Surface Inspection of polyurethane foam by image processing and Artificial Neural Networks Techniques

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Abstract. – Quality assurance is a necessity in the industrial processes. The machine vision technology is an efficient technology for the reliable and fast control of different types of products. This technology allows obtaining a big amount of visual information, superficial and dimensional at a high speed. The objective of this article is to describe a successful application of machine vision technology in a Foam production, a productive sector where this technology is scarcely inserted. The aim of this project is to obtain on-line visual parameters of the process in order to modify the variables of production immediately in an automated way. Those parameters were obtained off-line by means of human visual inspection two days later in a laboratory analysis before this project. The difficulty lies in the fact that visual characteristics of both samples (on-line and off-line) are very different.

Key-Words: **-** Machine vision, foam, quality control, pore, neural network, surface control, darkfield.

1 Introduction

The polyurethane foam is a material used in different industrial sectors, such as automotive, shoes, household goods, and furniture. To satisfy the necessities of quality of these sectors, the manufacturing of foam requires certain specific controls throughout the process. One of the main parameters to establish the mechanical characteristics of this product is the number of pores per centimeter that the external coat of the foam has at the end of the foaming process.

Besides, this parameter is an indirect way of knowledge of other parameters (hardness, permeability).

The number of pores per centimeter depends on the percentage of components of the mixture and the value of some variables (temperature, pressure) of the chemical process. The variation of these variables will cause the higher or smaller hardness, and higher or smaller pore density, among others.

To obtain the right number of pores per centimeter, a process expert "foamer" controls the foam in the first steps of the process by adjusting the variables of the process to increase or decrease the pore density. Otherwise, the real information of the characteristics of the pore is not obtained till the foam is "cured", about 48 hours after having started the foaming process.

The "foamer" uses indirect visual methods to try to estimate the final characteristics of the foam. Due to the fact that this observation is subjective and indirect, it has their limitations, and also the dependence of the company on one or two experts in this process must be taken into account.

The necessity of bringing in a new technology arises in order to guarantee the obtaining of these values in a reliable and repetitive way. The machine vision is revealed as a valid option.

Anyway, these techniques could be applicable to other applications of surface characteristics estimation.

2 Problem Formulation

The problem to solve is to obtain the characteristics of a sample acquired on-line at first

stage of the production by image processing techniques and to transform that information into that one that would be attained at the end of the process, off-line at the laboratory, having into account that the visual characteristics are very different according to the model of foam.

On the one hand, it is necessary to obtain from a sample acquired on-line enough data to characterize the foam. On the other hand, it is necessary to interpret those obtained values in the first steps of the foaming process and associate them with the final characteristics of the foam once it has completed its manufacturing cycle.

Both parts have their own difficulty. The obtaining of a good image that enhances the pores will be essential, and in spite of using a good lighting, the irregularity, break or low definition of the outline of the pore makes the processing difficult.

It is also needed to connect characteristics in different moments of the process that do not have any mathematical link and even they can lead to different output values with the same input data according to the features of the foam (model, color). The challenge is to model a non-lineal system generated by the chemical reactions among all the components. The only available information is the one provided by the foaming process expert.

This application is brand new, references of similar applications to this sector have not been found.

3 Problem Solution

The whole solution has been split up in two big blocks: conventional image processing and algorithm development with new techniques for the understanding of non-lineal systems.

Before that, it is necessary to design the vision system that can supply with the proper information for the later process. The choice of the elements and their proper arrangement is fundamental for the obtaining of good quality images. The 50% of success lies in this.

3.1 Design of the vision system

The system includes mechanical, electric, machine vision and software development. The mechanical system is a metallic frame with a structure inside that keeps the elements in fixed distances and isolates the sample from the external light and environmental attacks. It is constituted by:

1) An input platform (today the sample is introduced manually) and support of the obtained sample of the foam at a fixed distance.
2) A support portico for the suspended camera over the foam sample.
3) A variable mechanical element for keeping the lighting at a stable distance.

The illumination chosen method is a “Darkfield” type [6] with red LEDs. This layout of the LEDs in a circular element is specially indicated for those applications in which the enhancement of borders is needed or contrast improvement is required in surfaces where this is difficult to obtain by the use of other lighting methods. The isolation from external light is important. The distance light - foam was experimentally estimated.

