High-speed and Cost Effective Machine Vision System within the Industry of Preserved Vegetables

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Abstract

The paper describes a sophisticated and low cost Automated Visual Inspection System (AVIS) for quality control of preserved orange segments, widely applicable to production processes of preserved fruits and vegetables. Main constraints concerning these kind of inspection applications are addressed: the need of on-line operation together with an strong requirement of economic profitability. The strong commitment of above circumstances have forced the development of a flexible and low cost AVIS architecture. An special effort has been put in the design of the defect detection algorithms to reach two main objectives: accurate feature extraction and on-line capabilities, both considering robustness and low processing time. An on-line implementation has been possible by using IP cores over re-configurable FPGA based BallyNue card, capable to inspect up to ten orange segments by second.

1 Introduction

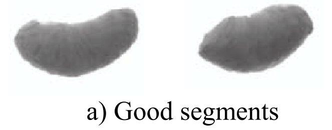
Along the last years more and more applications arise for visual inspection of many different products with on-line achievement [Jain, 1995][Jyrkinen, 1999][Kjaergaard, 1999]. This has been possible mainly due to the arrival of more powerful tools (hardware and software) into the vision developers community at better prices. These applications have not yet massively reached -although partial solutions have been reported, like fruit sorting- the fruit/vegetable processing industry due to several reasons: complexity of the inspection task, traditional idiosyncrasy within the manufacturers and market particularities for this kind of production. Production workshops are highly automated (raw fruit classification, washing, peeling, separation into different sizes, packaging…) being the inspection task the only one that is still performed by skilled operators, which represents the 30% of the man power in a typical workshop. Inspection mistakes and variability, cost to the Spanish producers of preserved fruit/vegetables 10 Meuro per year (aprox. 5% of 50.000 Tm produced every year).

Standards as Quality Standards for Preserved Vegetables Exportation or Quality Standards for Preserved Vegetables, among others, set commercial categories for preserved orange segments according to maximum percentage of broken slices and peeling defects. The challenge is to improve present manual classification by means of an automated system which assures on-line adaptation to production conditions.

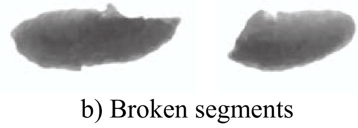
2 Specifications for the visual inspection task

The process of visual inspection at each workshop where preserved vegetables/fruits are prepared is made at the final stage, after the vegetables/fruits have been peeled and separated into pieces. In our case study –preserved orange segments- this inspection is achieved by four to six expert operators placed along both sides of a conveyor belt which carries the segments with a typical speed of 2 m/min with a global inspection rate of about ten segments by second.

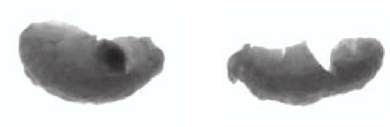
Illustration 1 show images from orange segments with different quality. There are different product qualities; final quality corresponds to a maximum content of broken segments. No strange elements are permitted (such as peels, leaves, ...), neither are the so called double segments.



a) Good segments



b) Broken segments



c) Bad segments

Illustr. 1. Orange segments.

The automated visual inspection demands:

1-High inspection rate: up to 10 orange segments by second.
2-High performance qualities: quality certification must be higher than the reached by human inspectors.
3-High flexibility adapted to on-line change of inspection criteria: it is necessary to easily change inspection parameters for updating actual product quality.
4-Compactness: the system must permit to include itself within the production line in an easy and fast way.

3 Orange segment characterisation

The required processing for the automated inspection can be divided into two different steps: color filtering [Miller, 1996] and bi-level image processing.

Color analysis supplies slice surface information, which allows the detection of defects like peel pieces, white filaments or presence of strange materials (e.g. labels). All these defects cause the segment to be rejected for canning and must be eliminated before following processing steps. For this purpose a combination of color filters has been arranged that permits immediate segmentation.

