Chapter XV

Grading of potatoes

Franco Pedreschi

Pontificia Universidad de Católica de Chile

Departamento de Ingeniería Química y Bioprocesos

Av. Vicuña Mackenna 4860. Santiago de Chile, Chile

Telephone: 56-2-23541229

Email: fpedreschi@ing.puc.cl

Domingo Mery

Pontificia Universidad Católica de Chile

Departamento de Ciencia de la Computación

Av. Vicuña Mackenna 4860 (143), Santiago de Chile, Chile

Telephone: 56-2-3544440 Fax: 56-2-3544444

Email: dmery@ing.puc.cl

Thierry Marique

Centre pour l'Agronomie et l'Agro-Industrie de la Province de Hainaut (CARAH)

11 rue P. Pastur, 7800 Ath, Belgium

Email: t.marique@skynet.be

Chapter XIV

Grading of potatoes

Franco Pedreschi

Pontificia Universidad de Católica de Chile, Departamento de Ingeniería Química y Bioprocesos, Av. Vicuña Mackenna 4860. Santiago de Chile, Chile

Domingo Mery

Pontificia Universidad Católica de Chile, Departamento de Ciencia de la Computación, Av. Vicuña Mackenna 4860 (143), Santiago de Chile, Chile

Thierry Marique

Centre pour l'Agronomie et l'Agro-Industrie de la Province de Hainaut (CARAH), 11 rue P. Pastur, 7800 Ath, Belgium

1 INTRODUCTION

Potato (*Solanunm tuberosum*) is the major agricultural crop in the world, is consumed daily by millions of people from diverse cultural backgrounds. Besides, potato is grown in over 110 countries throughout the world representing one of the most important staples of the human diet (Bradshaw and Ramsay 2005). Potatoes are processed into a great variety of products, including: cooked potatoes, par-fried potato strips, French fries, potato chips, potato starch, potato granules, potato flakes, dehydrated diced potatoes, among others (Pedreschi, 2012). Handling of potato tubers during all the steps of the production chain is of major importance since it could have a strong effect over the final quality of the final potato derived products (Gómez Galindo et al., 2007).

Potato tubers can vary tremendously in size, shape and regularity. The wide variation in size and shape, and vulnerability to damage makes the potato crop a difficult one to handle and grade. Regular-shaped potatoes are preferable because the irregular ones cause a great deal of losses during peeling and subsequent processing. A product with a good appearance, size and uniform shape will always be preferable to most consumers and will have a better sales appeal. Therefore, grading and sorting processes will ensure that the products meet defined grade and quality requirements for sellers and provide an expected level of quality for buyers (ElMasry et al., 2012). In this sense, grading and sorting of potatoes ensures that derived products meet defined grade requirements for sellers and expected quality for buyers (Heinemann et al., 1996).

Potato factors such as size, shape, greening, cracks, scab, etc. determine the final grade of a potato (Noordam et al., 2000). There is a real need for potato analysis standardization, especially since from the quality evaluation depend the acceptance or the rejection of submitted potato batches and of course subsequent payment of producers (Marique et al., 2005). In this sense, the potato-packaging industry is facing many labor-related problems such as rising labor costs and production waste owing to inconsistent sorting and grading and human errors (Zhou et al., 1998). Besides its inconsistency, variability and subjectivity, the manual process is very tedious, laborious, and costly, and is easily influenced by surrounding environments (Razmjooy et al., 2012). In this sense, automation is therefore desired because it can ensure consistency in product quality and handle large volumes. A completely automated inspection station requires the incorporation of machine vision and automation into a system consisting of the appropriate hardware and software for both product handling and grading.

Since the efficiency and effectiveness of potato tuber quality inspection processes determine the marketability of the product, there is a need for robust, automatic, consistent inspection systems to increase production speed and to improve the accuracy and efficiency with an accompanying reduction in production costs (ElMasry et al., 2012). Thus, nondestructive detections, like photoelectric detection, the electromagnetic characteristics analysis, Near Infrared Spectroscopy, X-ray analysis, computer vision and so forth, have been used increasingly in the agricultural industry for inspection and evaluation purposes as they provide suitably (Huangshan, 2009). The objective of this chapter is to present briefly how potatoes are graded automatically in industry and which are the principal potato features and surface defects that determine the strategies one has to apply for a proper grading.

2 SURFACE POTATO DEFECTS

In potato processing, during harvesting, transportation, washing, sorting, and packing, potato tubers are subjected to mechanical stress that may lead to crushing of surface cell layers (Gomez Galindo et al., 2007). Post-harvest and processing operations are traumatic for the fresh potato cells proximal to damage sites since they induce damage by mechanical stress (Charron & Cantliffe 1995). Additionally, mechanically stressed potato tuber tissue produces melanin-based pigments, leading to the blue-black discoloration of sub-dermal tissues known such as black-spot bruising which is a serious agronomic problem in quality of potato products during harvesting, handling and storage, leading to significant levels of rejection of potato harvests (Johnson et al., 2008; Potato Marketing Board, 1994). Finally, mechanical stress of tubers during handling (caused by falls and/or collisions) induces wound responses leading to undesirable physiological changes in potato tubers which results in reduced quality and storability (Johnson et al., 2008). On the other hand, some problems are also associated with the classical subjective evaluation procedures in which results may vary widely with the assessor (Marique et al., 2003). They also depend on the particular potato variety tested, as flesh color ranges from creamy white to buttery yellow. Moreover, defects can show broad variations of shape, aspect or color: white, gray, bluish, brown, black, etc. In practice, several very different criteria are evaluated, either after harvest or upon delivering (Marique et al., 2005):

