while between ρ_{RE} and ρ_R is about 5.6%.

These errors are evaluated by using the following equations:

$$E(\kappa_{RE}) = \frac{\|\kappa_R - \kappa_{RE}\|}{\kappa_R}\% \quad (6)$$

$$E(\rho_{RE}) = \frac{\|\rho_R - \rho_{RE}\|}{\rho_R}\% \quad (7)$$

The maximum error affecting this method is about 10% for both the peroxides number and for the acidity level. The mean error in estimation of the two parameters is about 3.8% for "Frantoio" cultivar.

VII. Conclusion

The present work describes a model system based on ANNs and MV able to estimate two qualitative parameters of olive oil. It can be used for an automatic control of an oil mill and it can reduce laboratory analyses number. Further specific tests could quantify the influence of various parameters concerning olive oil quality (cultivation, olive tree micro-environment, storing conditions, paste granulometry, etc.). These added information could extend software coverage to the whole olive oil productive line. It have to be noticed that the results reached by the project, at the actual stage of progress, are very accurate and reliable in case of good quality olives i.e. olives whose Sanitation Parameter is less than 0.5. Accordingly, comparing laboratory and software results, the described approach can be deemed valid.

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