Scientific quarterly journal e-ISNN 2449-5999
Agricultural Engineering
2015: 3(155):15-24
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.155.132

COMPUTER IMAGE ANALYSIS AND ARTIFICIAL NEURON NETWORKS IN THE QUALITATIVE ASSESSMENT OF AGRICULTURAL PRODUCTS

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ARTICLE INFO

Article history:
Received: June 2015
Received in the revised form:
July 2015
Accepted: August 2015

Keywords:
computer image analysis
vegetable
carrot
quality
artificial neural networks

ABSTRACT

The increasing use of modern information technology in agriculture involves an ever wider range of production, planning, monitoring and marketing processes. Information technologies are being applied in animal and plant production, and recent decades have witnessed a dynamic growth in research into artificial intelligence and thus into advisory (expert) systems such as artificial neuron networks. Obviously this is not the result of a coincidence or a temporary trend, this dynamic development has been made possible thanks to the rapid advancement of computer technology, allowing ever increasing speeds and volumes of data collection and processing. A large number of research-scientific work with the use of computer image analysis, computer-aided decision making and state of the art modelling tools, including artificial neuron networks, is carried out within the scope of agricultural engineering. The computer-aided decision making process in the area of the qualitative assessment of agri-food products is one of those areas using computer image analysis and neuron modelling. The objective of this research project was to develop and describe a computer image analysis method based on the example of carrots and lyophilisation dehydrates for the purpose of the qualitative assessment and classification of individual categories in the analysed sample in terms of quality.

Introduction

Dynamic changes have been observed recently in the area of animal and plant production. The surplus of supply over the demand in this sector of the economy enforces continuous improvements and adaptation to the dynamically changing rules of the consumer's and producer's market. It is this combination of high competition and consumer awareness that drives these changes, with consumers becoming more aware and their increasing expectations regarding quality. The trend in the area of health foods and foods with appropriate quality parameters is noticeable. Therefore this consumer behaviour forces the producers to use ever more precise methods in the quality assessment of their products. It could be concluded that the colour of the food is one of the material features, because the consumer and client makes the decision regarding the purchase or consumption of a given product based on external appearance (Zaborowicz et al., 2012). Appropriate colours and shapes that meet traditionally adopted standards form important assessment criteria, because changes here are usually the first noticeable indicators of deterioration of quality preceding the sensory quality changes (taste, smell and nutritional value). Human awareness contains many associations regarding colour and taste and thus specifically these criteria determine to a great extent the first general impressions of consumers (Koszela, 2012; Boniecki et al., 2014; Zaborowicz et al., 2014). At present there are a number of possible methods that may measure shape and colour. Sensory methods can be used, based on qualified verifiers, which could be considered to be low-repetition or subjective methods. The second group comprises the instrumental methods carried out by measuring devices. However, in the case of instrumental methods involving dedicated devices, the tests are very expensive and lack the universal ability to measure more than a few parameters, e.g. shape and colour. Another weakness related specifically to spectrophotometers concerns the measurement of colour based on a small image, which could be insufficiently representative for plant origin products. Fresh fruit and vegetables dedicated to direct consumption and to processing should have certain characteristic features determining their commercial value. The commercial quality standards were established in order to eliminate from trade those products of poor quality and for the purpose of monitoring products before their marketing (Koszela and Hartlieb, 2012; Koszela et al., 2014). These standards define the requirements that should be met by marketable vegetables. In addition the market presence of products differentiated in terms of quality, i.e. meeting the requirements of various quality categories, contributes to the increase in their competitiveness and thus the possibility of obtaining better prices for products of higher quality and the increase in the profitability of their production (Internet: http://www.minrol.gov.pl).