- Size distribution as well as the percentage of aberrant shapes (e.g. cracked, forked, “doll”, “diabolo”, etc.) that can lead to huge loss at peeling or transformation. Very high proportions can be attained as a consequence of bad meteorological conditions during the growth of the tubers, such as alternating periods of dryness and rain.
- Surface roughness resulting from bacterial or fungal attacks (e.g. common scab *Streptomyces sp.*, silver scurf *Helminthosporium sp.*, *Rhizoctonia solani*). This can lead to very unpleasant aspect of tubers cultivated in “heavy” soil (clay).
- Tuber germination generally as a consequence of senescence or of bad storage at too low temperature.
- Green spots or regions, following exposure to light. Sometimes superficial, it can also reach deeper under the skin of the tuber and thus affect peeled potatoes as well. Appreciation of these defects thus necessitates preliminary peeling of the sample under controlled conditions.
- Bruises, defined as colored marks that remain after two consecutive passes with a kitchen vegetable peeler. Tubers lifting and stockage are responsible for up to 40-50% of bruises on domestic potatoes, and up to 100% on loose industrial potatoes. Potatoes lose weight due to an increase of transpiration, they lose starch because of increased breathing and they are more subject to pathogen invasion (Rousselle et al., 1996).
- Tuber diseases due to varied viral, bacterial or fungal agents. Most common ones are certainly soft rot (*Erwinia*), late blight (*Phytophtora infestans*), dry rot (*Fusarium*) and gangrene (*Phoma*). These results in deep invasion and necrosis of tissues, eventually completely destroying tubers. External appearance can be extremely varied in shape, color or aspect so that microscopic inspection can be required for correct identification in some cases.

3 POTATO CLASSIFICATION

Potatoes can be classified into five grades based on USDA standards as shown in Table 1 (Heinemann et al., 1996). Some factors that contribute to the grade, such as size, shape, and external defects, can be assessed by machine vision. The USDA Standards for grades of potatoes (USDA, 1991) define three classes of shape: “well shaped” (potato that has the normal shape for the variety); “fairly well shaped” (potato is not materially pointed, dumbbell shaped, or otherwise deformed); and “seriously misshapen” (potato is very deformed). These shape requirements are somewhat abstract and difficult to comprehend since there are no standard shapes available for comparison. This is due to the unique shapes assumed by potatoes. These classes need to be quantified for automated grading (i.e., each shape classification should have a number or number range associated with it).

Table 1. The United States Department of Agriculture (USDA) requirements for size and shape of potatoes. (Reprinted from *Machine Vision and Applications*, Vol. 9, Paul Heinemann, Niranjan Pathare, Charles Morrow. An automated inspection station for machine-vision grading of potatoes. Pages 14-19, Copyright 1996, by courtesy of Springer Science and Business Media).

USDA Grade	Minimum diameter (cm)		Shape
U.S. Extra N °1	5.71	and	fairly well shaped
U.S. N °1	4.76	and	fairly well shaped
U.S. Commercial	4.76	and	fairly well shaped
U.S. Extra N °2	3.81	and	not seriously misshapen
Cull	<3.81	or	seriously misshapen

It is very important for the potato industry to supply tubers of uniform quality (Thybo et al., 2004). Consequently, potato tuber industry needs rapid on-line and at-line methods to: (i) sort the raw material into the given physical property categories prior to processing; (ii) predict the optimal use of the raw material; (iii) adjust the processing to obtain the optimal quality of the processed product. Nuclear magnetic resonance imaging (NMR-imaging) is a modern technique which besides giving valuable information about raw potato water distribution also gives information about anatomic structures within the tubers, which are of importance for the perceived mechanical properties of cooked potatoes. NMR-imaging has shown to have the potential to predict potato quality attributes, and hereby may be attractive methods to implement as in-/at-line methods in the potato tuber production (Thybo et al., 2004).

The sensory mechanical quality is of uppermost in cooked potatoes, as this is one of the most critical quality attributes in consumer evaluation of potatoes. Consequently, development of on-line/at-line sensors enables a grading and sorting of potatoes in relation to their final qualities before marketing (Thybo et al., 2004). These authors used non-destructive and non-invasive NMR-imaging to describe the sensory mechanical quality of cooked potatoes. This was done by studying the correlation between advanced image analysis features determined in different regions of raw potatoes, and sensory mechanical attributes of cooked potatoes. Moreover, correlations between specific image features and sensory data were also carried out. Features extracted from images of raw potatoes using different image texture analysis methods were able to classify the sensory mechanical variation in five potato varieties and to predict the sensory mechanical attributes in the cooked potatoes. Moreover, NMR-imaging on raw potatoes provides structural/anatomic information of importance for sensory perception in cooked potatoes (Thybo et al., 2004).

For instance, in the potato chip industry, each batch of potato tubers must be tested for quality before processing, and visual aspect is, of course of great importance (Marique at al., 2003). There are different procedures used in grading potatoes all over the world. Now, for whole tubers, these procedures are still dependent on visual inspection mostly. Some research groups are working on new automated ways to realize this task, but this is still under development. However, certain groups can surely give a thorough review of the different criteria used to evaluate potato tuber quality and so determine whether they are suitable for processing (i.e., surface appearance, illness, shape, bruises, etc.). This is strongly linked to image feature extraction which is one of the most active and research topics in computer vision. The major kinds of image features are: color, size, shape and texture. Each kind of image feature could contain important information require for food quality evaluation, inspection and grading. Besides, the proper combination of different kinds of image features, such as for instance combining size with shape, and color with texture, can normally increase the accuracy of the results. Sometimes such a combination might even reveal some quality attributes that can not be identified by using only a single kind of image features.

Computer vision systems have proven successful in the on-line non-destructively measurement of several food products with applications ranging from routine inspection to complex, vision guided, robotic control at high level of flexibility and repeatability at relatively low cost (Sun, 2008; Mery et al., 2013). In this sense, ElMasry et al. (2012) developed a fast and accurate computer-based machine vision system for detecting irregular potatoes in real-time with a success of in-line classification of moving potatoes of 96.2%. Concurrently, the well-shaped potatoes were classified by size achieving a 100% accuracy indicating that the developed machine vision system has a great potential in automatic detection and sorting of misshapen products. On the other hand, Huangshan (2009) proposed a novel inspection approach to detect external defects of some potato cultivars in order to implement an automatic potato grading and sorting station. This approach could be integrated with mechanical lines and incorporated in the inspection processes for other features such as shape, size, and green skin for complete automatic grading of potatoes. This could also be used to detect defects of other light-skin potato cultivars.

