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A novel methodology for the evaluation of distinctness of image of glossy surfaces

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ABSTRACT

There is a strong industrial requirement for the characterization of special surface aspects that are responsible for the appearance of final products. Quantitative values for the distinctness of image (DOI), gloss/haze and perceptual attributes of surface structures are to be found. Enhanced attractiveness due to appropriate quality control of perceptual attributes during manufacture is required subsequently. Human eye-apparatus notices aberration of edge-sharpness of surface reflected objects very accurately. For that reason measuring techniques are required which enable precise determination of image detail reproduction. In this paper the Intensity Profile Analysis (IPA), a novel methodology for the characterization of surface DOI, is presented. IPA is related to modulation transfer analysis methodologies and enables to measure fine detail reproduction of glossy surfaces with good correlation to standard DOI measurement techniques, while featuring enhanced preciseness for surfaces with just slightly variant distinctness of image. IPA is a contactless technique and therefore applicable for uncured or hot surfaces. Due to its conception IPA results are very intuitive concerning visual observation. In this paper IPA–DOI values of coil-coated car steel surfaces are presented in order to demonstrate the principles.

1. Introduction

Spray painting is state of the art in finishing automotive's body. Electro deposited corrosion protection and spray-coated layers of filler, colored basecoat and clear coat are deposited on formed body parts. This is an ecological as well as an economic expensive process. In construction and appliance industry, finishing follows the principal "finish first–fabricate later". Coils of flat sheet metal are decoiled, cleaned, pre-treated, coated, cured and coiled in a continuous process. Thereby one or more coating layers of special thermoset coating systems with a high degree of flexibility are applied [1]. Within the last few years thin, weldable coatings find increasing use as corrosion protection primers which significantly increase the resistance against flange corrosion in the automotive industry [2]. Beside corrosion protection the appearance of a surface forms another major quality factor. It is described by its color, waviness, gloss and distinctness of image (DOI), e.g. [3]. The first system for evaluating gloss, the "Glarimeter", was designed by Ingersoll already in 1914 [4]. It was the first apparatus that allowed comparing surface gloss in a definite way. Thenceforward research work has been done in order to quantify visual gloss perception. Hunter defined six different classes of perceptible gloss [5]. Judd derived physical quantities for Hunter's gloss classes and turned the subjective impression "gloss" into a measurable surface parameter [6]. For different products like high-gloss plastic parts and car coatings it is essential to show specular gloss with light scattering kept as low as possible. DOI quantifies the spread of light reflected at the specular angle. It gives an indication of how sharp a surface reflection is likely to be. A product with a shiny surface may be flat and smooth, giving a very distinct sharp image. Another batch of that same product may also be flat, smooth, and yield the same gloss values as the first, but give a fuzzy or distorted image. For this example, DOI values would give a better indication of the product, as general gloss values do [7]. Very glossy surfaces are visually judged almost exclusively by DOI, as Obein et al. showed [8]. In order to get quantitative values for the DOI for the enhancement of attractiveness of glossy surfaces due to appropriate quality control during manufacture, different concepts for measuring and quantifying DOI have been developed. Three test methods for the measurement of distinctness of image gloss of coating surfaces are proposed by ASTM

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D5767-95-2004. In test method (A) gloss reflectance factor measurements are made on the specimen at the specular viewing angle and at an angle slightly off the specular viewing angle. The values obtained are combined to provide a DOI value. Very narrow source and receptor aperture angles are used in the measurements. In test method (B) light falls through a small slit and is projected on the specimen surface. Its reflected image intensity is measured through a sliding combed shutter to provide a value of image clarity. In test method (C) light falling through a pattern is projected on the specimen surface. Its reflected image intensity is measured directly to provide a value of image clarity [9]. Further concepts have been proposed. Tse and Briggs projected a sharp edge onto a surface and captured the reflected image using a line sensor. DOI was evaluated by quantifying the distortion of the reflected image of the edge, caused by the surface structure of the specimen [10]. Measuring DOI by using distinct light pattern projected onto the surface at an angle of 30° and detecting the sharpness of the edge of the reflected beam was proposed by Q-Panel Lab [11]. One of the prevailing methodologies in quantifying the visual appearance of automotive bodies is wavescan–DOI by Byk-Gardner [12]. Wavescan produces a set of parameters to quantify dullness, waviness at several wavelengths and DOI of painted automotive body parts. The DOI value is calculated from short-wave parts of the detected signal and a dullness value. The latter is based on a conception described by Hentschel and Lex were light falls through a circular aperture onto the coating surface. The reflected image exhibits defined dullness in dependence on the surface structure. The dullness value is given by the ratio between the detected dullness, that is to say the measured intensity of the shine at the edge of the reflected aperture, and the intensity of a perfectly specular reflection of the aperture [13].

