Automatic Inspection of Moving Surfaces

Th. Laengle
Fraunhofer IITB
Karlsruhe, Germany
e-mail: thomas.laengle@iitb.fraunhofer.de

D. Paul
Fraunhofer IITB
Karlsruhe, Germany

M. Hartrumpf
Fraunhofer IITB
Karlsruhe, Germany

G. Struck
Fraunhofer IITB
Karlsruhe, Germany

Abstract[1]

In many industrial applications, the inspection of the produced product is an important step to guarantee the needed quality. Examples for that is the inspection of copper laminates as a basis for the production of printed circuit boards (PCBs). They consist of a web of fiber glass which is saturated with epoxy resin and covered with a thin copper foil on both sides. In the last steps of production the copper laminates are cut into sheets of e.g. 610mm x 480mm. These sheets are placed on a transportation system which is feeded by a robot system. After that, the material is visually inspected from both sides for defects which could lead to a short or an open connection on the PCB. The sheets with lower quality are then eliminated from the production process by use of a second robot system. In this paper, the measurement technique for automatic surface inspection is presented which delivers information on the photometric properties of the surface (colour and gloss) and 3D-features in a single pass. The technique is based on the principle of photometric stereo. By means of six groups of flashed LEDs six images of the surface are acquired simultaneously. Images representing the different physical properties of the surface with pixel accuracy are calculated by methods of image fusion; for detection and classification of defects information from the property images is combined. Based on the reliable information on the surface, very challenging applications of surface inspection can be solved with high rates for defect detection, good classification results and a very low false alarm rate. Results from the industrial application are also presented.

Keywords: sensor fusion, vision systems.

1. Introduction

Many industrial products, e.g. copper laminates or floor coatings, are manufactured in a continuous process at high speed. In these applications, the surface qualities of the products have to be inspected during motion. The defects to be detected are anomalies with respect to reflectivity, color, glossiness, texture and the 3D-profile of the surface. Challenging applications of automatic surface inspection (e.g. the inspection of textured surfaces for 3D-defects) require discriminating between defects and accepted modifications of the surface, e.g. variations of glossiness are accepted but discolorations and 3D-defects (elevations and depressions) have to be detected and classified. The images acquired by standard vision systems with one camera and one source of illumination do not contain the information required to solve these kind of tasks. What is needed is reliable and unambiguous information on colour, glossiness and 3D-features from each surface element of the surface under inspection.

This paper describes a measurement setup which gathers the desired information during motion by using a multi-image approach based on the principle of photometric stereo. The related methods for image fusion, feature extraction and classification are presented on the background of an industrial application.

The paper is organized as follows: in section two, the state of the art in surface inspection with respect to the developed method is shortly presented, further it is explained how these approaches differ from the goals we intend to reach. In section three and four, the new method of image fusion for automatic inspection of moving surfaces is presented. Section five describes the results of the new method in the application field of automatic inspection of copper laminates. Section six presents the

[1] *Permission to copy without fee all or part of this material is granted provided that the copies are not made or distributed for direct commercial advantage, the CSIT copyright notice and the title of the publication and its date appear, and notice is given that copying is by permission of the Institute for Contemporary Education JMSUICE. To copy otherwise, or to republish, requires a fee and/or special permission from the JMSUICE.*

**Proceedings of the 8th International Workshop on Computer Science and Information Technologies CSIT'2006
Karlruhe, Germany, 2006**

system developed at Fraunhofer IITB in Karlsruhe – so far this system is used in two different industrial applications. The paper closes with a conclusion and the description of further work.

2. State of The Art

To investigate the quality of products, it is often necessary to retrieve characteristics of the surface, e.g. colour, brightness, and defects in the surface of the material. In principle, it is possible to evaluate the remission of light to calculate this information (Fig. 1).

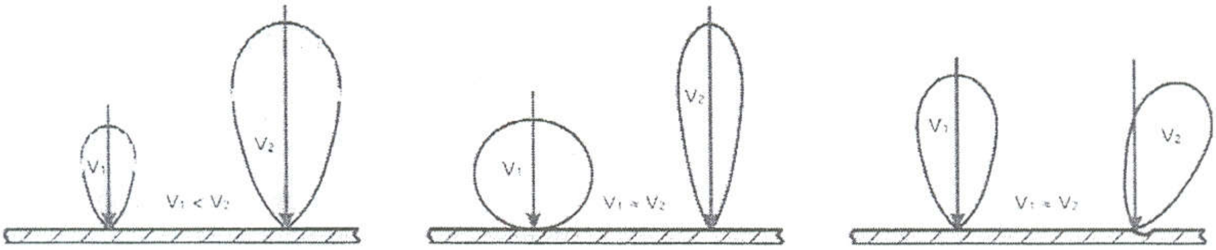

Figure 1. Characteristics of the Surface can be Measured: a) Remission Intensity; b) Remission Characteristics; c) Remission Direction

