Imaging Polarimetry for Industrial Inspection

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Abstract

The use of the polarisation properties of light for the determination of significant aspects of surfaces in an industrial setting is considered. It is concluded that the technique is both general and robust enough to warrant development. An example is presented of the use of the polarisation signature of surfaces to achieve efficient segmentation of metals and dielectrics in the presence both of uneven lighting and of a lacquer coating. The technique is intrinsically simple given a suitable image acquisition scheme and the necessary images could be acquired at video rates using only simple circuitry. The design of polarising optics is considered briefly.

1. Polarimetry as a Diagnostic Tool

Scattered light has polarisation properties which differ from those of the incident illumination. For initially unpolarised light the scattered light will be partially plane polarised with the azimuth of the largest component being contained either in, or perpendicular to, the plane of vision defined by the light source, observer and observed surface patch. If I_1 and I_2 are respectively the intensities of vibration perpendicular and parallel to the plane of vision the 'Degree of Polarisation', P, is defined by $P=(I_1-I_2)/(I_1+I_2)$; P may be either positive or negative and depends critically on both the viewing geometry and the composition and structure of the illuminated surface.

These observations are not novel. Polarimetry has been extensively used in astronomy as a tool for exploring inaccessible regions [1]. The application of the technique to industrial inspection does not appear to have been widely investigated. Use of high polarisation as diagnostic of highlights has been proposed but apparently not widely applied. Wolff [2,3] has reported preliminary studies, as have Koshikawa, Shirai and Mercsh [4,5,6]. Beyond these the literature is sparse.

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2. Example of Application

Wolff [3] has proposed use of the ratio of the intensities observed in the two planes of polarisation of specularly reflected light. However there exists no theoretical evidence that Wolff's metric is optimal. Nor is it necessary to restrict oneself to specularly reflected light. In our own work we adhere to the use of degree-of-polarisation which has a solid underpinning of physical theory [7].

Figure 1(a) presents a single image of a printed circuit board in unpolarised light. The image acquisition environment was deliberately kept highly unconstrained to maximise potential problems. Simple day-time office overhead lighting was used. The image was acquired in diffusely scattered rather than specularly reflected light. There are three region classifications which it is of interest to segment : a) 'bare metal' at the solder pads, b) copper plus translucent lacquer coating over the metallisation, c) substrate plus lacquer over the remainder of the board. As demonstrated in Figures 1(b) and (c) these regions are difficult to segment by simple thresholding due to lighting non-uniformities. Figure 1(d) is the degree-of-polarisation image obtained under the same lighting conditions. The improvement in discriminability is immediately apparent, and is born out by Figures 1(e) and (f) which show thresholded images obtained as for Figures 1(b) and (c).

3. Polarising Optics and Supporting Hardware

In order to make effective use of degree-of-polarisation images in an industrial context it is necessary to be able to acquire and process the paired images in a robust and timely fashion. For tasks involving the monitoring of moving parts simultaneous acquisition of the polarised images is desirable. Three potential designs have been considered :

1. Rotating polariser in the optic train. If a linear polariser is included in the optic train of the acquisition system then individual points in the image will be modulated by a sinusoidal signal with amplitude depending on the polarisation difference. Serial sampling, coupled with a knowledge of the polariser rotation rate, would enable computation of the degree of polarisation. This architecture would suffer from a number of drawbacks, including smear for moving scenes and high storage and processing costs.

2. Crossed calcite plates, a version of the Savart polariscope. The active component is a pair of cemented or optically contacted, equally thick calcite plates, cut so that the optic axis of each plate makes some fixed angle to the plate normal, and contacted so that the planes containing the plate normal and the optic axis in each case are orthogonal. Such a compound plate, when arranged normally to an unpolarised light beam, splits the beam into two parallel mutually perpendicularly polarised beams. By use of an input bar

pattern aperture and appropriate geometry for the system, adjacent columns of a CCD detector could be illuminated with equivalent bands of the input image, these having mutually perpendicular polarisation. Care would have to be taken with the effects of diffraction in the input bar pattern, and there is an inevitable loss in effective resolution due to the 'missing' stripes.