It has been chosen a BW IEEE1394 camera, 640 x 480. Although it is not a big resolution, it is enough for this, having in mind that the field of view is 12 mm. The distance between light and camera has also been calculated by tests, being fixed in that point where the quality of the image is optimum.

Besides, the camera offers an auto adjustable feature of brightness and contrast, since the chromatic characteristics of the foam are changeable.

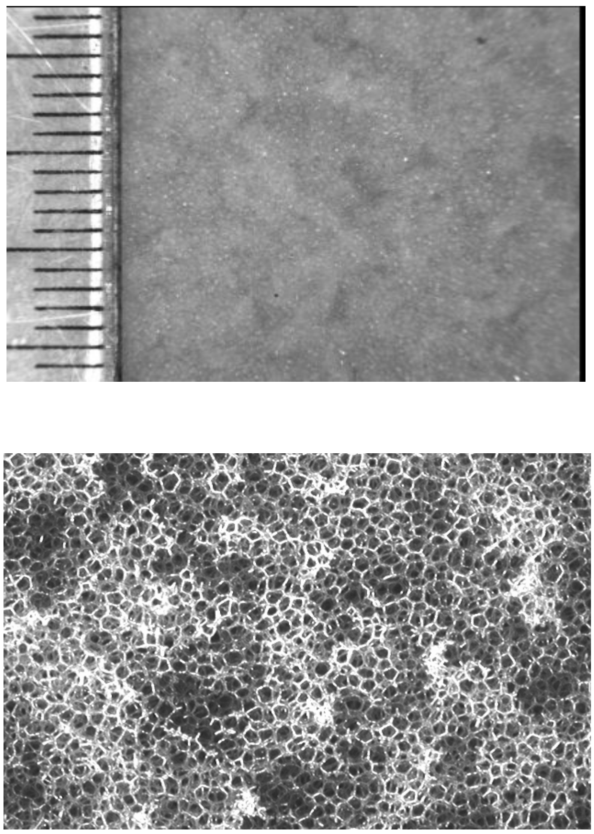


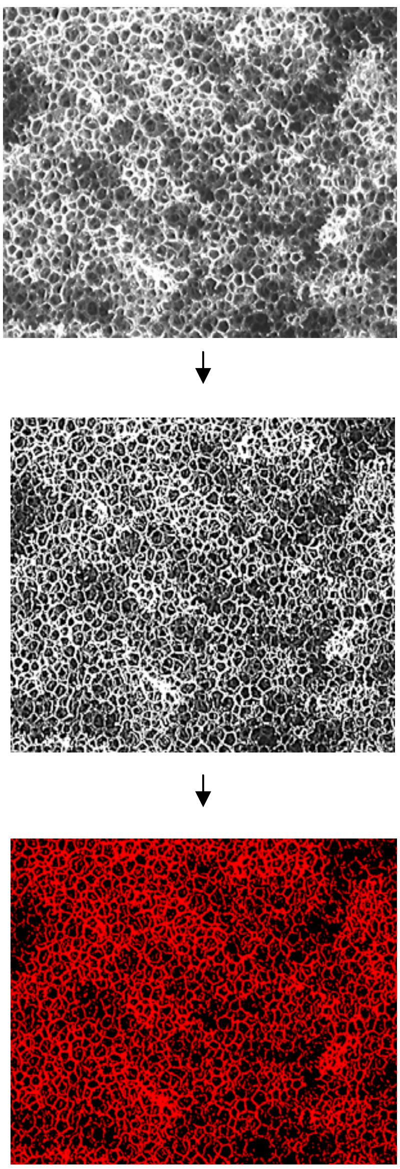
Fig. 1. Image of foam. Up) At the lab, with ambient light. Down) at production stage with darkfield illumination

3.2 Processing algorithm

The programming environment is NI LabWindows CVI, image processing libraries NI-IMAQ vision and MvTec HALCON, and NI-IMAQ control software for the communication protocol IEEE1394 and Matlab for neural network design. It has been developed a processing algorithm that consists of 3 levels: morphologic, statistical and neural analysis, since the classical image processing cannot itself solve the application.