The second phase consists on the identification and characterization of each segment to determine their quality. This face is accomplished using a two-level adaptive threshold which allows to extract the shape while isolating inner defects as seeds. After that, different measurements are made using binary images from segments.

To identify the quality of every segment, we get a feature vector containing different characteristics which give a measurement of the segment shape.

A. Features based on spatial distribution of segment mass.

After a deep statistical analysis [Baillie, 1997] of different features over a population of more than 500 orange segments, we have selected central moments –order 2 and 3- and the set of seven invariant moments proposed by Hu [Hu, 1962].

Also some others *aspect features* have shown useful, as compactness, ratio perimeter/area, and measurements from the segment inertia matrix:

$$IN = \begin{pmatrix} I_x & 0 \\ 0 & I_y \end{pmatrix}$$

$$\frac{Area^2}{I_x \cdot I_y} \qquad \frac{I_x}{I_x + I_y} \qquad \frac{I_y}{I_x + I_y}$$

B. Associated distribution to segment signature

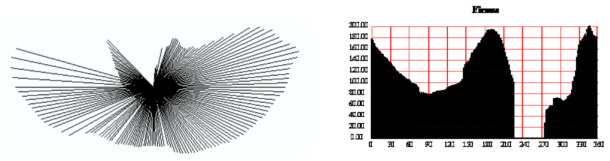
It has also been used a simple unidimensional representation of the segment perimeter corresponding to the distance from the central mass to perimeter points as a function of clockwise angle [Gonzalez, 1992].

A key point when using this feature –signature- for segment characterization has been a good selection for the starting point. Although promising results where obtained selecting most distant perimeter point from mass center, more robustness was obtained when considering the selection of most distant point situated on the principal axe of the segment. This is due to the way to determine this axe, from the covariance matrix calculated using all perimeter points.

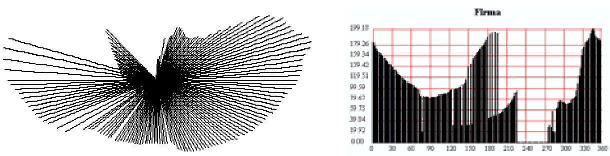
Under the hypothesis of scale uniformity concerning both axes and scanning in successive intervals of angle ϑ, a change in shape produce a corresponding change of signature amplitude. An efficient method to normalize this result consist of scaling all functions in such a way that we always get the same range of values (e.g. [0, 1]), although useless in presence of noise. To solve this drawback, we have implemented a normalization based on the signature standard deviation; for this purpose every sample is divided by the variance, which produces a variable scale factor inversely proportional to size changes, and working very closely to an automatic variance control.

When obtaining the signature two possibilities have been considered: to assign longer or shorter distance in a given direction, that is, considering extern or inner evolving. Better results are obtaining using the inner evolving as it can be observed in figure 1.

a) orange segment



b) inner evolving



c) extern evolving

Fig. 1. Signature considering extern and inner evolving.

4 FPGA-based image processing

Traditionally, the application prototyping is performed in different environments, using a high-level programming language for the SW, and VHDL or Verilog for the HW description. This makes difficult the co-simulation, and usually it is necessary to manually re-code the specification at the implementation stage. That is itself an error-prone process that leads to two versions of the same code in different programming languages. For this reason, some efforts have been made to construct co-design environments allowing co-simulation, rapid prototyping and straightforward HW/SW code generation [Arnout, 1999][Panda, 2001][Hwang, 2001].

The Xilinx blockset contains high-level blocks that map intellectual property (IP) cores that have been hadcrafted for efficient implementation in the target FPGA. However, the XSG toolbox includes only some basic blocks that serve as “bricks” for developing more complex structures. Based in these simple blocks, in this work the development of a visual processing library based on XSG for Simulink is presented. It constitutes the first step in the creation of a complete HW/SW co-design and co-simulation Simulink-based scheme that will allow the rapid prototyping and implementation of hybrid CVS applications.