Poland is the fourth largest European vegetable producer, after Italy, Spain and France, and is the largest producer of red beets, cabbage and carrots in the European Community, where the share in total crops is respectively: 46%, 23% and 15%. Carrots are one of the main species of vegetable cultivated in Poland. It owes its popularity mainly to its nutritional value as well as its dietetic and taste advantages (Rumpel, 2004). The increasing demand for dehydrated vegetables should be stressed as well, as this trend has an impact on the growth of dehydration facilities in Poland, contributing to the better management of production surpluses. Dehydrated vegetables are increasingly often used in various food product sectors, both due to a high nutritional value and changes in the nutritional preferences of the consumers. Dehydrated carrots also have a strategic role among dehydrated vegetables due to the broad spectrum of applications and high nutritional value. The dehydration process is a set of activities carried out under controlled conditions, during which the majority of the water occurring in the food is removed through evaporation by applying heat or, in case of lyophilisation, through sublimation. This process results in the reduced weight and volume of the products, hence also reducing the costs of their transport and storage. The major objective behind the dehydration process concerns the extension of the shelf-life of the products through the decrease of water activity, which results in stopping the growth of microorganisms and enzymatic activities (Hajduk et al., 1998). The initial water content in fruit and vegetables is within the 74-90% range; the dehydration process reduces the water content to at least 12% in dehydrated vegetables and 17-25% in dehydrated fruit (PN-72/A-77603, BN-80/8125-04). The higher threshold for water content in dehydrated fruit is caused by the higher accumulation of sugars and organic acids. The classic food dehydration systems can be divided into natural (sun-wind drying, wind-air drying) and artificial (conductive, convectional, dielectric, vacuum, lyophilisation, spraying, and microwave drying) (Pijanowski et al., 1997). The most common of these methods include: convectional lyophilisation and microwave-vacuum drying. Each of them has their strengths and weaknesses and their own specific further uses of the produced dehydrate.

Lyophilisation dehydrates were selected for the purpose of this project. This drying method concerns the removal of water (dehydration) from the product to reach a water content of 1-3% through sublimation of the ice formed as a result of earlier freezing of the raw material (Jarczyk and Berdowski, 1997). The vacuum and low temperature of the process results in reduced losses of volatile compounds as well as compounds sensitive to oxidisation. The disadvantage of the dehydrate concerns its mellowness, creating the potential of oxidisation losses, and increasing the prices of packaging and the relatively high dehydration costs by a factor several times higher compared to ordinary food dehydration methods (Pijanowski et al., 1997). Therefore it can be concluded that computer image analysis is increasingly often used to assess the quality of food products based on information coded in the form of digital photographs (Tomczak et al., 2012). The application of this technique allows, for example, better objectivism of the assessment and automation of the identification processes. The study included the tests aimed at supporting the decision-making processes taking place during the assessment of the quality of physical parameters of the selected carrot species based on the determined geometrical criteria such as: length of the root, width of the root, length of the occurrence on top of the carrot of the violet-purple discoloration and percentage of the defect surface area. In the case of lyophilisation dehydrate this was the colour, geometry (length, width, area and circumference) of the cube and shape coefficient (Boniecki et al., 2015; Koszela et al., 2013; Przybył et al., 2014).

Materials and methods

The Nerac F1 carrot variety was selected for quality assessment of carrot roots. The Nerac variety by the company Bejo Zeden is a medium-late variety. This variety has a cylindrical shape to the root, which is intense in colour and high carotene, sugar and dry matter content. Carrots of this variety are very tasty and sweet, resulting in its high popularity among consumers. The Karotan variety was selected for the quality assessment of the lyophilisation dehydrate. The Karotan variety by the company Rijk Zwaana is a late variety. The vegetation period for the industry is 23 to 25 weeks, length of the root from 20 to 30 cm, with crop rates of 94.4 $t \cdot ha^{-1}$. It has a conical root with intense colour and high carotene, sugar and dry matter content. Figures 1 and 2 present the objects for testing.

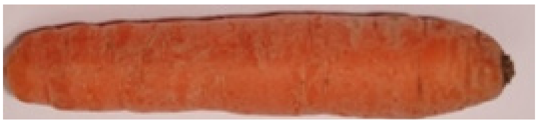


Figure 1. Carrot root for testing

Figure 2. Lyophilisation dehydrate for testing (correct dehydrate)

The project implementation stages included the following, both for the carrot roots and the lyophilisation dehydrate:

- selection of an appropriate variety of carrot popular in Poland, which is frequently subjected to the quality assessment and consumption,
- acquisition of digital images of carrots and dehydrate,
- development of functional and non-functional requirements of the created computer program,
- designing and production of software for analysis of carrot and dehydrate images for the purpose of quality assessment and classification to respective categories (according to the criteria stipulated in the relevant commercial quality standards),
- measurement of characteristic features and quality classification with the support of the prepared software,
- preparation of artificial neuron network models based on earlier collected data,
- selection of topology and learning method for artificial neuron networks,
- testing, analysis and comparison of neuron networks,
- verification and validation of the software,
- analysis of results and comparison with other quality assessment methods.

