19th Symposium IMEKO TC 4 Symposium and 17th IWADC Workshop
Advances in Instrumentation and Sensors Interoperability
July 18-19, 2013, Barcelona, Spain

Contactless measurements for on line quality monitoring in rubber extrusion processes

Giuseppe Di Leo, Consolatina Liguori, Alfredo Paolillo, Antonio Pietrosanto

Department of Industrial Engineering, University of Salerno Italy,

Abstract- This paper is concerned with the topic of contactless measurements for industrial applications. It presents the case of vision-based systems realized by the authors expressly for the measurement of geometric and/or chromatic parameters of rubber profiles for the automotive industry. After a brief description of the extrusion process, a stereo vision system for the on-line measurement of the dimensional characteristics of the profile transversal section is first described in all its main components and features, then two modules for the inspection of the finish of profile surfaces are presented.

I. Introduction

Thanks to new technologies that today allow to implement automatic nonintrusive solutions at convenient costs, on line inspection systems are going to be widespread also in areas driven by off-line quality control requirements. Dimensions and external finish of products can be today monitored on-line at costs that can be recovered after few months of production waste reduction. A number of inspection techniques have been thought to be implemented on-line and the choice among them must be made on the basis of the product nature. Contactless measurements are strongly recommended in many applications, e.g. to avoid load effects when deformable objects are to be inspected. Machine vision methods have provided the efficient and reliable techniques for the design of image-based contactless measurement systems [1].

In some industrial fields, such as the production of either electronic components and boards or mechanical parts, automated inspection using machine vision has already had a relevant number of applications. This is not the case of the production of rubber profiles, due to the complexity of the production process and to the flexibility and the dark color of the product.

In this field the authors realized an image-based measurement system for inspection tasks in a plant producing rubber profiles for the automotive industry [2]-[5]. A stereo vision system was designed to make the on-line contour extraction, the 3D reconstruction of the transversal section of rubber profiles, and the measurement of the main dimensional parameters. It is based on the registration of each observed profile onto a reference profile. A suitable software tool let users specify the dimensional lengths to be measured. In this way, users have been able to maintain the software up to date for new models of profiles and new measurements [5]. Nevertheless the measurement system still keeps some limits: i) the robustness of the contour extraction algorithm gets low when a metal reinforcement is included in the profile section; ii) the software does not provide statistical information on the product quality; iii) no inspection is made on the external surface of the profile. In this paper the authors, after a brief recall of the overall structure of the extrusion line, describe the solutions they propose to overcome the aforementioned limits of the contactless measurement system.

II. The extrusion line

At the site of Battipaglia, Italy, the Cooper Standard Automotive S.p.A. manufactures rubber profiles for car window and door sealings. The production cycle is divided into several basic steps (see Figure 1). The extrusion essentially compresses the pasty material at high pressures through a matrix which reproduces the interior and exterior shape of the piece. Some profiles, the so-called armed profiles, have a metal insert with stiffening function. The extruded rubber flows through ovens for the vulcanization which causes a change in the molecular structure of the polymer resulting in an increase of the elasticity and tensile strength and in an improvement of other physical and chemical properties. Subsequently, the product passes to the phase of electrostatic flocking which gives the rubber a velvety appearance, obtained first sprinkling an adhesive solution over the surface and then uniformly distributing fibers over it by means of an electrostatic field. After a cooling step, those products

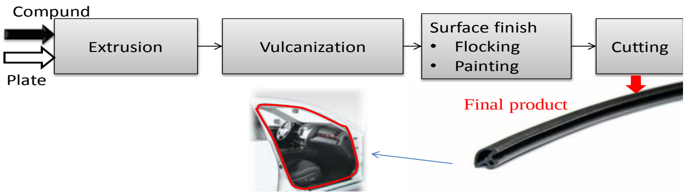


Figure 1. Stages for the rubber manufacturing

for which it is required undergo a brushing step. This phase has a predominantly aesthetic purpose so as to give it a matt appearance to part of the outer surface. The step of cutting to a given length ends the in-line processing, followed by the collection of the products in the cases for the transport.