Recently, different image features of color, size, shape, and texture are combined together for their applications in the food industry because in this way, they increase the performance of the computer vision methods proposed. For instance, coefficients for the principal component regression (PCR), partial least square regression (PLSR), and neural network increase if a texture feature is added. Thereby, to capture more proper information about the quality of food from images, multiple kinds of features corresponding to the grading system of the food products should be processed (Du and Sun, 2004; Brosnan and Sun, 2004). However, for computer vision systems to be successful and useful in the potato business, improvements in grading and sorting speed as well as the ability to detect external (bruises, chilling injuries, blemishes, rots, etc.) and internal defects (black heart, frost damage, water core, internal cavity, etc.) are needed. These could be achieved by integrating both imaging and spectral techniques in one system called imaging spectroscopy or spectral imaging (ElMasry & Sun, 2010; Li et al., 2011). In addition to image processing regimes as the corner stone of designing all machine vision systems, mechanization is another paramount challenge in applying machine vision for food quality evaluation to transfer the decisions made by the imaging algorithm and for synchronization, separation, grading and sorting processes. Therefore, the main approach was how to implement all image processing routines in an in-line mode to perform the essential operations in a term of milliseconds and how to evaluate several products in one second instead of taking several seconds to evaluate one product. This approach requires overcoming all computational complexity (ElMasry et al., 2012).

4 APPLICATIONS

Various studies related to machine vision inspection of potatoes have been reported in the literature. An automated inspection station for machine vision grading of potatoes on size and shape has been reported (Tao et al., 1990; Grenander and Manbeck, 1993; Deck et al., 1992; Heinemann et al., 1996). The color segmentation results of a multilayer feed forward Neural Network (MLFN-NN) and a traditional classifier for the color inspection of potatoes have been compared (Kim and Tarrant, 1995). The throughput of the system as reported by Heinemann et al., (1996) was three potatoes/min and the classification results decreased significantly when potatoes were moving (Tao et al. 1990). All systems described above cannot fulfill the potato industry requirements for high throughput and real-time speed. Besides low throughput, none of the systems is capable to inspect for size, shape, and multiple color defects. To overcome this low throughput, a PC-based high-speed machine vision system for potato inspection with a throughput of 50 images/sec has been reported (Lee et al., 1994). The system is capable to classify potatoes for size, weight, cross-sectional diameter, shape and color. The weakness of the system is that the color classification procedure discriminates between good potatoes and green potatoes only and detection of multiple color defects is not possible.

Heinemann et al., (1996) designed and implemented a prototype automated station for machine-vision inspection and classification of potatoes focused on size and shape which includes: (i) integration of discrete machine vision and automation tasks into a complete software package; (ii) building a machine vision inspection station interfaced with automation equipment and processing computer using a data-acquisition system; (iii) evaluation of the system performance based on two potato quality features: shape and size. The station specifically consists of an imaging chamber, conveyor, camera, sorting unit, a personal computer for image acquisition, analysis and equipment control. The throughput rate of the station was three potatoes/min which was prohibitively slow for sorting large quantities of potatoes but it was almost adequate for grading based on sampling. The motion of potatoes interfered with accurate assessment of shape, although motion had little effect on determining the size. The developed automatic inspection station did not consider external defects for potato grading and was capable of size and shape evaluations with some limitations.

Zhou et al. (1998) developed a PC-based vision system and applied it in computer-aided potato inspection which was able to classify 50 potato images/sec for potato weight, cross-sectional diameter, shape and color, which are the most important criteria in sorting potatoes in practice. An ellipse was used as a shape descriptor for potato shape inspection and color thresholding was performed in the hue-saturation-value (HSV) color space to detect green color defects. The average efficiency of this system was 91.2 % for weight inspection and 88.7% for diameter inspection. The shape and color inspection algorithms achieved 85.5 % and 78.0 % success rates, respectively. The overall success rate, combining all the above criteria, was 86.5 %.

Greening, other defects such as cracks common scab and rhizoctonia are also important features which influence the consumer preferred quality. For a vision machine system to become successful in the potato packaging industry, defects as described above must be detected (Marique et al., 2005). Noordam et al., (2000) developed a computer vision system to inspect and grade potatoes based on multiple external color defects, size and shape. The High-speed Quality Inspection of Potatoes (HIQUIP) system incorporated conveyor lanes to transport the potatoes to and from the vision unit. Dust and dirt were removed before inspection by washing, and after inspection and grading, the potatoes were transported to a packaging device where they are packed in little bags and sold on the consumer market. As the machine must operate in a potato packaging plant, some extra demands are being imposed to the concept and apart from recognizing external defects and detecting misshapen potatoes, it must also have a high accuracy and a capacity of 12 tons/hour. Noordam et al. (2000) developed a high-speed machine vision system for the quality inspection and grading of potatoes. This real-time computer-aided potato inspection system allows determining potato weight, cross-sectional diameter, shape and color which are the four primary features in sorting potatoes in practice, and external defects as well. A 3-CCD line-scan camera inspects the potatoes as they pass under the camera. To achieve the required capacity of 12 tons/hour, 11 SHARC Digital Signal Processors perform the image processing and classification tasks. The total capacity of the system was about 50 potatoes/sec. The color segmentation procedure uses Linear Discriminant Analysis (LDA), in combination with Mahalanobis distance to classify the pixels. The procedure for the detection of misshapen potatoes used a Fourier based shape classification technique and features such as area, eccentricity and central moments were used to discriminate between similar colored defects. Experiments with red and yellow skin-colored potatoes showed that the system was robust and consistent in classification.