3. Modified Glan-Thompson Prism. Amman and Massey [8] have described a number of mixed calcite/glass prisms which duplicate, or extend, the properties of all-calcite prisms of standard type. Of most interest in the present context is their "modified Glan-Thomson polariser (Version No.2)" which may be further modified into a very efficient beam splitter, two mutually perpendicularly polarised beams being produced [9]. This modification also avoids the image distortion inherent in Amman and Massey's version. Simultaneous acquisition of a pair of images using synchronised video cameras is possible, and video-rate processing of polarisation images would then be a simple matter [10].

The third design involves minimum interference with the input beam and retains maximum resolution in the image. It has therefore been selected as the basis of an ongoing design study for a complete practical imaging photopolarimeter system. Results of this study will be published in due course.

4. Conclusions

It appears that the use of degree-of-polarisation data is both of high utility for certain industrial inspection problems, and requires only relatively simple supporting hardware. No reduction in throughput need be incurred in the use of degree-of-polarisation images in comparison with standard video images.

References

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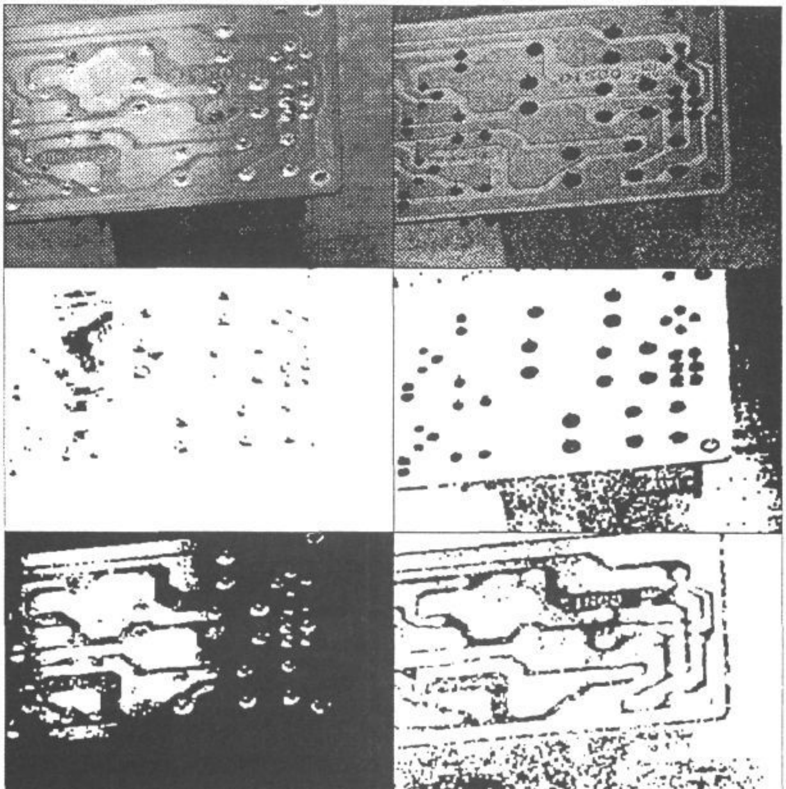

a	d
b	e
c	f

Figure 1 A demonstration of the advantages of use of polarised light. (a) Printed circuit board and bench background in unpolarised light; (b) and (c) thresholded versions of (a) optimised to segment the metallisation [bare and coated respectively]; (d) degree-of-polarisation image of the same board and background under the same lighting conditions; (e) and (f) as (b) and (c) respectively. Note that in the preparation of (b), (c), (e) and (f) morphological opening and closing have equally been used to optimise connectivity of segmented regions.