III. The measurement system

The measurement station for the verification of the geometrical dimensions of the profile has been placed at a side of the second conveyor belt used for the collection of the finished product (Figure 2): It is constituted by two cameras, an illuminator, a photocell and a data acquisition system. The cameras are suitably positioned to frame the cross section of the profile with different angles of view. The on-line operation of the measurement station can be viewed as a sequence of modules, detailed in the following and shown in Figure 3. The main module is the on-line procedure, which is executed each time a new profile goes into the visual field of the two cameras. Both (left and right) images feed the 2D procedure which outputs the edge points of the two contours. Then, starting from the contours of the two 2D images, a 3D reconstruction of the section of the profile is run. In order to determine the position in the space of the profile points of the profiles from the pair of images, taken by the two cameras, it is necessary to know the parameters of the intrinsic and extrinsic cameras, obtained by means of a calibration procedure. The measurements are carried out on the three-dimensional reconstruction by a third module of the developed application, called the Profile Editor.

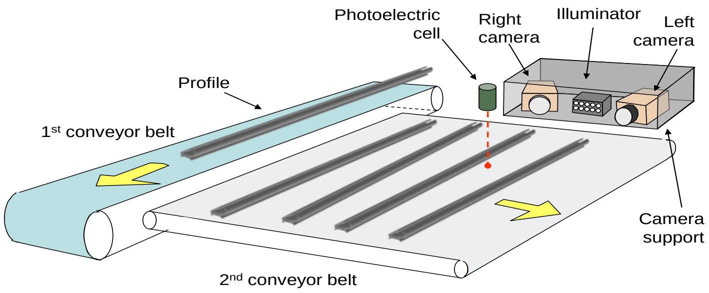


Figure 2. The hardware architecture of the measurement station.

A. Two-dimensional image processing

Since the measurements are made on the 3-D reconstruction of the 2-D contours, the localization of the cross-section contour plays a key role in the measurement procedure. The developed image processing algorithms apply a sequence of known image processing techniques: a histogram enhancement routine normalizes the grey level distribution in the image, a region growing stage locates all the pixels belonging to the profile section (the foreground region), and a contour tracking algorithm locates the contour as the border of the foreground region. For the profiles with metal reinforcement, the tuning of parameters such as integration time, lens aperture and amplifier gain of the camera becomes critical as they have a direct influence on the brightness of the captured image. If a value of these parameters is found so that the rubber part of the front section is represented with a sufficiently high grey level, the metal sheet, which has a much higher reflectance, saturates (i.e. reaches the maximum grey level) and generates glares, smearing or blooming broadening the appearance of the lit part and affecting the measurement.

In order to obtain high-contrast and to avoid these undesirable phenomena, the dynamic range of the image on which measurements have to be done must be expanded. Two techniques were considered: the HDR Imaging [6] and Exposure Fusion (EF) [7], which, starting from a sequence of images of the same scene taken with different exposures, reconstruct an image with a higher dynamic range. The HDR technique aims to reconstruct the radiance map of the scene: from the sequence of images at different exposures, the characteristic function (CRF, room response function) which relates the radiance of the scene to the brightness of individual pixels is first reconstructed. Then by inverting this function the radiance map of the scene can be achieved. The HDR processing, however, imposes a significant computational load that is not compatible with the requirements of on-line control. Furthermore, the images obtained with this technique tend to create undesirable halos around bright areas of the image, and then for the presence of reflections on the metal part would result in a broadening