There are several steps necessary before a potato inspection system can be deployed in the field (Noordam et al., 2000): (i) integrate a proper machine vision system with a mechanical system; (ii) evaluate the integrated system thoroughly at a packing site (e.g., on many more potatoes with real mixes and varying environmental conditions). Besides, more complicated algorithms could be explored and compared to asses whether this additional computational complexity can be justified. Also, development of new algorithms to detect potato features such as bruises and knobs needs to be initiated. In this sense, Huangshan (2009) developed a novel inspection approach detect external defects of three potato cultivars. Adaptive Intensity Interception (AII) and Fixed Intensity Interception (FII) methods have been proposed to extract the suspect defects. Otsu segmentation combined with morphologic operation was used to remove the normal skin and background. Area threshold and black ratio threshold were used to identify defects in the suspect defects. The results showed this approach was fast, valid and convenient for defect detection on yellow-skin potatoes. The approach described above could be integrated with mechanical lines and incorporated in the inspection processes for other features such as shape, size, and green skin for complete automatic grading of potatoes. This could also be used to detect defects of other light-skin potato cultivars. Finally, ElMasry et al., (2012) developed a fast and accurate computer-based machine vision system for detecting irregular potatoes in real-time. This system is composed of supported algorithms specifically developed and programmed for image acquisition and processing, controlling the whole process, saving the classification results and monitoring the progress of all operations. A database of images was first formulated from potatoes with different shapes and sizes, and then some essential geometrical features such as perimeter, centroid, area, moment of inertia, length and width were extracted from each image. Also, eight shape parameters originated from size features and Fourier transform were calculated for each image in the database. All extracted shape parameters were entered in a stepwise linear discriminant analysis to extract the most important parameters that most characterized the regularity of potatoes. Based on stepwise linear discriminant analysis, two shape features (roundness and extent) and four Fourier-shape descriptors were found to be effective in sorting regular and irregular potatoes. The average correct classification was 96.5% for a training set composed of 228 potatoes and then the algorithm was validated in another testing set composed of 182 potatoes in a real-time operation. The experiments showed that the success of in-line classification of moving potatoes was 96.2%.

4.1 AUTOMATED DEFECT DETECTION

Considerable research efforts in computer vision applied to food quality evaluation have been developed in the last years; however, they have been concentrated on using or developing tailored methods based on visual features that are able to solve a specific task. Nevertheless, today's computer capabilities are giving us new ways to solve complex computer vision problems (Mery et al., 2013). Potato quality includes a low incidence of colored bruises as a result from bad storage or manipulation practices. Up to now, automation has mainly focused on detection of bruises or necrosis spots on peeled potatoes. Some work has also been done to sort incoming potato batches according to shape or green areas. One can seek two different aims. For on-line sorting, the important thing is to eliminate any defective individual, since the presence of a single one in a package can result in rejection by the consumer. For scoring incoming batches, more complex data is to be obtained, equivalent to the classical visual evaluation by an operator. Marique et al. (2005) developed a procedure to process and segment potato images by using Kohonen's self-organizing map. Anomalous regions could be distinguished on 3 potato varieties. Bruises that were very dissimilar in appearance were correctly identified, and some particular defects such as green spots could be located as well.

4.1.1 On-line sorting

For whole potatoes, on-line sorting is applied immediately after peeling, to eliminate tubers presenting necrosis, bruises or any defects resulting into abnormal coloration. Cameras scan the stream of tubers, defective individuals being rejected by application of ultra-fast air ejectors. The same device is generally equipped with lasers that allow detection of foreign bodies such as stones, glass, wood, metal, etc. These can discriminate either between objects with similar color and different aspect or between objects with similar aspect and different color. The general principle is that laser light will be reflected or scattered in various ways by different objects. One finds these devices not only for whole tuber sorting, but also for chips or potato flakes sorting. In all cases, the general principle remains the same, lower air pressures being used for lighter products (Marique et al., 2005).

4.1.2 Bruise and green spot detection

CARAH's food technology laboratory developed a model, based on artificial neural networks that permit identification and discrimination of both bruises and green spots on peeled potatoes. This work was initiated to provide help to laboratories devoted to potato quality evaluation, since it is extremely difficult to standardize assessor response in different laboratories, let alone at different time in the same laboratory (Marique et al., 2005).

Artificial Neural Networks were selected as this kind of mathematical model is endowed with both good performance and broad capacities of generalization, especially for complex and non-linear systems. In particular, Kohonen's self-organizing map (SOM) is a neural learning structure, involving networks that perform dimensionality reduction through conversion of feature space to yield topologically ordered similarity graphs or maps of clustering diagrams (Schalkoff, 1997). Kohonen's SOM has previously been employed in a number of varied recognition tasks such as medical diagnostic, multi-scale image segmentation or grapevine genotype clustering (Haring etal., 1994; Manhaeghe et al., 1994; Mancuso, 2001) to baking curve identification (Yeh et al., 1995; Hamey et al., 1998; Hamey et al. 1997).

When presented with RGB pixel data values from a selection of three healthy potato cultivars differing in flesh color (*Asterix, Bintje, Charlotte*), the SOM nodes organize themselves according to the structure of the data, capturing its topological and density features in the node locations as shown in Figure 1.