The test instruments and a properly prepared station for image acquisition were used to perform the tests. The elements of the station included: a digital camera, shadeless chamber, set of illumination lamps, and a photographic stand. The following parameters of the digital camera were defined within the scope of assumptions: a manual photographic mode, lighting – artificial white light, white balance 3000°K, photographic mode – macro, sensitivity ISO-50, lens focal length F-34.7 mm, lens stop f-7.8, shutter opening time 1/8 s. The photographs were taken for individual fractions of dehydrate to conduct the analysis of images of dehydrated vegetable cubes. A total of 600 root samples were prepared for the tests on carrot roots, which were of differentiated quality. In respect of the lyophilisation dehydrate some 1500 cubes were prepared from each fraction of the dehydrate. The cubes were placed on a uniform contrasting background, separated from each other.

In case of the quality assessment of the carrot roots each root was photographed separately subject to identical acquisition parameters. In the course of the works an assessment of various computer image analysis technologies was carried out in terms of their suitability for the execution of the issue related to vegetable quality assessment. As a part of planning the IT system it was resolved that the operating method and the end result should refer to existing commercial quality standards containing the requirements that should be met by vegetables in order to be accepted for trade. The division criteria for the assessed carrots to respective quality categories were defined based on information contained in the detailed carrot quality standard: EKG no. 920/89, which was in force until mid-2009 in all European Union countries. This standard defines the minimum requirements that should be met by the product in order to be recognised as of good quality and it defines the requirements for individual quality categories. Three quality categories were specified (Extra, I and II), to which the product is classified depending on its properties. As the number of requirements to be met by a vegetable to be included in a respective quality category is extensive and in the majority of cases is descriptive, it was resolved to base the creation of the program on just a few properties that could be derived from the photograph during the image analysis process.

It was decided that, based on these four parameters describing the carrot read from the image, the quality of the carrot could be defined in a satisfactory manner. The parameters read by the program, such as length of the root, width of the root and the length of the occurrence on top of the carrot of the violet-purple discoloration for each quality category were strictly defined in the standard and were defined in the same manner in the program. The parameters determining the percentage of the surface defects were added and defined for the purposes of conducting the study, because the standard defines this parameter in a descriptive manner only. This parameter is defined as a relation of the pixel area showing signs of losses to the total pixel area contained in the detected object. Table 1 presents the parameters read by the program describing the carrots and the range of values for each of the categories. The product is allocated into the respective quality category based upon meeting all the requirements defined for the given category.

Table 1
Values of parameters describing the carrots in a given quality category

Category	Root diameter	Length of the violet-purple discoloration on the top of the carrot	Percentage of defect surface
Extra	> 20 mm, < 45 mm	0 , unacceptable	< 5%
I	> 20 mm	Up to 1 cm for root length < 10 cm, Up to 2 cm for root length > 10 cm	< 10%
II	> 20 mm	Up to 2 cm for root length < 10 cm, Up to 3 cm for root length > 10 cm	< 15%
Not classified	< 20 mm	> 3 cm	> 15 %

In case of vegetable dehydrates the quality analysis was carried out based on the computer image analysis and artificial neuron networks. The creation of a neuron model required collection of appropriate input data, which constitutes a determined number of cases. The characteristic feature of an artificial neuron network is the fact that they process numerical data belonging to a strictly defined range. The neuron model for classification of carrot dehydrate operates based on acquired dehydrate images (Boniecki et al., 2014; Koszela and Zaborowicz, 2014). The computer program designed as a part of this study was applied to convert empirical data from the photographs to values suitable for artificial neuron networks, the following dehydrate parameters being selected to achieve correct classification: cube colour [1], cube geometry (area [2]; circumference [3]), and selected shape coefficients (Table 2). These coefficients are determined by sensitivity to the shape variability of the analysed object with parallel maintenance of insensitivity (invariability) to change in the method of presentation of the object in the image. Generally the shape coefficients can be divided into two groups. The first one concerns coefficients determined mainly by the possibility of their quick calculation, which is very important in a system that needs to deliver image processing results in real time. Clearly this group includes Feret, Malinowska and circularity coefficients. The second group comprises coefficients that are used when the speed of operation is not the most important factor, while the accuracy of description of the objects with the support of their features is more important. This group includes the Blair-Bliss coefficient.