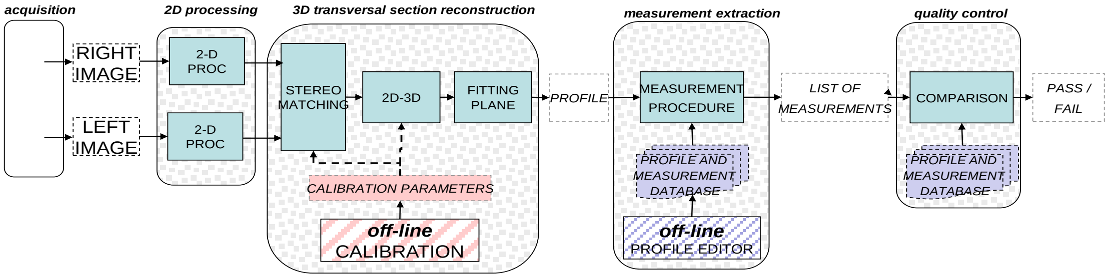


Figure 3. The software architecture.

of the contours. The EF technique addresses some of the limitations of HDR: The final image is composed by taking the individual pixels from images of the sequence on the basis of a score, according to specific figures of merit associated to the individual pixels of each image. By this way, two goals can be achieved: i) the execution of the algorithm is much faster, because there is no need to sort the map of radiance again; ii) the effect of halos that was observed in HDR processed images is eliminated, thus allowing a more accurate contour extraction. Figures 4a) and b) show the images obtained with the two techniques mentioned above and the related measures. In both cases the rubber part is measured correctly, while the measurements of the metal part have a maximum error of 21% compared to the reference for the image obtained by means of HDR, and 6% in the case of images obtained via EF, thus demonstrating the effectiveness of the EF technique in preserving the outlines of the brighter areas.

B. Three-dimensional reconstruction

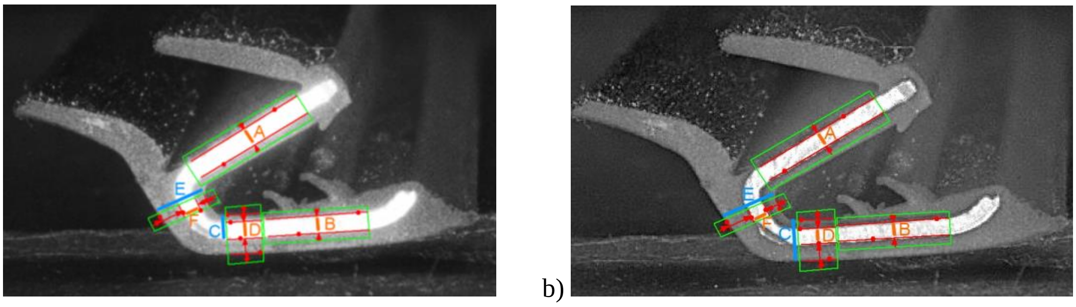
The two 2-D contours determined in the previous step are processed in order to obtain a 3-D reconstruction of the contours of the leading cross-section. The procedure can be divided into two phases: i) the search for matching stereo pairs, namely the pair of image points in the left and right images generated by the same real point, and ii) the calculation of the 3-D coordinates of the profile contour points as a function of the two stereo pairs. The search for stereo pairs is performed by exploiting the epipolar constraint [5]: given a point on one image (e.g. the left one), the corresponding point on the other (e.g. the right) image lies on a line, the so-called epipolar line, whose localization can be determined from the calibration parameters. The point on the right image which corresponds to a given point on the left image can be searched for within the intersections between its epipolar line and the profile contours. Once the calibration parameters of the two cameras and the pixel coordinates of two image points are known, a triangulation algorithm [8] allows to obtain the measurement of the three absolute coordinates of each point of the contour. In order to simplify the subsequent extraction of measurements from the 3D contour, a fitting plane is determined as the least square plane approximating the points of the cross section of the profile, and then the measurements are performed on the 2-D projection of the contour on this plane.