As already discussed, it is not possible to detect concurrently anomalies in the surface with respect to reflectivity, colour, glossiness, texture and the 3D-profile by the use of just one camera. To solve that problem, multiple images can be taken using a setup with several cameras, but this leads to a problem with image registration. Due to the fact that the product is moving between the several camera positions, the independent images have to be matched. The problem is avoided when only one camera and several sources of illumination are used [1]. Another principle [2] uses a laser scanner with different detectors (Fig. 2a), or to take a series of images from the object under inspection with the same camera and to vary the direction of the incident illumination between successive images, while holding the viewing geometry constant (Fig. 2b).

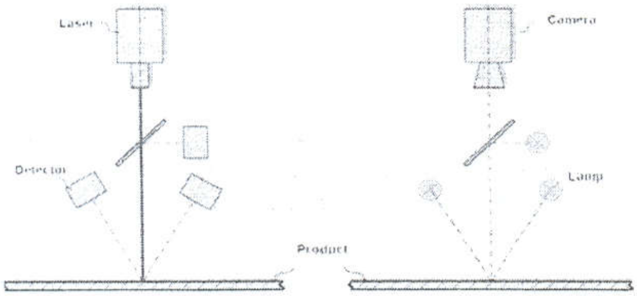

Figure 2. a) Laser Scanner; b) Camera with Different Illuminations

It is known that the series of images provides sufficient information to determine the orientation for each surface element of the object under inspection and that it is possible to calculate the 3D-shape of the object.

The method requires that the reflectance distribution of the surface is known. This does not hold for applications of automatic surface inspection: particularly in defective regions of the surface the reflectance distribution has to be regarded as unknown. Furthermore, the method requires that the images are matched perfectly.

Other methods use the coding of illumination by color. In that approach, different colored light sources with a color camera are used, and based on the R, B and G channel, it is possible to calculate the gloss, brightness and surface defects of the product. However, that method is only applicable for objects without texture, because it is necessary to calibrate the system regarding the color of the product, otherwise the inspection systems detects defects on the surface (changes of color, e.g. green and blue light) as 3D-effects that are not existing.

A further concept for surface inspection uses the projection of well defined patterns on the surface of the product and interprets the image received by a camera system. The evaluation of the image deformation delivers the attributes of the surface. This method is applicable to no reflecting surfaces (Fig. 3).

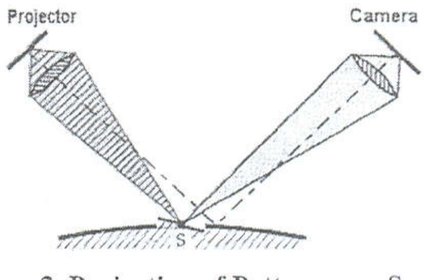

Figure 3. Projection of Pattern on a Surface

A similar idea, applicable for reflecting surfaces, is the method of deflectometry [3]. In this case, the reflecting surface of the product acts like a mirror. The shape of the surface leads to a significant image of the LCD. If the surface provides 3D defects, this image is disturbed.

Other concepts can be found in literature; also e.g. publications that deal with general agent architectures for fusion of sensor data [4], with texture analysis [5] or with robot based inspection systems [6]. Many of these concepts intend to reconstruct the 3D-shape of the product.

If flat surfaces are inspected, it is often not necessary to reconstruct the 3D-shape of the surface. In this case, a new method developed by Fraunhofer IITB can be used. This idea is explained in more detail in the next section.

3. New Measurement Setup

In many industrial applications, the inspection system has to evaluate flat surfaces, e.g. steel strips, copper laminates, floor coatings or tiles. In these examples, a complete reconstruction of the 3D surface is not necessary, instead it is sufficient to know whether a surface element is plane or tilted. This information can easily be extracted by comparing a pair of images taken with a camera looking perpendicularly onto the surface and a symmetrical illumination setup consisting of two light sources, where one source is illuminating the surface e.g. from the north for the first image and the other source from the south for the second image. The pair of images contains information on the reflectance characteristics of the surface (at the color chosen for illumination), and 3D-information: for each surface element continuous information can be derived whether it is plane, or sloping towards north or south. If the reflectance distribution of the surface elements is mirror-symmetric with respect to north/south the information on reflectivity and the 3D-information are completely independent. The measurement setup consists of a line-scan-camera and six groups of LEDs. The camera looks perpendicularly onto the surface under inspection. The LEDs illuminate the surface from six different directions. They are flashed in succession synchronously with the cycle of the line-scan-camera. Thus, the result of image acquisition is an image with six channels, corresponding to the set of

$$\text{light sources} = \{N, S, E, W, N\&S, T\}.$$

The six light sources are grouped into three pairs: the first pair illuminates the surface under dark field conditions symmetrically from north (N) and from south (S) respectively (Fig. 4a and 4b). The LEDs of this pair are green.