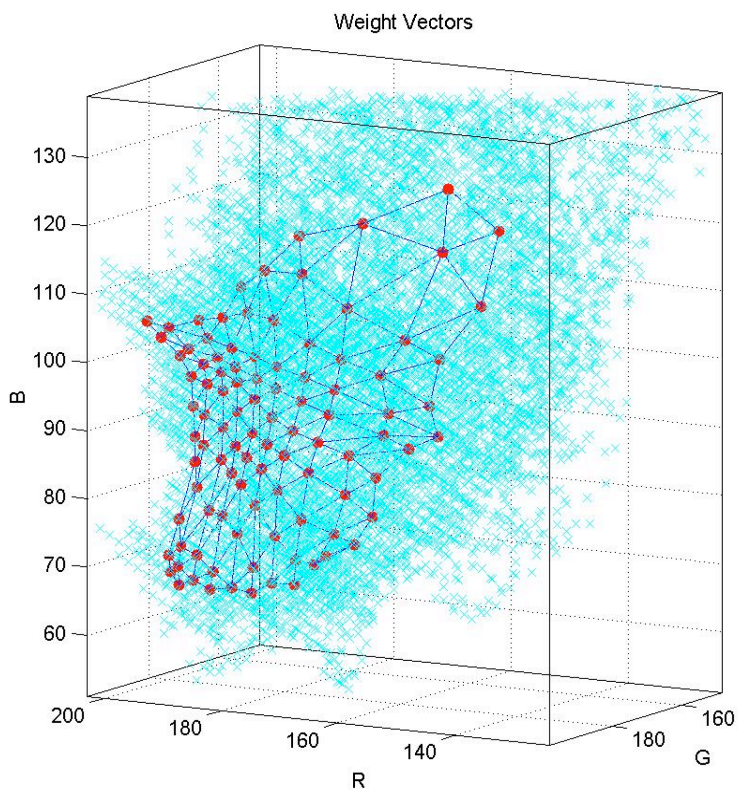

Figure 1. Structure of a trained two-dimensional hexagonal 10x10 Kohonen's SOM in RGB space. Cyan crosses: cluster of all pixels' RGB values from three potato varieties. Red dots: neuron positions. Blue lines: Euclidian distances between adjacent neurons. (Reprinted from *Journal of Foood Science*, Vol. 70, Thierry Marique, Stephanie Pennincx, Ammar Kharoubi. Image segmentation and bruise identification on potatoes using a Kohonen's self-organizing map. Pages 415-417, Copyright 2005, by courtesy of Institute of Food Technologists).

In a second step, the trained SOM can be presented with data values from bruised or greenish potatoes. Pixels from healthy parts of the tubers will then be positioned near the SOM network while pixels from bruised parts will stand far away (Figure 2).

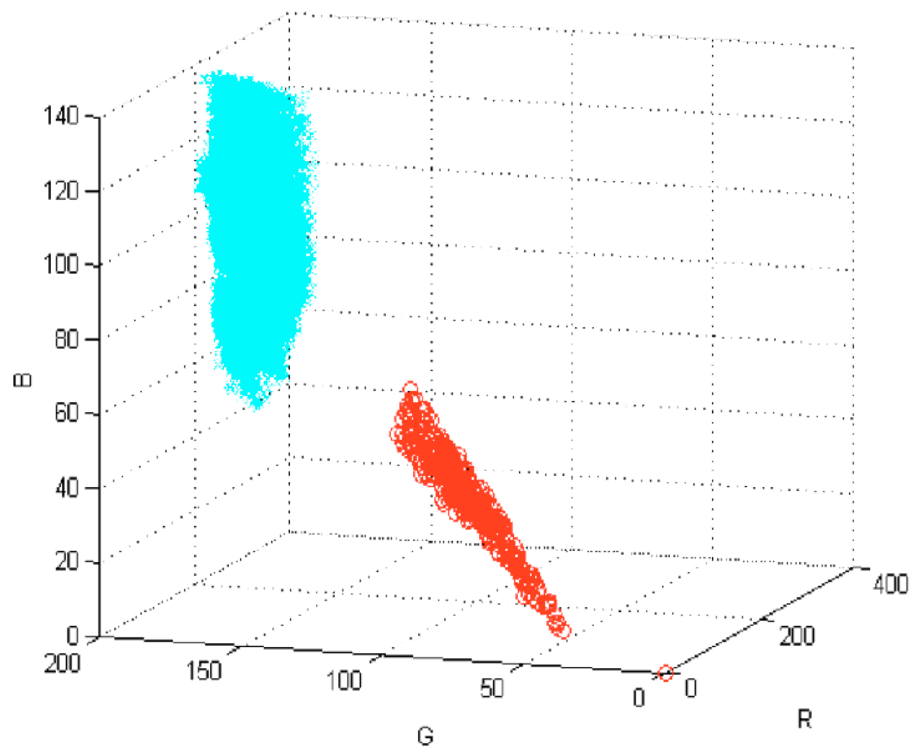

Figure 2. Distribution in RGB color space of pixels from the half-potato image. In blue: pixels from healthy parts of the tuber. In red: pixels from the bruised part of the tuber. (Reprinted from *Journal of Foood Science*, Vol. 70, Thierry Marique, Stephanie Pennincx, Ammar Kharoubi. Image segmentation and bruise identification on potatoes using a Kohonen's self-organizing map. Pages 415-417, Copyright 2005, by courtesy of Institute of Food Technologists).

Figure 3(left) shows a typical image of a bruised half-potato, selected from a series of 50 image samples that then were submitted to the trained SOM. Figure 3 (right) shows the performance of the SOM, by highlighting on the tuber image the region detected as a bruise, but no outside the region.