3.2.1 Morphological processing

Once the image is obtained, conventional processing algorithms are applied [3]: Auto threshold algorithm, enhancing filters, masks, so that **a first approach to the characteristics of the foam are obtained**. The regions in the images that do not provide information are removed. A sample of sequence of operation is shown underneath:



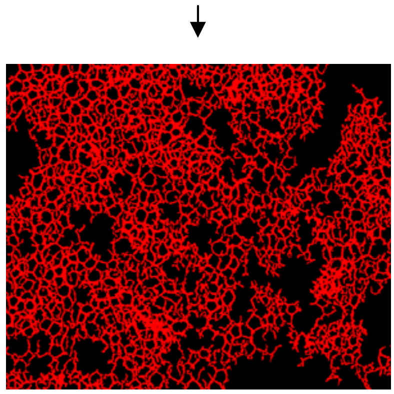


Fig. 2. Morphological analysis sequence (Enhancing filters, Auto threshold algorithm, and masks removing background elements)

3.2.2 Statistical processing

From the morphological processing result on, different methods have been evaluated for the obtaining of the number of pores. But the foam is not still cured and the pore presents discontinuities, the superposition of different layers of pores and the low definition of some of them. This all originates processing difficulties. Finally, it has been chosen a method that reproduces the counting way of the foaming experts: row transition counting, but processing all the rows (only 3 rows are evaluated at laboratory)

This transition counting allows the obtaining of a redundant value in each of the 480 lines in the image. With statistical methods, some extreme counting values in the Gauss bell and those that do not have an established threshold value for available information [4] are removed. With those ones that have this admissible value, an average calculus is made and it is related with a previous gauging of the field of view and unit of surface. In this way, the first useful value is obtained: number and characteristics of pores per centimeter in that initial moment of the foaming chemical process. **It is necessary to remark that this number is very different to that one obtained for the same foam at the laboratory.**

3.2.2 Neural analysis

The value that must be the output of our system is the number of pores per centimeter that that foam will have when the foaming process has finished. If this value is not suitable according to the established requirements for that model of foam, the variables of the process will be changed, this is, the amount of the components that take part in the reaction.

The initial available value is the number of pores per centimeter obtained in the statistical stage of the process. What we are looking for is the laboratory number of pores, radically different. How can these two values be connected? How can this non-lineal system be simulated? It is needed to associate an output to each input? [1,2,5]

It is necessary to "learn" how many final real pores correspond to certain characteristics of the initial number of pores according to the model of foam. To solve this last point, it was thought to use Artificial Neural Networks. One of the more powerful aspects of the neural networks is that they allow simulating the behavior of non-linear systems without having to find a mathematical model that describes them. Simply, they "learn" the behavior.

In this way, once the network has been designed and developed, the neural network will be trained, by providing a wide range of filtered data got from the images (initial value) and the real number of final pores (obtained from the human counting in the laboratory once the process is finished). If the network is properly designed, and the range of samples is wide enough to cover all the cases, in the moment when another situation is provided, the network will be capable of giving the correct value of number of pores as output.

The general scheme of a neural network is:

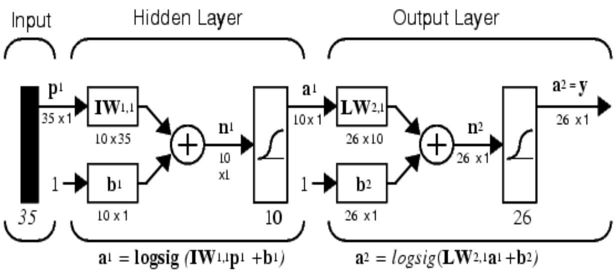


Fig. 3. General scheme of neural network

The neural network accomplished for this application is "back propagation" type and has 2 layers and 5 neurons in its hidden layer, 5 inputs and 1 output. The training is supervised.

