Real-time estimation of olive oil quality parameters: a combined approach based on ANNs and Machine Vision

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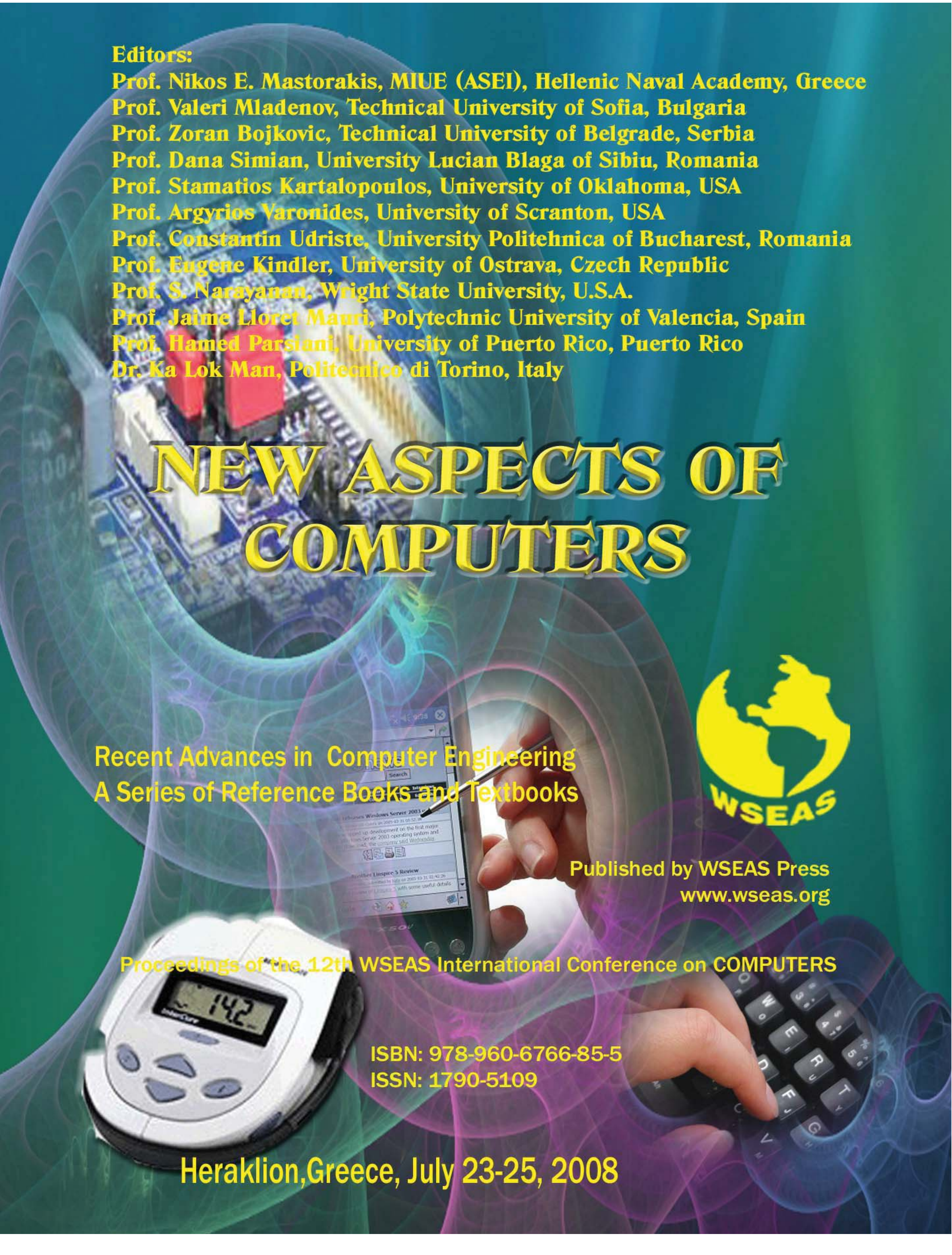

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Proceedings of the 12th WSEAS International Conference on COMPUTERS

ISBN: 978-960-6766-85-5
ISSN: 1790-5109

Heraklion, Greece, July 23-25, 2008

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All papers of the present volume were peer reviewed by two independent reviewers. Acceptance was granted when both reviewers' recommendations were positive.
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ISSN: 1790-5109
ISBN: 978-960-6766-85-5

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Real-time estimation of olive oil quality parameters: a combined approach based on ANNs and Machine Vision

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Abstract: -The present work describes a combined approach based on Artificial Neural Networks and Machine Vision for the real-time estimation of some qualitative olive oil parameters. The proposed methodology proves to be a useful tool for the real-time estimation of acidity level and of peroxides number of olive oil extracted with a continuous extraction process. The two qualitative parameters are estimated on the basis of a number of technological and agronomical parameters. Some of the parameters correlated to the sanitary condition of olives and to ripeness are evaluated by means of image processing algorithms. The estimation may be performed during the extraction thus allowing a quality control of the oil quality without the requirement of a time-expensive chemical analysis.