C. Measurements

A procedure of measurement valid for all the profiles and products has been implemented and set up. The procedure can also be extended to future production, since the list and the description of the measurements can be easily tailored for a new model of profile. The dimensions to be measured must be only once specified by the user on the coordinate system of the reference profile contour. Then, the measurement procedure consists of two main steps: i) each new observed 3D contour of the profile is superimposed ("registered") to the reference contour of the profile; ii); the measurements specified on the reference are made on the observed contour.

The reference profile library management is entrusted to another application module, called Profile Editor. This module allows the user to select and view the reference profile of a section, to specify the measurements to be made on the profile. The measurements are defined by primitives, each of which requires the user to define two points on the reference contour; these couples of points must be placed in the coordinate system of the reference contour. The different types of measurement primitives that can be applied to profiles are:

- the “gauge”, distance between the two intersections of a specified segment (P, Q) and the observed profile;
- the so-called “tip-to-tip”, distance between the two points of the profile observed that best correspond, in terms of proximity and curvature, to two specified points on the reference profile (P, Q). It is also possible to projects the measured segment onto a straight line ("axis") determined by two points belonging to the contour (R and S of Figure 5a) and specified using the Profile Editor. For each selected measurement the nominal value can be stored in the data base and on line compared with the measured one. In Figure 5b) a screen output of the software is shown.



a) b)

Figure 4. a) HDR image with overlaying measurement indicators; b) enfused image with overlaying measurement indicators.

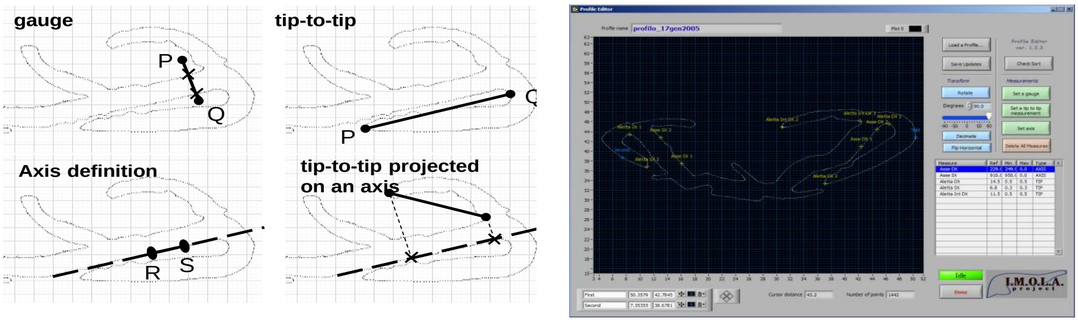


Figure 5. a) Measurement primitives; b) example of use of the Profile Editor.

D. Calibration

In order to determine the spatial position of the profile contour points the three-dimensional reconstruction algorithm requires that the intrinsic and extrinsic parameters of the cameras are known. Goal of the calibration procedure is the determination of the intrinsic and extrinsic parameters of the cameras. It must be repeated whenever one of the configuration parameters of the system (position or angle of the cameras, distance, focus) are expected to have changed. The authors' proposal is based on the approach of Zhang [9], which requires the two cameras to observe a different a planar target, whose geometry in 3-D space is known with very good precision, shown at a few different unknown poses. A sandblasted metal plate containing a pattern of 6x5 square holes (120 squares corners) is adopted as the target, due to its good accuracy (~10 μm). The knowledge of the corner positions in several pairs of images, at least five, and of the target geometry in mm, allows specific calculations based on the maximum likelihood criterion in order to determine the intrinsic and extrinsic parameters of the cameras.