Strauß und Rogner reported that the appearance of pre-primed and spray-finished steel sheets meet the quality of conventional coatings if a silver topcoat is used [14]. By using the most critical color black especially in the case of DOI influencing surface structures adjustments have to be made and very precise measurement of DOI is required. In this paper the Intensity Profile Analysis (IPA), a novel methodology for the characterization of the distinctness of surface reflection, is presented. Due to its conception it features enhanced preciseness compared to other DOI measurement systems. IPA makes use of the deterioration of the resolution of surface reflected images caused by scattering at surface structures at the microscale. It enables to measure reflected image resolution with good correlation to standard DOI measurement methods, while featuring enhanced distinction between surfaces exhibiting just slightly different distinctness of image. IPA enables to measure the effect of surface treatment with varying abrasives on the image resolution, for instance. IPA is a contactless technique and therefore applicable for uncured as well as hot surfaces. IPA is a fast result-by-one-shot technique and therefore applicable for high frequency in-line and in-situ measurements. In this paper the IPA values of coil-coated car steel specimen are presented in order to demonstrate the principle.

2. Theory

The ability to mirror surrounding objects in a distinct way is one of the most important attribute of a high quality coating surface. Light scattering caused by the microstructures of particular orders deteriorates the sharpness of surface reflected objects. This phenomenon is perceived as “loss of sharpness and brilliance” and it is closely related to physical image resolution. The evaluation of Contrast Transfer Functions (CTF) and Modulation Transfer Functions (MTF) are well known approaches for the determination of image resolution transferred by optical systems [15]. A number of publications were particularly inspiring for our work. They demonstrate the potential of the MTF approach by means of evaluation of contrast transfer and spatial resolution of different types of imaging systems, e.g. [16–22]. Their common ground is high precision detection of aberration of light transferred through optical systems, which is related to the determination of perceptual surface properties regarding DOI. The concept is based on the transfer of a reference chart by the optical system and subsequent decomposition of the intensity distribution of the chart and the image of the chart in sets of base functions. High image resolution is indicated by the ability of the optical system to transfer the base functions with little loss. In the mathematical description image transfer through an optical system equals a convolution of the input image $i(x, y)$ with a positive invariant point spread filter function $p(x)$ [23]:

$$o(x, y) = p(x, y) * i(x, y). \quad (1)$$

As consequence one gets in the frequency space

$$O(u, v) = P(u, v) \cdot I(u, v) \quad \text{thus} \quad P(u) = FT(p(x)), \quad (2)$$

where O, P and I are the FOURIER transformed functions o, p and i. $P(u)$ is the transfer function of the optical system. In the literature not only the function itself, but the magnitude of the transfer function is frequently termed MTF:

$$\mathrm{MTF}(u, v) = |P(u, v)|. \quad (3)$$

Since

$$|O(u, v)| = |P(u, v)| \cdot |I(u, v)|, \quad (4)$$

then

$$\mathrm{MTF}(u, v) = \frac{|O(u, v)|}{|I(u, v)|} \quad (5)$$

The MTF describes the ratio between the observed and the expected diffraction of the amplitudes of object and image (Eq. (5)). Usually a reference chart with a sequence of light and dark lines (line-pairs) with variable spatial frequency is imaged by the optical system that is going to be measured. The achievable resolution is determined by the transferred contrast in dependence on the spatial frequency of the line-pairs of the chart. The MTF provides the information about the relation between the spatial resolution of the reference chart and the image of the chart.

3. Methodology

Since in most cases the imaging system itself is evaluated by MTF, line-charts are imaged right through the lens system of the instrument. However in order to measure the resolution of a surface reflected image, a special setup is required. Its pre-condition is to provide the possibility to capture surface reflected images with minimal and by all means defined influence of the imaging system.

Coil-coated car steel specimens are placed in opposite to a line-chart at the angle (α) with one edge in contact at the origin (o) (Fig. 1, setup). The line-chart, a laser printed sequence of line-pairs on a transparent plastic sheet, is illuminated from the back side by a 5400-K, 40 kHz high-frequency light source. Sand-streamed glass diffusers provide homogeneous illumination of the chart. The surface reflection of the chart is captured by a CCD-camera. In contrast to usual setups for MTF evaluation of optical instruments, where the spatial frequency of the line-pairs of the chart increases linearly or in a logarithmic way, the spatial frequency of line-pairs in the IPA-chart keeps constant. Chart-to-specimen distance and therewith light scattering distance (d) between the chart and the surface increases from zero at the origin to a maximum at the top edge of the measured area of the specimen. The resolution of the