Nallatech offers one of these platforms for rapid prototyping, consisting on an FPGA based commercial card called BallyNue; which can be suitable for image processing and if it is combined with and additional module (BallyVision) offers the possibility of capturing analog video for digital processing. Main features of the Ballynuey system are:

• PCI/Control Xilinx® Spartan2 FPGA, pre-configured with PCI/Control Firmware
• User Virtex-II® FPGA available exclusively for user designs/applications
• JTAG configuration headers
• Xilinx Chipscope ILA support

The main drawback of this system is that it is necessary a huge amount of time to develop functional processing algorithm, because it usually requires a low level hard work with VHDL modeling and simulation tools. He have made a big effort in developing the proposed image processing algorithms using Xilinx System Generator to reduce this gap of time, not only to model the processing algorithm, but also the type of camera used for capturing imaging and the different elements of the Ballynuey architecture. In this way, we have obtained a system level model of a commercial card that can be used for a high level modeling of user-defined image processing algorithms.

5 The developed system

To achieve the above mentioned requirements, the developed AVI System –showed in illustration 2- is formed up by:

Mechanical supporting System (MSS). Its aim is to align orange segments as they come from size selectors and move them at controlled speed under the camera. The MSS also assures separation among segments. Main components are the align and centering device, the speed-controlled conveyor belt and the selector module.

Control Unit (CU). The mechanical system is driven by the Control Unit. It receives orders from the Master Unit and converts them into signals for the aligning and separating elements. Also transmits to the Master Unit signals coming from different sensors. Finally, it drives the pressured air jets and automatically governs the shooting of cameras.

Image Acquisition Unit (IAU). For enhancing the visual properties of the product under inspection it has been set a combination of back and front lighting and a CCD progressive scan camera with programmable shutter.

Image processing Unit (IPU). Nallatech BallyNue with Virtex-II® FPGA available exclusively for user designs/applications and PCI/Control Xilinx® Spartan2 FPGA, pre-configured with PCI/Control Firmware.

Master unit (MU). The overall supervision and intelligence of the AVI system relies on the Master Unit. It is responsible for AVI system interfaces with the Control Unit, the human operator and the production process. The MU generates inspection strategies as a result of inspected product and requirement from the operator. Also, the MU hosts a Quality Assessment System, which seeks for quality evolution and takes corrective actions when necessary.

Illustr. 2. View of AVI System on workfloor

6 Results

We have considered a pattern as a collection of data binned in k (k=180) classes forming the desired distribution for the segments. Therefore the inspection process consists on analyzing if the signature obtained is statistically equal to that pattern. Using the theoretical $\chi 2$ 0.95 statistic ($\chi 2$=212) and passing a $\chi 2$ test over a sample of 132 orange segments we obtained a percentage of 14,6% of classifying a good segment like bad (type I error) one and a 10,4% percentage of classifying a bad segment as a good one (type II error).

The result is a desired improvement of the speed and quality of the inspection process compared to the current one carried out by human inspectors as figure 3 shows. Although the type I error does not have an important reduction the type II error does; and most of all there is a considerable increment of the inspection speed with an additional advantage of objectivity during the classification.

Actual prototype performance qualities include the inspection of up to ten orange segments by second, which makes it compliant with on-line requirements.

Classification accuracy reaches a 10.4% producer's risk (good segments classified as bad segments) and around 14.6% customer's risk (bad segments classified as good ones). These results improve about 20% average classification score reached by manual inspection.

	Human Inspection	Automated Inspection
Type I Error	18%	14,6
Type II Error	30%	10,4%
Speed (pentium III)	600 ms/segment	64 ms/segment
Speed (FPGA)	600 ms/segment	22 ms/segment

Fig. 3. Human inspection vs Automated Inspection.

The AVI system will help to introduce a new high quality for this product not reachable by human inspection (extra fancy, containing less than 5% broken segments). As it is the think of preserved fruit/vegetable producers, this is the action line which will make the Spanish industry capable to face low prices coming from direct competitors in Asia and North of Africa. Once more, competitive advantage comes from higher quality rather than from lower prices for manpower.

7 References

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