An automated visual inspection system for the glass industry

Francesco Adamo, Filippo Attivissimo, Attilio Di Nisio and Mario Savino

Laboratory for Electric and Electronic Measurements
Department of Electrics and Electronics (DEE) – Polytechnic of Bari
Via E. Orabona 4, 70125 Bari
Tel. 080 5963266   fax 080 5963410
e-mail [adamo, attivissimo, dinisio, savino]@misure.poliba.it

Abstract- Today, computer vision inspection systems are widely used for quality control in order to reduce the costs and to improve the product quality. The glass industry is constantly trying to improve quality by substituting the human control with automated inspection systems but several problems must be solved. In this paper the problem of detecting and measuring the defects of satin glasses is investigated and a real-time system is proposed that is able to analyze the glass surface under inspection, to assess its quality and to characterize its defects.

A prototype has been carefully designed and optimized for validating the proposed approach and to reproduce the real issues of quality control. The prototype is composed by several CMOS cameras, a controllable conveyor bend, and an image processing system. Currently the prototype, which is cheap and reliable, is under further development in cooperation with a specialized electronic industry.

I. Introduction

Satin glass can be used in different field as decorative arts, housing, furniture factories, light bulbs and so on; its translucent quality is desirable in many situations because provides privacy where the full transparency of the glass is undesirable. The satin glass can be produced in different ways but in most cases the dull finish is achieved by hydrofluoric acid vapor treatment; common defects produced by these manufacturing techniques are *scratches* and *spots,* a real issue for the glass industry.

As common in other manufacturing areas, due to the growing competition, the prices of satin glass reduce more and more but the quality requirements increase. In this context, many glass companies have higher and higher interest to replace manual inspection with automatic processing and analysis systems based on computer vision techniques. However, as a matter of fact, the acid glass process is largely mechanized, while the inspection process is not yet appreciably automated.

The human eye has good capabilities to find imperfections in structures and surfaces; in the case of glass surfaces, the defects are seen as irregularities. However the conclusion about the quality of the product is subjective; this means also that the judgment is influenced by prior knowledge and by the tiredness caused by repetitiveness of job.

The automated systems assure several advantages with respect to the human-made inspection, such as objectivity, accuracy, costs reduction, fine regulation of the quality control process and of the quality limits. Computer vision techniques do involve many tasks difficult to automate, because several aspects must be taken into account: analysis time, position and orientation of the subject, calibration of the system, presence of dust and moisture, lighting of the glass surface. Besides, to successfully replace the manual inspection, the enhancement of images processing techniques and the reduction of both processing time and false positives are recommended.

To this aim, several methods relevant to the inspection of glass have been proposed in literature; examples are the *scanning laser beam* [1] - [2], the *neural network system* [3], the *independent component analysis model* [4], the *area* or *feature based techniques* [5]; unfortunately, there is no method which is really accurate, low cost and reasonably at the same time. Moreover, the systems already on the market do not agree with the flexibility requirements of these industrial applications.

In this paper, the authors propose an accurate and affordable prototype able to perform analysis of satin glass sheets; the method peculiarity is that it detects small defects in non-uniform intensity and low-contrast images and it is rather robust with respect to changes of the glass type and to other operating conditions. The preliminary results, obtained by means of several tests, encourage the authors to deepen some technical problems and to suggest the reported system as a reliable alternative to more expensive techniques.

II. The proposed system

The prototype of the inspection system (Figure 1) consists of many different functional blocks: a motion system, an image acquisition unit, an illumination source and an image processing unit where the elaboration algorithm is computed by a MATLAB based software.

The *motion system* is composed by two roller conveyors moved by two high torque stepper motors which are controlled by a custom designed microcontroller based electronic circuit (Figure 2); this circuit has been developed with modularity and expandability in mind. Every module is equipped with a 4-bit hexadecimal switch that serves to configure its address on an RS485 serial bus; all the modules present on the transport chain are linked in a daisy chain fashion between them and with the PC.

The choice of this kind of communication link has been imposed by the necessity to control many motors distributed over the transport chain. The stepper motor can be driven in full, half, quarter and micro-step mode and at a programmable speed to adapt the traction to the analysis phase.

Figure 1. The roller conveyor used in the glass inspection system.