E. Quality checks, report and metrological characterization

Each measurement result is compared with the specification limits in order to assess its compliance with design tolerances and the software reports the outcome of the dimensional test with a "pass/fail" indication. The presentation of the results includes, for each piece, the superimposition of the observed and the reference profiles, the table of last results, the time chart of the results and some statistics. Some report pages can be recalled to view the chart of the quantities of interest. The user's queries can include: the line, the section, date and time of beginning and ending of observation, and the quantity of interest. Summary reports of different types can be generated: i) Basic, ii) Advanced, iii) Failure Chart, iv) Production Line, v) Summary. The metrological characterization was carried out on the system in use at Cooper Standard Automotive plant in Battipaglia, Italy. Tests have been performed to assess: (i) the influence of the relative position of the cameras, (ii) the systematic errors of the system, and (iii) the repeatability of the measurement results. Choosing the optimal position of the cameras and after performing a correction of systematic errors, the standard uncertainty of all types of measurements was contained in 0.2 mm. The processing time of the proposed measurement system, at the typical extrusion speed of the line (3 pieces / min), allows to monitor the 100% of the produced pieces.

IV. A system for painting quality control

The coating process consists in depositing a transparent silicone paint on the exterior surface of the profile. The coating has both an aesthetic and a functional purpose: To confer a shiny effect and to make a waterproof seal.
The coating system in use at the plant is produced by Kremlin, consists of four air spray guns, and is managed by the operator by means of PLC, which allows to set for each gun both the pressure of the paint and the atomizing air. The system for regulating the pressure is based on the use of electronic controllers, which allow to obtain a

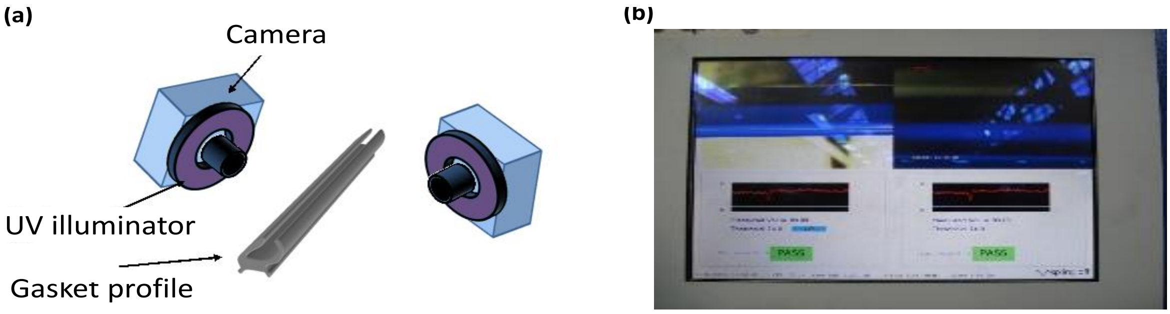


Figure 6. a) Painting quality measurement system; b) software user interface

great precision in regulating the value of air flow and paint. This results in an excellent finish quality with a very high degree of pulverization, and in a very low thickness of the painting (from 10µm to 30µm). Nevertheless, temporary or permanent gun failures may result in parts not painted that must be detected and discarded. Since the paint is transparent, in order to allow visual verification by the operator, it is mixed with an additive (UVITEX OB by CIBA) which emits in the visible when illuminated with ultraviolet (UV) radiation. A human operator had to periodically check whether the image of the seal illuminated with a UV lamp and displayed on a monitor presents specific characteristics of brightness. The vision system designed by the authors replaces the human operator in the control of paint. It has been designed to detect the presence of paint and to estimate the amount of paint deposited on the surface of the profile. It is based on the measurement of the amount of blue color present in each acquired image, assuming it is proportional to the amount of additive and then of paint. The control panel (Fig. 6b) embeds the processing unit, the monitor for display, the tower to the visual and acoustic signaling devices and power. The vision system, schematically shown in Fig 6a), is positioned immediately after the spray booth and uses two camera-illuminator pairs in order to monitor the whole external surface that must be painted. The two 640 x 480 color cameras are featured with ring type illuminators having a wavelength of 365 nm. The system acquires at regular time intervals two images of the profile surface and then processes them to measure the amount of paint and compare it with a predefined threshold chosen by the human operator. If the measured value is out of tolerance, an alarm is generated. The algorithm identifies a sub-image centred onto the profile contour, and calculates an index proportional to the average brightness of the blue component extracted from the acquired sub- image. A chart is also shown on the operator panel with the history of the last 300 measurements.