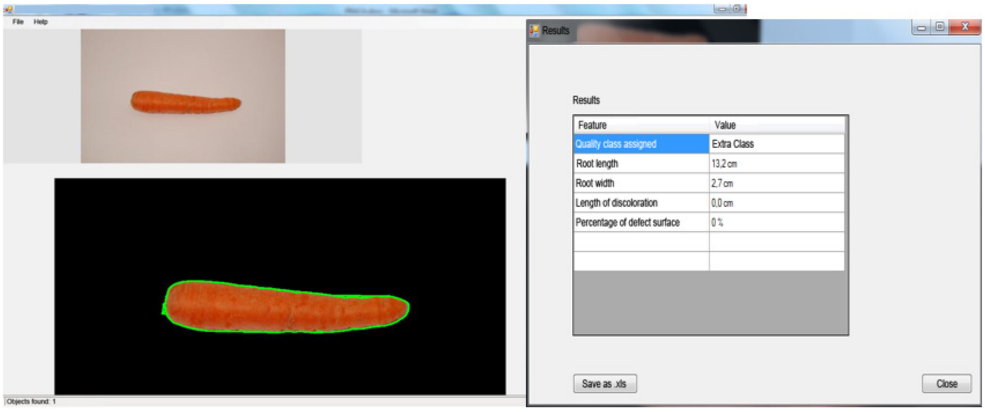
Table 2
Selected shape coefficients

	Coefficient name	Formula
[4]	R_S – dimension-free shape coefficient, For quantitative determination of shape of particles	$R_S = \frac{L^2}{4\pi S}$
[5]	R_F – Feret coefficient describing elongation of the object	$R_F = \frac{L_h}{L_v}$
[6]	R_{C1} – circularity coefficient describing the diameter of the circle, whose area is equal to the area of the analysed object	$R_{C1} = 2\sqrt{\frac{S}{\pi}}$
[7]	R_{C2} – circularity coefficient describing the diameter of the circle of circumference equal to the circumference of the analysed object	$R_{C2} = \frac{L}{\pi}$
[8]	R_M – Malinowska coefficient	$R_M = \frac{L}{2\sqrt{\pi S}} - 1$
[9]	R_e – regularity coefficient	$R_e = \frac{S}{ab}$
[10]	Blair-Bliss coefficient in relation to centre of gravity	$R_{bbsc} = \frac{S}{\sqrt{2\pi \sum_i r_i^2}}$

where: L – object circumference, S – area of the entire object, a – object length, b – object width, r – distance of object pixel from the centre of gravity, I – number of pixels in the object.

Results and discussion

A computer program, *AnalisysVEG,* was created for the purpose of classifying carrot roots based on photographs. This program was created to find a solution for the objective set in the subject of this study. The application used an algorithm for the image analysis with the support of the methods contained in the AForge.Net image processing libraries, which contain an extensive range of functions and methods dedicated to image processing and analysis. This process takes place by removing the background from the image followed by another algorithm to determine the length of a violet-purple discoloration on the top of the carrot. The next stage concerned measurement of the length and width of the root, and its classification.



Results

Feature	Value
Quality class assigned	Extra Class
Root length	13,2 cm
Root width	2,7 cm
Length of discoloration	0,0 cm
Percentage of defect surface	0 %

Figure 3. Main window with displayed analysis results

The testing of this application included the image analysis of a dozen or more randomly selected photographs of carrot roots. The program allocated the respective quality category based on the read parameters describing the given root. The values of the parameters read by the application for all the photographs and the features describing the quality category are presented in Table 3.

Table 3
Values of the parameters describing the carrots in a given quality category

Image no.	Root length (cm)	Root width (cm)	Length of the occurrence of discoloration on carrot top (cm)	Percentage of surface defects (%)	Allocated quality category
01	18.0	3.6	0	0	Extra
02	16.7	2.8	0	12	II
...	...	...	...	...	...
18	12.5	2.5	1.4	2	I
...	...	...	...	...	...
63	13.2	2.7	0	0	Extra
64	11.6	2.5	0	1	Extra

Neuron modelling was used for classification of the lyophilisation dehydrates, during which 23 different neuron networks were generated. The tests included the following types of neuron networks: linear network, PNN (Probabilistic Neural Network) networks, MLP networks with three layers (one hidden layer) and four layers (two hidden layers).

Networks with the radial base functions (RBF) neuron topology of the MLP type was found to be the optimum network: 10:7:1 (MultiLayer Perceptron) having ten neurons in the input layer, seven in the hidden layer and one in the output layer. The selection of the best neuron model from among all the networks used for the quality classification process was carried out based on three sets: learning, validating and testing. The measures used to determine the quality of the networks were found to be independent for these sets. However the one-way neuron networks of the MLP type are one of the most extensively tested network types and most often used in network topology practice. The multilayer perceptron represents the category of parametric neuron models, which is a one-way network, multilayer, learning by a technique using a "teacher". One of its typical features concerns the fact that the number of neurons constituting its structure is substantially smaller than the number of the cases in the learning set.

The quality of the generated network should be regarded as very good. The RMS (Root Mean Square) error was respectively:

- 0.02875 for the learning set,
- 0.03195 for the validation set,
- 0.08234 for the testing set.