The firmware of the motor drivers implements a simple command parser which allows to set many of the working parameters of the transport conveyor: speed, run length, brake status, etc. Commands are sent by the control software on the PC using a common RS232 serial port and an RS232/RS485 bidirectional converter; all the commands are coded as follows:

destination_address:*command_mnemonic*[<SP>[*command_parameter1*]<SP>[*command_parameter2*]]<CR>

where:
- *destination_address* = address of the module to which the command is directed expressed as the ASCII equivalent of a two digit hexadecimal number; due to the fact that the hexadecimal switch used to set the address on the module has only 4 bits, valid addresses range from '00' to '0F'. If *destination_address* = '0F' the command is parsed and executed by any module on the bus (that is '0F' is a broadcast address);
- : = character ':' (acting as a separator between the address and the command mnemonic);
- *command_mnemonic* = command mnemonic ('STOP', 'DIR', 'RESET', etc.);
- *command_parameter1* = possible first command parameter (there are commands that do not have parameters at all like 'STOP' of 'RESET'); parameters can be strings or numbers according to the particular command;
- <command_parameter2> = possible second command parameter (there are commands with only one parameter);

- <SP> = Space character (ASCII code 0x10) used as a field separator;
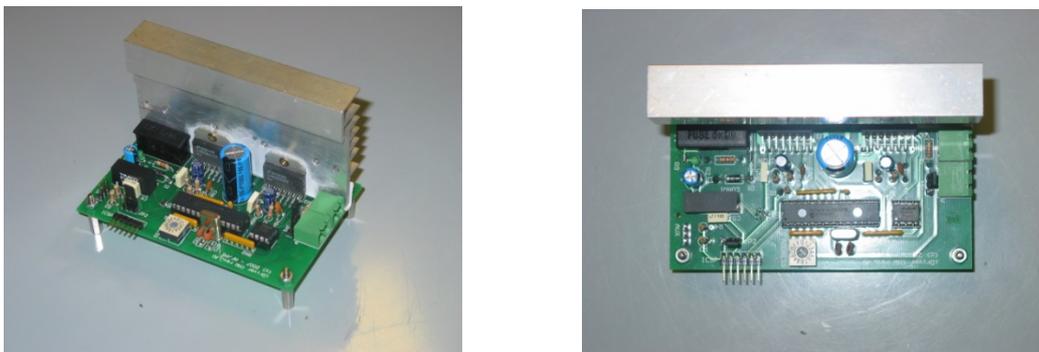- <CR> = Carriage Return (ASCII code 0x0D) used as a command terminator;

Figure 2. The custom designed microcontroller-based motor controller.

The *acquisition system* in the prototype is limited to only two USB cameras based on a 1.3 Mpixels CMOS CCD sensor; more cameras can be added to increase the width of the analyzed surface. The cameras receive a trigger signal by one of the motor controllers and then they acquire synchronized images of the glass sheet.

To avoid saturation caused by the presence or absence of the target, auto-iris cameras that automatically adapt the diaphragm aperture to the brightness of the scene have been avoided. The adopted cameras are progressive scan with 256 gray levels and acquire images in a cyclical way without compression in order to avoid loss of meaningful information.

The *illumination system* is realized in order to guarantee a grazing light which is a good compromise for the correct visualization of the irregularities; in this case the scratches appear brightest and the spots appear darkest with respect to the background. Really, a wrong illumination of the layer causes erroneous results: normal irregularities of the satin layer could appear as defects whereas real spots or scratches could disappear at all.

The *image processing* system is the core of the prototype; the software has been developed in Matlab and assures processing times acceptable for the foreseeable in-line use of the final system.

III. The processing subsystem

Much effort was aimed at maintaining the system as simple and cheap as possible. The complex tasks the system is involved in have been transferred to the software side, reducing the criticality of the hardware components and enhancing the modularity and scalability of the project. A common problem for this approach is that the processing unit tends to become a bottleneck. For this reason, attention has been given to the actual software implementation. The prototype, which relies on careful coding and distributed computing techniques, has shown that this is an effective strategy for solving our quality control problem.

The main tasks of the processing subsytem are described below. They are:
- system registration,
- cameras setting and calibration of lighting,
- mosaicing, correction of geometrical distortions and correction of lighting nonuniformities,
- glass sheet detection and selection of the regions of interest,
- defects detection,
- defects classification,

where the first two tasks are involved in the system calibration, which is executed only in an earlier stage, while the following task are executed during the normal use of the system.

The *system registration* step consists in the acquisition of several reference images with the aim of calculating those parameters useful for the mosaicing of frames acquired by different cameras. The system takes into account the movement of the glass sheet on the conveyor, as well as the geometrical distortions introduced by the lenses. The reference images used for registration are composed by identifiable elements, whose apparent positions are matched against their nominal positions. The registration procedure is automatic, the only manual operation requested to the user is to ensure that there is a minimum overlap between the fields of view of different cameras; moreover, the registration functionality avoids the necessity of accurately positioning the imaging system, thus lowering exercise costs.