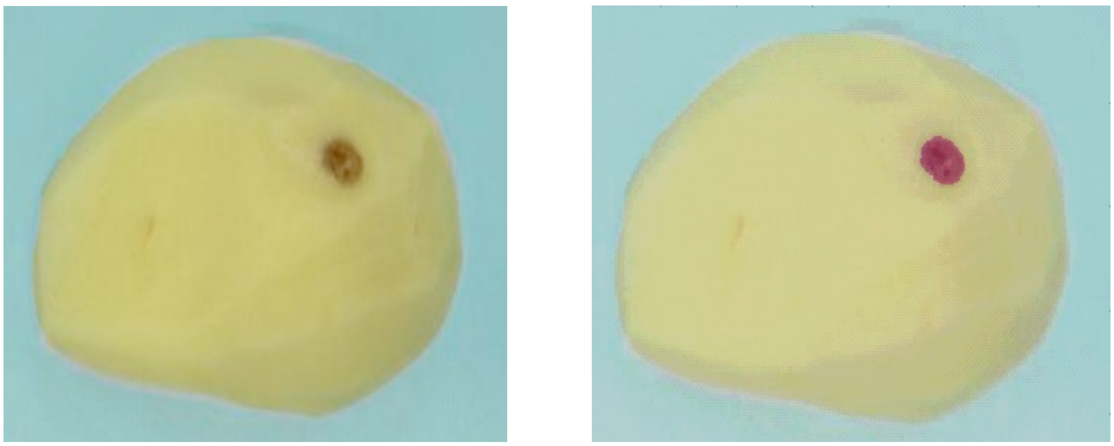

Figure 3. Image of a half-potato tuber, showing a brownish bruise (left). Bruised area (in red) identified by the SOM, superposed on the image of the half-potato (right). (Reprinted from *Journal of Foood Science*, Vol. 70, Thierry Marique, Stephanie Pennincx, Ammar Kharoubi. Image segmentation and bruise identification on potatoes using a Kohonen's self-organizing map. Pages 415-417, Copyright 2005, by courtesy of Institute of Food Technologists).

The performance of the trained SOM was extended to more complex bruises, e.g. bruises with irregular shapes or heterogeneous color, and to green areas due to sunlight exposure (Figure 4). For example, bruises with irregular shapes or heterogeneous color. Some tubers also presented green areas due to sunlight exposure (Figure 4, left side). As can be seen in Figure 4 (right side), the SOM correctly interpreted the RGB shades of the pixels, and a good segmentation of different areas was obtained.

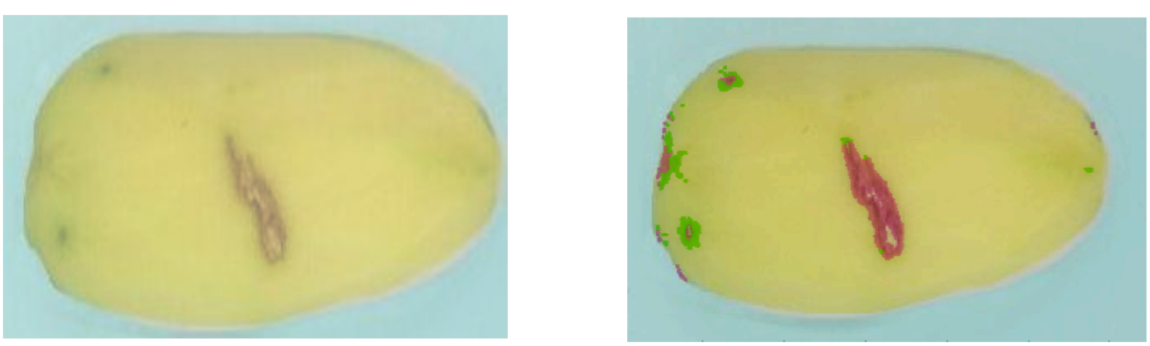

Figure 4. Half-potato image showing both bruised and green areas (left) and same image with superposition of regions identified by the SOM as green (in green) or bruised areas (in red) (right). (Reprinted from *Journal of Foood Science*, Vol. 70, Thierry Marique, Stephanie Pennincx, Ammar Kharoubi. Image segmentation and bruise identification on potatoes using a Kohonen's self-organizing map. Pages 415-417, Copyright 2005, by courtesy of Institute of Food Technologists).

Kohonen's self-organising map is thus suitable for identifying both bruised and green areas on potato flesh. As bruises clearly contrast over healthy potato flesh, very uniform in color, excellent results could be easily obtained. Further developments will involve improvement in image capture, measurement and processing, as well as calculation of relevant surfaces of healthy and bruised areas.

4.2 MACHINE VISION SYSTEM

The complete potato inspection system developed by Nordam et al., (2000) consists of a conveyor unit, a vision unit and a rejection unit, all placed in a single line. The conveyor consists of two singulating conveyors (SC1 and SC2) to separate the potatoes and to create a single line of potatoes. The speed of conveyor SC2 is slightly higher than the speed of conveyor SC1 to separate the potatoes at the transaction from SC1 to SC2. Conveyor SC2 transports the potatoes towards the vision unit where the inspection takes place.

The conveyor belts (VC1 and VC2) of the vision unit, place one after another, transport the potato under the camera for inspection. A digital 3-CCD color line-scan camera scans the narrow gap between the conveyors VC1 and VC2 to achieve in-flight inspection of the potato. To obtain a 360º view of the potato, mirrors are placed in the small gap (4cm) between conveyors VC1 and VC2. The lack of product holders and the use of mirrors guarantee a full view of the potato.

The camera must grab 2000 lines/sec to obtain the required resolution (2 pixels/mm) and thus, it requires powerful lighting equipment. The camera grabs continuously and the software detects when a potato passes the gap between the conveyors VC1 and VC2. Therefore, the camera requires no additional starting signal when a potato approaches the imaging area.

After inspection, the potato is transported to the rejection unit. The rejection unit consists of individually controlled product holders. Each product holder is kept upwards by electro magnets. Once a potato arrives at the correct rejection lane, the magnets are released and the potato drops at the correct rejection station.

A high grab frequency requires dedicated hardware for the image processing and classification tasks. A Spectrum Signal PCI-card with 11 SHARC's (Analog Devices ADPS-21060) Digital Signal Processors (DSP) is responsible for the image acquisition and classification tasks. One DSP communicates with the Host PC and transports the measurement results to the screen for visualization. The DSP's perform the color segmentation, image compression and spurious pixel removal. The remaining three DSP are divided over the three conveyors are divided over three conveyor lines to perform the operations for color and shape classification.

4.3 CHARACTERIZATION OF POTATO DEFECTS

In particular, a new paradigm on machine learning techniques has emerged posing the task of recognizing visual patterns as a search problem based on training data and a hypothesis space composed by visual features and suitable classifiers. Furthermore, now it is possible to extract, process, and test in the same time more image features and classifiers than before. Thus, we propose a general framework that designs a computer vision system which is able to select automatically from a large set of features and a bank of classifiers those features and classifiers that achieve the highest performance (Mery et al., 2013).