The next stage concerned the performance of sensitivity analysis, the purpose of which was to determine the level of importance for the input data of the selected neuron model (Table 4). This action also enabled the identification of those variables that can be omitted without a loss of quality in network operation and the determination of those key variables that cannot be omitted. Prudence should be exercised in the course of the assessment and drawing of the conclusions due to the interdependencies between variable inputs. Usually the variable inputs are independent. The sensitivity analysis is presented separately for the learning and validation set. These indicators are valuable in determining the correctness of the given assessment. Sensitivity was defined as the error quotient indicator and the rank:

- error quotient – this is the relation of error to error obtained with the use of all independent features, so the higher the quotient the higher the importance of the given feature,
- rank – this indicator determines numerically the features according to a decreasing error, a rank of 1 has the highest importance for the network.

Table 4
Sensitivity analysis for the model

Variable inputs	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Quotient	0.9976	0.9836	1.0003	0.9659	1.0015	1.0148	1.0150	1.0278	1.0246	1.0223
Significance	8	9	7	10	6	5	4	1	2	3

The colour parameter generated during the classification of the lyophilisation dehydrate into correct and incorrect cubes had a very low significance, with just eighth place in the ranking of significance. This result is justified, because incorrect selection of dehydration parameters during the lyophilisation process does not have significant impact on the disturbances in cube colour. The colour sensitivity in this process is low. The shape coefficients had a high place in this model, the most important features concerning Malinowska coefficient, regularity and Blair-Bliss coefficient. Recapitulating, it can be concluded that the geometry of the cube is the determining parameter in the course of classification of the lyophilisation dehydrate. In respect of this model it can be observed that there is an association between mutual features, because the removal of the colour feature reduced the network error by 34%.

Conclusions

The conducted tests regarding the use of computer image analysis and neuron modelling proved to be a suitable method capable of effectively supporting the decision making processes taking place in the course of quality assessment or classification. Suitable software was designed and created to acquire information from the image of related to characteristic features for cutting carrots and carrot dehydrate, which affect the results of the quality classification. The obtained results give the following conclusions and findings.

1. The results of the study confirm the hypothesis that artificial neuron networks and image analysis technologies are effective tools to support the process of quick and reliable assessment of quality and classification of carrot roots and dehydrate.
2. There is an option of creating new carrot quality assessment methods to improve efficiency and minimise human participation in this process.
3. The quality analysis of the neuron models indicated that the best classification capability was represented by a neuron topology of the multilayer perceptron type, with the structure: 10:7:1.
4. The sensitivity analysis of the generated neuron model to variable inputs demonstrated a high level of significance of the proposed representative features in the quality classification process for lyophilisation dehydrates.

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KOMPUTEROWA ANALIZA OBRAZU I SZTUCZNE SIECI NEURONOWE W OCENIE JAKOŚCIOWEJ PRODUKTÓW ROLNICZYCH

Streszczenie. Zastosowanie coraz bardziej nowoczesnych technologii informatycznych w rolnictwie obejmuje coraz szerszy zakres procesów produkcji, planowania, monitorowania i marketingu. Stosowane techniki informatyczne wykorzystuje się w technologii produkcji zwierzęcej oraz roślinnej. W ciągu ostatnich dekad można zaobserwować dynamiczny rozwój badań nad sztuczną inteligencją, a tym samym nad badaniami w zakresie systemów doradczych (ekspertowych), jak również nad sztucznymi sieciami neuronowymi. Oczywiście nie jest to wynik zbiegu okoliczności czy rezultat chwilowej mody. Ten burzliwy rozwój jest możliwy dzięki szybkiemu postępowi techniki komputerowej, która umożliwia zapamiętywanie coraz większej liczby danych oraz coraz szybsze jej przetwarzanie. Duża liczba prac badawczo-naukowych z wykorzystaniem komputerowej analizy obrazów, komputerowego wspomagania decyzji i nowoczesnych narzędzi modelowania, jakimi są sztuczne sieci neuronowe, realizowana jest w ramach inżynierii rolniczej. Jednym z obszarów wykorzystywania komputerowej analizy obrazów i modelowania neuronowego jest wspomaganie podejmowania decyzji w zakresie oceny jakościowej produktów rolno-spożywczych. Celem projektu badawczego było opracowanie i charakterystyka metody komputerowej analizy obrazów na przykładzie korzeni marchwi oraz suszu liofilizacyjnego do oceny jakościowej i klasyfikacji poszczególnych klas w badanej próbie pod względem jakości.

Słowa kluczowe: komputerowa analiza obrazu**,** warzywa, marchew, jakość, sztuczne sieci neuronowe