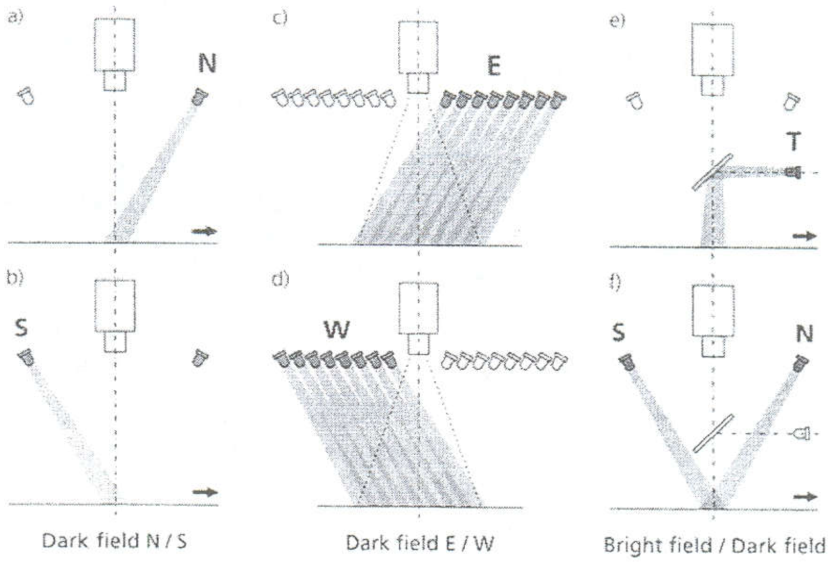

Figure 4. Six Channeled Illumination for Fraunhofer MultiScan

The second pair illuminates the surface from east (E) and west (W) (Fig. 4c and 4d). The LEDs of this pair are blue, the incident angle of the illumination is the same as for the {N, S} pair. The last pair of light sources illuminates the surface from the top (T) under bright field conditions and from north and south (N&S) under dark field conditions respectively (Fig.4e and 4f; same geometry as the green {N, S} pair). The LEDs of this pair are red. For extraction of 3D-information the images of the {N, S} pair and the {E,W} pair are compared, while information with respect to glossiness is extracted by comparing the images of the {N&S, T} pair.

For best results and simple methods of comparison it is essential that the images of each pair are perfectly registered. This problem was solved by a special solution developed at Fraunhofer IITB and results in a perfect matching between the two images of each of the three image pairs.

4. Processing of the Multi Channel Images

From the six images the desired information on the different physical properties of the surface (color, reflectivity, gloss and slope) can be derived by a sequence of elementary functions as shown in Fig. 5 Only the principle is illustrated, the methods are modified corresponding to the needs of the application at hand.

The colour image simply results from combining the three components R, G and B from the respective dark field images. The red channel is a copy of the channel with symmetric dark field illumination: R = N&S.

The green channel results from averaging the dark field images with illumination from N and S:

$$G = \frac{1}{2}(N + S),$$

and the blue channel from averaging E and W:

$$B = \frac{1}{2}(E + W).$$

The color image is subject to further processing depending on the application, e.g. calculation of the color distribution of a textured floor coating. This is not shown in Fig. 5.