A second group of tasks pertains to the setting of both cameras gain and exposure time, and to the *calibration of lighting*. Presently, the gain and exposure setting is preceded by a manual adjustment of the iris and focus of the objectives, but the use of motorized objectives is scheduled. A useful functionality that has been developed is the determination of the lighting nonuniformities, which provides a means for improving the nonuniform illumination of glass sheets caused by a very cheap illumination system. For this purpose, an image of clean glass sheet is acquired by each camera, then corrective parameters are estimated in order to remove large scale intensity gradients. An example of such a correction is shown in Figure 3. The experimental results have shown that a low cost dark field imaging system guarantees good results without resorting to more expensive polarized or coherent sources.

A third group of tasks is related to the *mosaicing* and to the real-time application of the corrective parameters already determined. The implemented mosaicing algorithm restores the image of the sheet starting from the partial images obtained with different cameras and in different sampling instants.
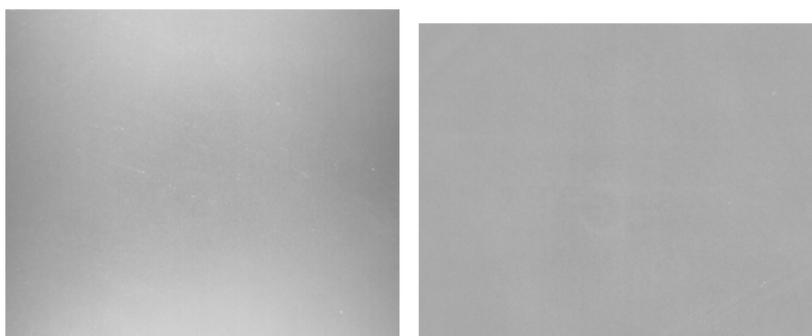

Figure 3. Acquired image before and after the correction of lighting nonuniformities.

In the *glass sheets detection* phase the system checks the presence of the object on the conveyer belt. The glass sheet is revealed relying only on image processing, thus avoiding the necessity of additional sensors. The target is separated from the background by means of thresholding and analysis of the shape of the resulting object. The edges of the glass sheet are detected and a region of interest where to perform the analysis of defects is selected, as in Figure 4. In the subsequent processing only the highlighted rectangular area of the segmented glass sheet are taken into account.
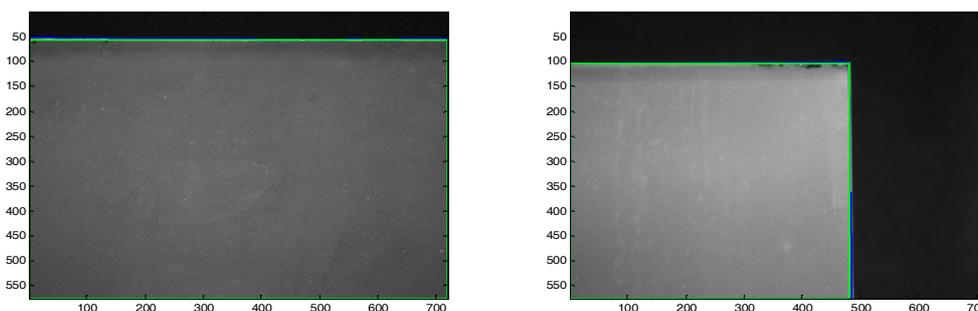

Figure 4. Segmentation of the glass sheet.

The *defects detection* is accomplished, basically, by using the Canny edge detector. The thresholds of the detector are calculated according to the desired sensitivity and evaluating the statistical properties of the analyzed image. The algorithm has been optimized in order to be rather insensitive to thickness and granularity of glass as well as to lighting conditions and resolution. These features simplify considerably the tuning of the detector.

Finally, the *defects classification* is a post-processing stage where meaningful properties relevant to the detected defects are calculated, among which the centroid, the area, and the mean intensity. The defects are classified into scratches or spots according to their properties. Moreover those defects are discarded that, according to their size and intensity, are more likely dust grains rather than true defects. The system provides a complete log of: all the operating parameters, the calibration constants, the unprocessed raw images, the processed images of the glass sheet whit the identified defects. As a consequence, the entire image processing can be reproduced off-line, working on already acquired images.

IV. Experimental results

The system has been tested in order to prove its robustness in a large range of operating conditions. As a matter of fact, it is rather insensitive to variations and nonuniformities in the lighting subsystem, due to the correction technique implemented. The registration procedure also is successful despite of a bad illumination, even in dusty working environments.