Key-Words: - Olive oil, ANNs, Machine Vision, peroxides, acidity, ripeness, sanitation condition.

1 Introduction

Nowadays Italian olive oil production sector is experiencing some technological and commercial changes; the introduction 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.

2 Problem Formulation

The interest surrounding these 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 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.

2.1 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 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 olive 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 (Fig. 1);
- 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 and washing, 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 and oil carton filtration to eliminate suspended elements.

Fig. 1 - Vertical kneading machines and Stratification centrifuge

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. The data collected have been stored in a database with the intent of developing the ANN based software. In Tab. 1 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 1 – 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

2.2 Olive oil parameters

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. 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 2): 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.

Table 2 - Parameters used in modelling process.

	Process phase	Involved parameters
Agronomicparameters	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

3 Problem Solution

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 three basic steps:

1. Machine Vision design and image processing; a vision system able to perform real-time image processing has been developed in order to measure some of the characteristics of the olives.
2. ANN based software; a predictive, intelligent, software able to perform a real-time estimation of peroxides and acidity of olive oil has been developed.

3.1 Machine Vision system

In order to develop a reliable estimation of the oil acidity level and of the peroxides number it is necessary to consider 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 (upper left) it is possible to see one of the acquired images of an olive lot (acquired in November 2007) of "Frantoio" cultivar.

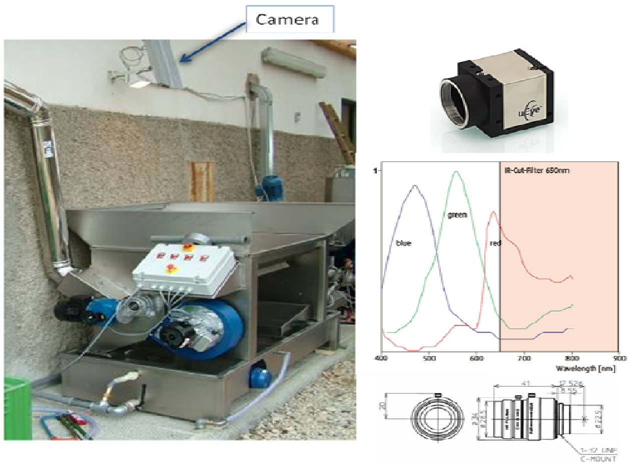

Figure 2 - Positioning of the CMOS camera, camera mode, spectral response and optical.

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, a GUI in Matlab® environment has been developed.

3.1.1 Ripeness parameter R_P

Once acquired and transferred to the PC, the images are 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 R channel of the acquired image allows the segmentation of the leaves in the image as showed in Fig. 3 by means of a local thresholding. 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 have been developed in order to count up the global area occupied by the green and the blackish-purple olives. 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 olives. Once evaluated the areas occupied by green and blackish-purple olives, it is possible to define a parameter, called Ripeness Parameter R_P 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):

$$R_P = \frac{A_{BP}}{A_{BP}+A_G} \qquad (1)$$

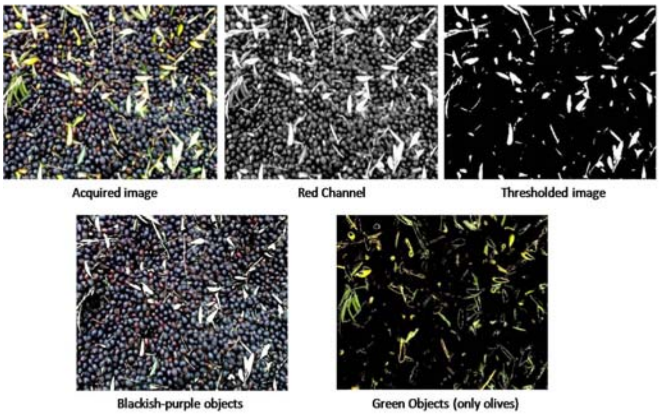

Figure 3 - Acquired image,Red Channel, Thresholded image, Segmentation of blackish-purple objects (left) and green objects (right).

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.

3.1.1 Sanitation parameter S_P

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. 5) by means of a LTM method [14]; this operation allows the detection of the surface defects as black spot onto each olive, represented by white pixels.

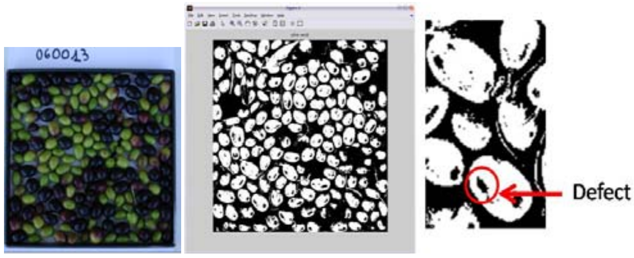

Figure 4 - A selection of olives from lot 060013, a segmentation of the Red Channel and detection of a defect

- A labeling [14] of the binary image obtained with the previous task.
- A blob analysis [14] 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:

$$S_P = \frac{A_D}{A_O} \qquad (2)$$

3.2 ANN based software

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.