Specifically, product experts characterize potato defects and diseases on color and shape. Factors such as size, shape, greening, cracks, scab, etc. determine the final grade of a potato. The potatoes are graded into four different categories dependent on the presence of a defect and the area of the defect (Noordam et al., 2000). Similar diseases on potatoes of different cultivar (scab, skin spot and black scurf) may have a distinct color due to the underlying skin color of the potato. This requires a different reference set of images for each potato cultivar. Besides the difference in skin color for different cultivars, differences in skin structure and shape are also important features. From each cultivar an image collection of all possible defects was created. Each potato image is accompanied with a sensorial description and stored in a database which is then use for the development and testing of the color and shape algorithms.

4.4 ALGORITHM DESIGN

The superficial appearance and color of food are the first parameters of quality evaluated by consumers, and are thus critical factors for acceptance. Although human inspection is quite robust even in the presence of changes in illumination, the determination of color is in this case, subjective and extremely variable from observer to observer. For this reason, we recommend a controled illumination setup (León et al., 2006).

(i) Color segmentation: The majority of external defects and diseases are identified by its color, which makes the classification of pixels into homogeneous regions an important part of the algorithm. Multi-layer-feed-forward Neural Networks (MLF-NN) and statistical discriminate functions have been used successfully for the segmentation of potato images (Heineman et al., 1996; Kim and Tarrant, 1995; Guttag et al., 1992; Marique and Wérenne, 2001). Six different color classes in potatoes are identified: background, potato skin, greening, silver scab, outward roughness and rhizoctonia. Due to the difference in skin color it is not enough to use a single model for different potato cultivars (Noordam et al., 2000).

Mery & Pedreschi (2005) developed a robust algorithm to segmenting food image from a background by using colour images. Although the suggested threshold separates the food image from the background very well, the user can modify it in order to achieve better results. Recently, Moallem et al. (2014) developed a robust potato color image segmentation through a combination of a fuzzy rule based system, an image thresholding based on Genetic Algorithm (GA) optimization and morphological operators.

(ii) Discrimination between similar colored objects: There are a number of defects and diseases which have similar color. Defects such as cracks and rhizotocnia both have a black color. Discrimination between these defects is important since cracks are a more serious defect. Rhizoctonia and cracks both appear as unappetizing defects but cracks may become rotten and infect other potatoes. Therefore, cracks must be removed from the batch. For the discrimination between cracks and rhizotocnia additional shape features are used. Shape features must be able to discriminate between the different defects, as cracks and growth cracks appear as more or less elongated in comparison with rhizoctonia spots and common scab. Eccentricity (which can vary from 1 to ∞) can be considered as a measure of length/width and is used to discriminate between cracks and rhizotocnia (Noordam et al., 2000).

(iii)Shape classification: Fourier Descriptors (FD) and Linear Discriminant Analysis (LDA) are used to discriminate between good and misshapen potatoes. A single shape model is not enough to segment all potato cultivars into the classed good and misshapen. Good shaped potatoes may vary from round, oval to extreme oval. Therefore, different shape models are created for different potato cultivars. A shape training set and shape test was created for each cultivar to discriminate between good potatoes and misshapen potatoes (Noordam et al., 2000).

5 CONCLUSIONS

Product inspection is a process that requires evaluating large quantities of product based on limited sampling. Inspection is usually done by trained human graders, but unavailability of these inspectors has led to efforts to automate the process. Prototype automated potato inspection stations based on previously developed algorithms for shape and size has been developed and tested.

An automated station developed by Heinemann et al., (1996) was capable of size and shape potato tuber evaluation with some limitations. The motion of the potatoes interfered with accurate assessment of shape, although motion had little effect on determining the size. The throughput rate of the station was 3 potatoes per minute which would be prohibitively slow for sorting large quantities of potatoes.

Noordam et al., (2000) developed an affordable real-time computer-aided potato inspection system for inspecting potato weight, cross-sectional diameter, shape and color which are the four primary features in sorting potatoes in practice. This machine vision was capable of handling up to 50 potato images per second improving the classification accuracy of the system developed by Heinemann et al., (1996) for detecting other features while still achieving the real-time performance.

Marique et al. (2005) implemented algorithms to detect potato features such as bruises. They showed that Kohonen´s self-organizing map is suitable for identifying both bruise and green areas on potato fresh. A bi-dimensional SOM can be fitted to RGB space distribution of pixels corresponding to 3 different potato varieties. Pixels situated too far from the SOM are then identified as abnormal. As bruises clearly contrast over healthy potato flesh, very uniform in color, excellent results could be easily obtained. Further developments will involve improvement in image capture, measurement, and processing, as well as calculation of relevant surfaces of healthy and bruises areas.

ElMasry et al. (2012) designed and constructed an experimental machine vision system to test the image processing algorithms' ability to detect misshapen potatoes. Algorithms were developed to acquire and process images of potatoes in real time while they travel over a high speed conveyor belt. Stepwise linear discriminant analysis was used to determine which shape parameters were most responsible for detecting misshapen potatoes. The in-line evaluation of the proposed system showed that the overall accuracy of the system for detecting potato shape was 96%. In briefed, it could be concluded that integration between size–shape parameters and Fourier-shape parameters were very efficient in shape classification.

As we can see, considerable research efforts in visual food quality evaluation have been concentrated on using or developing ad-hoc features and classifiers that are able to solve a specific task. The traditional strategy to solve this problem is to use a low number of features and a few number of classifiers, because the cost is considerably reduced for experimenting, training and testing. Using today's computer capabilities, however, it is now possible to extract a very large number of features and to test several state-of-art classifiers, in order to select which features are really relevant and at the same time which classifier achieves the highest performance for these selected features (Mery et al., 2013).

6 ACKNOWLEGDMENTS

Authors acknowledge financial support from FONDECYT Project N°1150146.