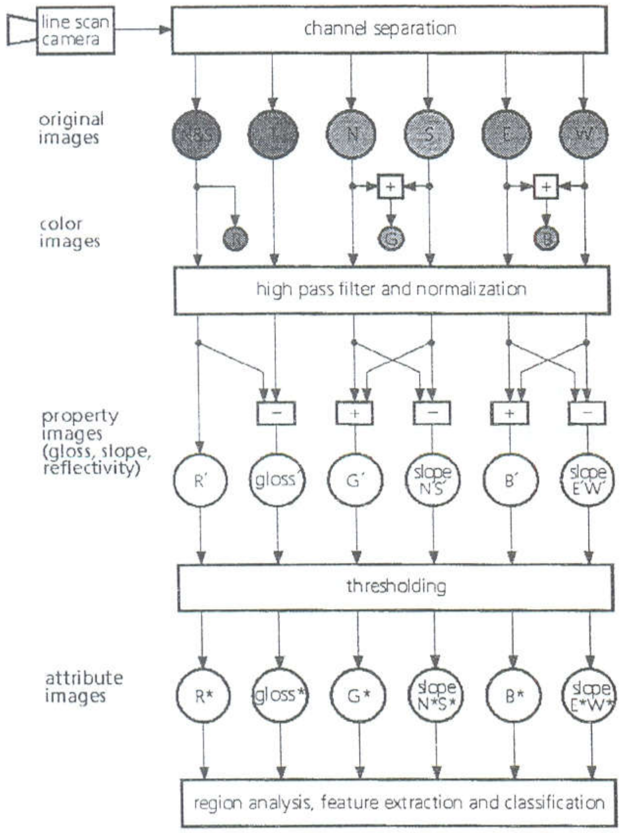

Figure 5. Basic Steps of the Image Processing

In the next step the original images are filtered by high pass filters. Gray scale variations with low spatial frequency, e.g. due to long wave deformations of the surface, are eliminated. The resulting images are scaled to an average gray value of 127 in order to allow for a direct comparison of the image pairs {N, S}, {E, W} and {N&S), T} even if the original images are not in balance. From the filtered images property images are calculated simply by subtracting or averaging.

A "gloss-image" (gloss′) is calculated by subtracting the filtered dark field image N&S from the bright field image T: the higher the gloss of the surface the higher the intensity in the bright field relative to the dark field and vice versa. The information on the slope of the surface elements is calculated by subtracting the filtered images N-S and E-W. As long as the surface elements are plain, the corresponding pairs of images are in balance, for sloping surface elements the balance is distorted. Subtraction therefore results in an image where the gray value of the pixels can be regarded as an estimate for the slope of the corresponding surface elements in the direction of N/S or E/W respectively.

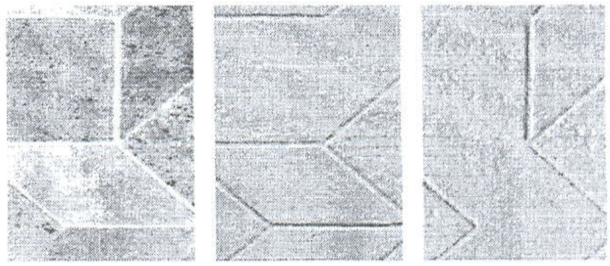

Figure 6. Floor Coating with Imprinted 3D-Pattern: a) Color Image; b) Slope N′S′; c) Slope E′W′

Fig. 6 shows the color image and the slope images Slope N′S′ and Slope E′W′ as obtained from a piece of floor coating with a colored surface and an imprinted 3D-pattern. This example illustrates that it is essential to have the two orthogonal pairs of images {N, S} and {E, W} in order to detect 3D-defects regardless of their orientation. Please note that the slope images show only 3D-information, there is no cross talk from color contrasts in the surface. On the other hand the color image shows nearly no shadow effects.

In addition to the images for gloss and slope, images representing surface reflectivity for the color components R, G and B are calculated. For Red the filtered image S&N is used directly, for Green and Blue the channels N and S and the channels E and W are averaged. The resulting images are R′, G′ and B′. In the next steps the property images are segmented by a set of thresholds, resulting in attribute images which are input for the stages of region analysis, feature extraction, clustering and classification. These methods apply for automatic inspection of homogenous (non textured) surfaces as described in the example below.

5. Automatic Inspection of Copper Laminates

Copper laminates are the basic material for the production of printed circuit boards (PCBs). There are different types of defects: flat ones and 3D-defects, e.g. raisin spots, areas stained from oxidation, dents, holes and scratches. For the automatic inspection the measurement technique according to Fig. 4 is used and the methods according to Fig. 5. Because color is of minor importance in this application the green LEDs for the illumination from North and South are replaced by red LEDs, the color images R′, G′ and B′ are not calculated and the Dark Field Green (G′) is omitted from the six property images. To illustrate the results the following figures show the images from the different steps of processing only for the channels with illumination from top (T), North (N) and South (S).