A. Experimental results

It was not possible to perform a complete metrological characterization of the system, since a reference measurement system is not available, which allows to measure quickly and with high precision the amount of paint deposited on the surface of the extruded rubber. However, tests have been carried out in order to verify the functionality of the system and the compliance to production needs. In particular, the sensitivities to the major failures of the coating system, to total or partial obstruction of a paint spray gun and to variations of the spray angle or position of the gun have been verified: In all the tests the system has detected the defects in painting. As for the measurement rate, since the system processes approximately 10 images per second and the maximum line speed is 30 m/min, a measurement is performed every 5 cm. Then, system is able to detect the lack of paint for length at least greater than 5 mm. These characteristics fully respond to specific requests of the factory quality control system.

V. On-line gloss meter

One of the final stages of the production line is the brushing. Also this stage has a predominantly aesthetic purpose: to give a matt appearance to part of the outer surface of profiles. The measurement of the degree of gloss (expressed in gloss unit, GU) were previously performed only off-line on some samples and using a commercial gloss-meter which exploits the phenomenon of specular reflection of a surface illuminated by a light beam. The gloss-meter projects a non-polarized white light on the sample surface, at a predetermined angle of incidence and it measures the reflected light with a sensor located in a specular position with respect to the light source [10]. The common angles of incidence for the gloss measurement are 20°, 60° and 85°. The research activity has been aimed at achieving an on-line contactless gloss-meter. Such measurement system uses a camera and an illuminator ring and measures the average brightness of the captured image, assuming that this value is proportional to the degree of gloss of the analyzed surface.

The measurement station is positioned immediately after the brushing cabin and consists of a smart camera, a

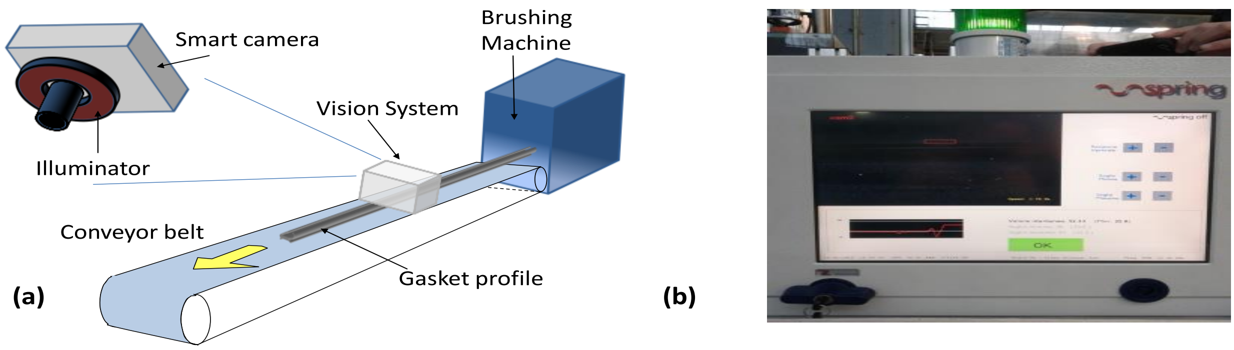


Figure 7. a) Gloss measurement system; b) software user interface.

LED illuminator ring type and a control panel containing the monitor (Fig. 7a). The smart camera positioned at the top of the profile acquires an image of a portion of the profile at regular intervals and processes it so as to measure the degree of gloss and compare it with the tolerance values defined by the human operator. The algorithm adaptively locates a sub-image that contains the portion of profile and then calculates an index proportional to the average brightness within that region. If the measured value is out of tolerance, an alarm is generated. On the operator panel (Fig. 7b) in addition to the acquired image and the calculated index also a chart with the history of the last 300 measurements is displayed.