The defects detection algorithm has been applied to actual glass sheets and to batches of sample images. To evaluate the performances, the subjective notion of defect must be clarified; in relation to different application areas, defects could be identified as variations in structural parameters, deviations in size, changes in texture features and so on. In the proposed system the defects are perceived as irregularities in the random texture of the satin glass.

The implemented algorithm has demonstrated to produce a low number of false positives and to be both accurate and reliable for different kinds of glass. This flexibility is required because many different types of glass are often produced in the same factory; they differ from each other by the granularity degree of the satin layer and by the reflectivity of the surface.

In Figures 6 and 7 are shown two examples of defects detection. Figure 6 is relevant to the identification of scratches and Figure 7 reports both scratches and spots. In each figure the starting image in shown on the left, and an intermediate binary image of the defects is shown on the right. Morphological operations are applied to the binary image, resulting in the individuation of filled objects whose boundaries are shown with continuous (red) lines.
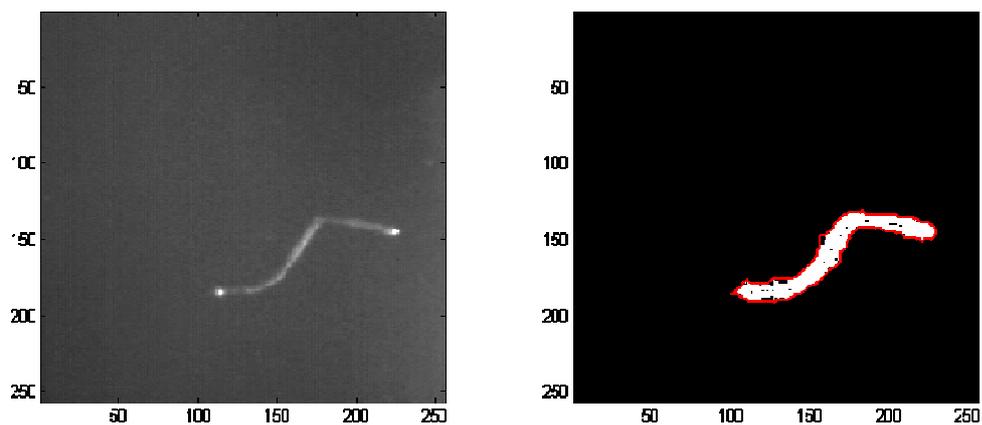
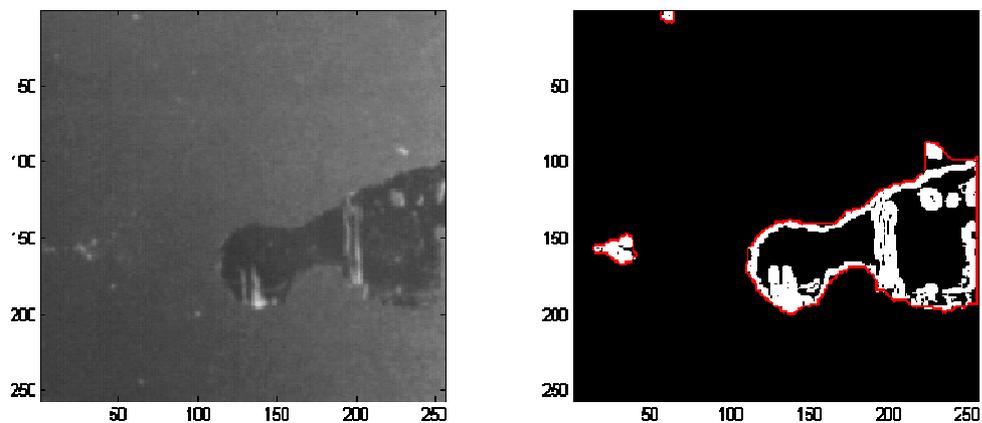Figure 5. Example of identification of scratch like defects.

Figure 6. Example of identification of both scratch like and spot like defects.

V. Conclusions

This work presents the preliminary results obtained by means of an experimental automatic and computer-based visual inspection technique that gives good results in the detection and classification of manufacturing imperfections of satin glasses. The components of the developed prototype and the functionalities of the image processing system have been described. The system is scalable according to the size of the glass to analyze still having processing times suitable for industrial production; indeed, distributed computing techniques have been developed to face the increase of the computational load.

The framework already developed is sufficiently flexible to serve as a basis for investigating vision inspection technique in several manufacturing contexts. Further work involves the extension of these techniques to other materials, such as textile, leather and steel sheet.

Acknowledgements

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