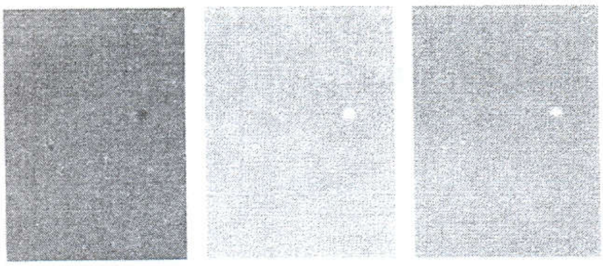

Figure 7. Original Images from Copper Laminate: a) Illumination from Top (T); b) Illumination from North (N); c) Illumination from South (S)

Fig. 7 shows original images from the channels T, N and S respectively. The format of the images is 150 x 200 pixels, corresponding to an area of 22.5mm x 30mm on the surface (the width of inspection is 300mm).

From the property images a human observer can correctly classify the anomalies in the surface. For automatic detection and classification the property images are segmented by a set of thresholds. The results are attribute images as shown in Fig. 8.

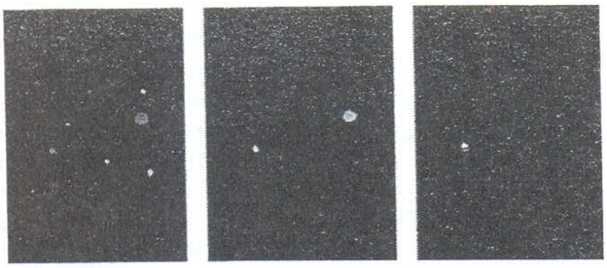

Figure 8. Attribute Images: a) Gloss*; b) R* (Dark Field Red); c) Slope N*S*

6. Industrial Applications

The described method was first implemented in a research prototype and then transferred to two different industrial applications. One system is used for the automatic inspection of copper laminates as described in section five, the second one is used for automated inspection of steel strips.

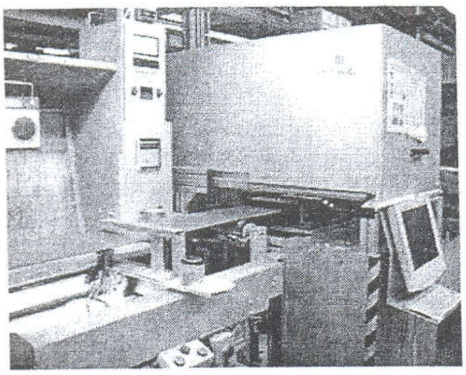

Figure 9. The Fraunhofer AVISI System

In Fig. 9 the installation of the system for steel strips is shown. The industrial setup has an inspection width of 300 mm, the resolution is 150 µm by use of a 2000 pixel camera. The system can handle a 450 mm/s velocity of the steel strips.

7. Conclusion and Further Work

In this paper, a new measurement technique for automatic surface inspection is presented which delivers information on the photometric properties of the surface (color and gloss) and 3D-features in a single pass. This method can be used for flat surfaces that are not too much reflecting, e.g. steel strips, copper laminates, floor coatings or tiles.

By means of six groups of flashed LEDs six images from the surface are acquired simultaneously. Images representing the different physical properties of the surface with pixel accuracy are calculated by methods of image fusion; for detection and classification of defects information from the property images is combined.

Although the system is already used in industry and fulfils the specification, we are currently improving the system. Further work handles some adoptions to further reduce the false alarm rate, and thus to improve the classification quality.

References

1. Woodham R.J. "Photometric method for determining surface orientation from multiple images". *Optical Engineering*, 1980; 19: 139-144.
2. Piironen T., Paul D., Kontio P. "Arrangement and method for inspection of surface quality". US Patent US 6,327,374 B1, 2001.
3. Heizmann M., Beyerer J. "Sampling the Parameter Domains of Image Series". In: Dougherty E.R., Astola J.T., Egiazarian K.O. (eds) *Image Processing: Algorithms and Systems IV. Proc. of SPIE/IS&T Electronic Imaging (SPIE),* Vol. 5672, 2005, pp. 23-33.
4. Beyerer J.; Heizmann M., Sander J. "Fuselets - An agent based architecture for fusion of heterogeneous information and data". In: Dasarathy B.V. (ed) *Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications. Proc. of SPIE*, Vol. 6242, 2006.
5. Condurache A., Aach T., Grzybowski St. and Machens H.-G. "Imaging and Analysis of Angiogenesis for Skin Transplantation by Microangiography". In: *IEEE International Conference on Image Processing (IC IP-2005).*
6. Woern H., Laengle Th., Gauss M. "Adaptive Robot Based Visual Inspection – ARIKT". *German Journal on Artificial Intelligence*, 2003, pp. 33-38.