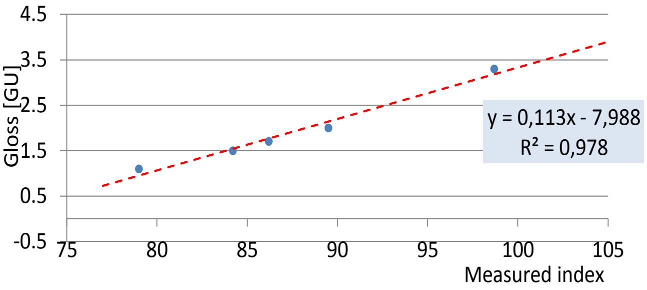


Figure 8. The results of calibration

A. Experimental results

The calibration of the system for the gloss measurement was performed using, as a reference, the system currently in use at the plant: Erichsen Pico-Glossmaster 500 which has a measurement range [0, 100] GU and accuracy equal to 0.2 GU. Data collected by the on-line system during a long time measurement campaign have been compared with corresponding measurements made by the reference instrument in order to calculate the relationship between the index measured by the system and the value of the gloss measured off-line in the laboratory. Figure 8 shows the curve obtained by considering some gloss values: the standard deviation is always less than 0.3. Using a linear interpolation, a determination factor equal to 0.978, is obtained, representing an acceptable approximation. As far as the measurement rate is concerned, since the system is able to process about 5 images per second and the maximum speed of the line is equal to 30 m / min and the size of the visual field is approximately 10 cm, the system is in able to perform a measurement every 10 cm. The obtained metrological characteristics meet the requirements of the quality control system.

VI. Conclusions

A vision based system for the on-line measurement and control of dimensional and aesthetic parameters of rubber profiles has been designed and characterized by the authors. The measurement system has demonstrated to be efficient and to fully meet the specification of the industrial quality production control system. Moreover, this on-line contactless solution has caused a drastic reduction of production waste, and then a decrease of costs.

References

[1] Te-Hsiu Sun, Chun-Chieh Tseng, Min-Sheng Chen, “Electric contacts inspection using machine vision” *Image and Vision Computing*, Volume 28, Issue 6, June 2010, Pages 890-901

[2] L. Angrisani, P. Daponte, A. Pietrosanto, C. Liguori, “An image based measurement system for the characterization of automotive profiles”, *Measurement*, 25 (1999) 169-181.

[3] C. Liguori, A. Paolillo, A. Pietrosanto: “An on-line stereo vision system for dimensional measurements on rubber extrusions”, *Measurement*, vol.35, N.3, Aprile 2004, pp. 221-231.

[4] R. Anchini, C, Liguori, V., Paciello, A. Paolillo, (2006), “A comparison between stereo-vision techniques for the reconstruction of 3-D coordinates of objects”, *IEEE Trans on I&M*, 55(5), 1459-1466.

[5]R. Anchini, G. Di Leo, C. Liguori, A. Paolillo, “Metrological Characterization of a Vision-Based Measurement System for the Online Inspection of Automotive Rubber Profile”, *IEEE Transactions on I&M*, Vol. 58, No. 1, Jan. 2009, pp. 4-13.

[6]E. Reinhard, G. Ward, P. Debevec, W. Heidrich et al., “High Dynamic Range Imaging: acquisition, display and image-based lighting”, 2nd ed., 2010, Morgan Kaufmann.

[7] T. Mertens, J. Kautz and F. Van Reeth, “Exposure Fusion”, *Pacific Graphics* 2007.

[8] R. Anchini, G. Di Leo, C Liguori, A. Paolillo, (2009), “A new calibration procedure for 3-D shape measurement system based on phase-shifting projected fringe profilometry”, *IEEE Trans. on I&M*, 58(5), 1291-1298.

[9] Z. Zhang, “A flexible new technique for camera calibration”, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 22(11):1330-1334, 2000.

[10] ISO 2813:1994, “Paints and varnishes - Determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees”.