3.2.1 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 the Ripeness and the Sanitation Parameter, as showed for instance in Table 3.

Table 3 –R_P and S_P 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

3.2.2 ANN development

As wide known, Artificial Neural Networks can be seen as a complex system built with calculating cells (neurons), capable of reconstructing the function linking an input to its output, after an iterative training on a correct input-output training set. This training ends when the error between training network output and target is minimized. The devised ANN consists of a Feed-Forward Back Propagation network with 5 sigmoidal activation functions as input layer, 12 hidden neurons and 2 outputs (sigmoidal). A Levemberg-Marquardt algorithm [15] has been used to perform neural training. The training set was achieved with 80 samples, each containing the following inputs:
- kneading temperature (T_M). Range: 293 K - 308 K.
- kneading time (t_M). Range: 1200 s - 7200 s.
- dilution water percent ($D_{C\%}$) at spin decanter entry (% H20). Range: 0% – 50%.
- ripeness parameter of the olives R_P, stated by means of the previously mentioned image processing algorithm.
- sanitation parameter S_P of the olives, also stated by means of the Machine Vision system.

The oil mill where the system has been developed and tested works with parameters varying in the following range: T_M = [27–35 ◦C], t_M = [30–60 min], $D_{C\%}$ = [18–40%]. 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).

The comparison between calculated and effective (known) value has shown a average error of 6%. This shift is linked to two parameter evaluation using just the 5 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 by means of the procedure developed in [5] using the new data collected during experimental campaign.

3.2.3 Refining of the estimation

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 $c\_T_{ol\_us}\_Np$ at spinner decanter exit (T_{ol_us}) is defined as follows:

$$c\_T_{ol\_us}\_Np = \delta(T_{ol\_us})^2 - \varepsilon(T_{ol\_us}) \quad (3)$$

where δ=0,005, ε=0,3, ζ=5;
- The weighed oil temperature influence factor for Acidity number $c\_T_{ol\_us}\_A$ at spinner decanter exit is defined as follows:

$$c\_T_{ol\_us}\_A = \theta(T_{ol\_us})^2 - \lambda(T_{ol\_us}) + \mu \quad (4)$$

where θ=0,002, λ=0,1, 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.

4 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 4 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 4 – 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. 5). Concerning acidity output the software output shows an error distribution confirming approach effectiveness (see Fig. 6).

5 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. The mean error in estimation of the two parameters is about 3.8% for "Frantoio" cultivar. This error increases to 5% for other kind of cultivar, due to the less accurate evaluation of Ripeness Parameter. Moreover it have to be noticed that these results 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.

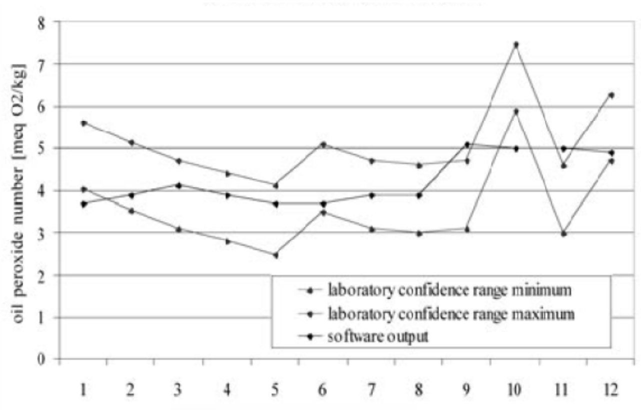

Figure 5 - Comparison between chemical analysis and software estimation of oil peroxide number.

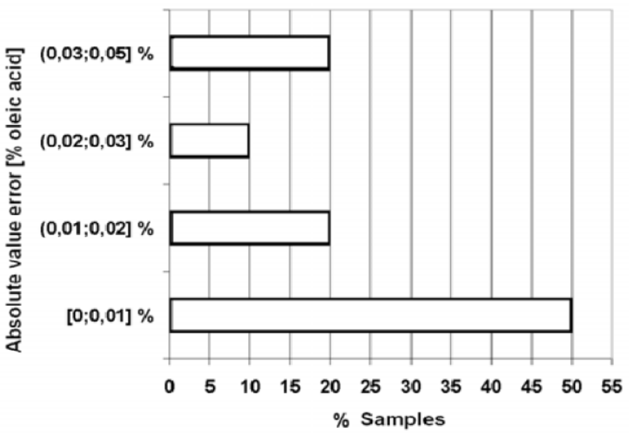

Figure 6 – absolute value error for estimation of Acidity.

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