7 REFERENCES

Brosnan T, Sun D (2004). Improving quality inspection of food products by computer vision – a review -. *Journal of Food Engineering*, **61**, 125-135.

Deck S, Morrow CT, Heinemann PH, Summer HJ (1992). Neural networks for automated inspection of product. *American Society of Agricultural Engineers*, **92**, 3594-3601.

Du C, Sun D (2004). Recent developments in the applications of image processing techniques for food quality evaluation. *Trends in Food Science and Technology*, **15**, 230-249.

ElMasry G, Cubero S, Moltó E, Blasco J (2012). In-line sorting of irregular potatoes by using automated computer-based machine vision system. *Journal of Food Engineering*, **112**, 60–68.

Gomez Galindo F, Sjöholm I, Rasmusson A, Widell S, Kaack K (2007). Plant Stress Physiology: Opportunities and Challenges for the Food Industry. *Critical Reviews in Food Science & Nutrition*, **47**, 749-763.

Grenander U, Manbeck KM (1993). Astochastic shape and color model for defect detection in potatoes. *Journal of Computer Graphic Statistics*, **2**, 131-151.

Guttag K, Gove RJ, VanAken JR (1992). A single hip multiprocessor for multimedia: The MVP. IEEE *Computer Graphics Applied*, **12**, 53-64.

Hamey LGC, Yeh JC-H, Westcott T, Sung SKY (1998). Pre-processing Colour Images with a Self-Organising Map: Baking Curve Identification and Bake Image Segmentation. In: Proc. 14th International Conference on Pattern Recognition, Brisbane, Australia. p. 1771-1775.

Hamey LGC, Yeh JC-H., Ng C (1997). Objective bake assessment using image analysis and artificial intelligence. In: Cereals '97: Proceedings of the 47th Australian Cereal Chemistry Conference, Perth, Australia. Royal Australian Chemical Institute. p. 180–184.

Haring S, Viergever MA, Kok JN (1994). Kohonen networks for multiscale image segmentation. *Image and Vision Computing*, **12**, 339-44.

Heinemann PH, Pathare NP, Morrow CT (1996). An automated inspection station for machine-vision grading of potatoes. *Machine Vision and Applications*, **9**, 14-19.

Jin J, Li J, Liao G, Yul X, Viray LC (2009). Methodology for Potatoes Defects Detection with Computer Vision. *Proceedings of the International Symposium on Information Processing (ISIP'09)*, 346-351.

Kim Y, Tarrant J (1995). Computer-aided inspection of potatoes and other agriculture products by digital image processing. *A Focused Technology Initiative Proposal*. University of Washington, Seattle, WA.

Lee W, Kim Y, Gove RJ, Read CJ (1994). Media station 5000: Integrating video and audio. *IEEE Multimedia*, **1**, 50-61.

León K, Mery D, Pedreschi F, León J (2006): Color Measurements in L*a*b* units from RGB Digital Images.. Food Research International 39(10):1084-1091

Mancuso S. (2001). Clustering of grapevine (*Vitis vinifera L.*) genotypes with Kohonen neural networks. *Vitis*, **40**, 59-63.

Manhaeghe C, Lemahieu I, Voglaers D, Colardyn F (1994). Automatic initial estimation of the left ventricular myocardial midwall in emission tomograms using Kohonen maps. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* **64**, 259–266.

Marique T, Pennincx S, Kharoubi A (2005). Image segmentation and bruise identification on potatoes using a Kohonen's self-organizing map. *Journal of food science*, **70**, 415-417.

Marique T, Kharoubi A, Bauffe P, Ducattillon C (2003). Modelling of fried potato chips color classification using artificial neural network. *Journal of food science*, **68**, 2263-2266.

Marique T, Wérenne J (2001). A general artificial neural network for the modeling of culture kinetics of different CHO strains. *Cytotechnology*, **36**, 55-60.

Mery D, Pedreschi F (2005): Segmentation of Colour Food Images using a Robust Algorithm. Journal of Food Engineering, 66(3):353-360.

Mery D, Pedreschi F, Soto A (2013). Automated Design of a Computer Vision System for Visual Food Quality Evaluation. *Food and Bioprocess Technology,* **6**, 2093-2108.

Moallen P, Razmjooy N, Mousavi BS (2014). Robust potato color image segmentation using adaptive fuzzy inference system. *Iranian Journal of Fuzzy Systems*, **6**, 47-65.

Noordam JC, Otten GW, Timmermans AJM, van Zwol BH (2000). High speed potato grading and quality inspection based on a color vision system. Proceedings-Spie the International Society for Optical Engineering, 3966, 206-219.

Pedreschi, F. (2012). Frying of Potatoes: Physical, Chemical, and Microstructural Changes. *Drying Technology*. **30**, 707–725.

Rousselle P, Robert Y, Crosnier JC (1996). La pomme de terre. Production, amélioration, ennemis et maladies, utilisations. Paris, INRA éditions, p. 607.

Schalkoff RJ (1997). Artificial neural networks. McGraw-Hill, New York, p. 448.

Tao Y, Morrow CT, Heinemann PH, Sommer HJ (1990). Automated machine vision inspection of potatoes. *American Society of Agricultural Engineers*, **90**, 3531-3539.

Thybo AK, Szczypinski PM, Karlsson AH, Donstrup S, Stodkilde-Jorgersen HS, Andersen HJ (2004). Prediction of sensory texture quality attributes of cooked potatoes by NMR-imaging (MRI) of raw potatoes in combination with different image analysis methods. *Journal of Food Engineering*, **61**, 91-100.

Yeh JCH, Hamey LGC, Westcott CT, Sung SKY (1995). Colour baking inspection system using hybrid artificial neural networks. In: *Proceedings of the IEEE International Conference on Neural Networks*. Volume 1, Perth, Australia, Nov. IEEE, p. 37–42.

Zhou L, Chalana V, Kim Y (1998). PC-based machine vision system for real-time computer-aided potato inspection. *International Journal of Imaging Systems and Technology*, **9**, 423-433.