In a first approach, an only neural network for the whole range of foams was designed, but the obtained error in the first stage of tests was considered too high. **The objective is an error rate even lower than the one obtained in human inspection with laboratory techniques.**

This is why it was decided to accomplish 3 neural networks, one for each of the 3 groups in which all the foam samples have been classified: one for the foams of clear hue and small pore, another for dark foams and with small pore, and another for dark foams with big pore. The structure of each of them is similar, but the training is executed in every case with different samples of the related group.

The 5 chosen inputs for the network are: the number of pores per centimeter obtained after the statistical analysis; other values extracted from the stages of morphological and statistical processing of the image, such as standard deviation of the number of pores in each line, average of histogram, moda and standard deviation of the histogram. The output is the final number of pores per centimeter that that block of foam will have at the end of the foam manufacturing process.

The developed software module presents a user interface. It has been allowed not only to get this control parameter but also other functionalities, such as system configuration, live grabbing, grabbed image displaying and zooming and its comparison with a previously saved reference image for each model of foam. It is also possible to select each model of the range of foams, and the storage of the results in an Excel report for registering the progress of production.

4 Experimental results

This project has been developed by ROBOTIKER and IPF in the framework I+D INTEK of the SPRI.

The prototype is now being tested at production facilities, and the results are still preliminary.

The system has been developed and installed in ICOA (foam producer), and several tests have been carried out with a double aim:

1. To verify the validity of the obtained value with regard to the real value.
2. To check the reliability of these results and the robustness of the accomplished system with a sufficient number of samples.

4.1 Reliability of the system

To check the trustworthiness of the system, several tests have been done with different models of foam. It was verified the existing error between the obtained output value and the real counted value by a foaming counter at the end of the process.

These ones are some of these results, with two images of the same model in each case:

Foam model	Pores system	Real pores
Srf	20	20
	19	20
S28	19	18
	18	18
S30hfr	18	18
	18	18
S40bpd-1	31	30
	31	30
S40bpd-2	29	27
	29	27
Sh60	11	12-13
	13	12-13

It can be seen that the maximum error is close to 8% meanwhile the average error is of 3%. They are even smaller than the ones obtained in the laboratory in two different random samples of the same foam.

4.2 Repetition of results and robustness of the system

The robustness and reliability of the system was evaluated. For that, the average value and the standard deviation were calculated with 10 images from the same piece of foam. These images are different each other, due to the fact that the sample is shifted under the camera to grab a different zone every time (remember field of view 12 mm).

As example, the results obtained for a type of foam are shown next:

Model	Image-sample	Pores system	Real pores
S40bpd	1	30	30
	2	30	30
	3	31	30
	4	30	30
	5	31	30
	6	30	30
	7	31	30
	8	30	30
	9	30	30
	10	30	30

Average value: 30.3
Standard deviation: 0.42

These results allow stating the repetition of the values provided by the system and its reliability. The use of neural networks has implied a big advance in the analysis of data and has supplied a trustworthy solution.

At the moment, this application is operative in the manufacturing plant ICOA and has been installed by INGENIERIA DEL POLIURETANO FLEXIBLE, S.L. Nowadays, new samples of all types of foams are being inserted so that it is being increased the number of samples to accomplish the training. Once the network is trained with this bigger and bigger range, the system will have an even more trustworthy response and it will be susceptible of use for all the materials of ICOA.

5 Conclusions

The application of machine vision technologies in the industrial sector of the foam is scarce; being characterized this chemical process by a manual control of the worker according to his experience and knowledge. This fact limits the efficiency of the manufacturing process and the quality of the resulting element.

The developed application shows many advantageous features:

1. A solution is presented adapted to the problem from the very moment of grabbing, with an architecture of lighting and camera suitable for the requirements of the user and inexistent in the market.
2. It is considered an ”on-line” analysis of the image in the very first stage of the foaming process, but giving the response similar to one obtained at laboratory. Having this in mind, proper information of how it is being formed makes it possible to act over it, and in this way, to improve the final quality of the foam. Before, this information was only available 2 days later in the laboratory, once the chemical foaming process is finished.
3. The application of methods based on neural networks in the process is absolutely novel and pioneering.

The reached results validate the use of neural networks in the process, as well as the approach of the previous morphological and statistical analysis. The disposal of the elements and the choice of the lighting method have been successful.

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