QUALITY CONTROL OF PRINTED PRODUCTS BY IMAGE ANALYSIS AND PROCESSING

Tomić, I., Dedijer, S., Novaković, D., Pinćjer, I.
University of Novi Sad

Abstract
Controlling reproduction of printed products imply colour and gloss measurement, as well as evaluation of secondary print quality parameters (reproduction of text and lines, sharpness, uniformity etc.). In the last decade it was shown that the vast majority of quality attributes in printing could be controlled by image analysis and processing. In this article we summarise image processing methods for evaluating quality parameters in printing and finishing, with the focus on the possible drawbacks and industrial solutions.
Keywords: *image processing, quality attributes, printing, quality control*

Introduction

The perceived quality of printed products depends on many parameters usually termed quality attributes [1]. These attributes include colour, gloss, uniformity of large areas, contrast, sharpness, artefacts etc.

Colour and gloss, as well as the print contrast, can be objectively characterised by measuring devices – densitometers, colourimeters and spectrophotometers for colour measurement; gloss meters for gloss characterisation. Their control has been traditionally incorporated in many international standards (ISO 12647 series, ISO 2813:2014, ASTM D523 – 14(2018)). In the last decade, however, it was shown that the reproduction of colour could also be estimated by image processing of digitized imprints [2,3]. Same stands for the gloss uniformity [4].

The rest of the parameters, sometimes referred to as secondary quality attributes, can only be evaluated by processing the digital image of a printed product. The image can be digitised by scanners or digital cameras, where the chosen device should be able to acquire the image at a minimum of 600 ppi [1]. This resolution has been proven to be sufficient for proper detection of lines and text, as well as the differences in colour in the uniform areas.

The goal of this paper is to provide a short overview of the most common image analysis methods for evaluating print quality attributes, with a focus on possible drawbacks, corresponding standards and industrial solutions.

Reproduction of Colour

For evaluating colour reproduction, digital cameras or camera-based systems are normally used as acquisition devices. The main reason is non-contact measurement, as well as the speed and the possibility to inspect larger areas with a single shot [5]. The camera captures the print, and consequent processing is done in order to obtain the necessary information.

In general, evaluation of colour reproduction implies measuring the deviation of the primary colour values from those defined in the standard or by the proof, as well as the variations within the print run. If the goal is to match the chosen standard, the output of image processing should be CIELAB data. Unfortunately, typical RGB cameras normally do not satisfy Luther–Ives condition, i.e. the sensor response curves are not a linear combination of the colour matching functions. Therefore, even though the cameras produce the visually pleasing result, the image is not colourimetrically correct.

Hence, to obtain accurate CIELAB data, it is necessary to find a correct transformation function that will accurately map camera RGB signals to colourimetric data [2,5,6]. The process of obtaining the function is referred to as camera characterisation and is explained in details in [6,7]. In practical application, empirical characterisation is often used [6,7] implying that the transformation function is created by using a training set, i.e. the set of data with the known CIELAB values.

Different algorithms have been proposed for the transformation function, where the best results are obtained with polynomial and other regression models, as well as the Artificial Neural Networks - ANN. ANNs are lately used to estimate colourimetric values of goniochromatic prints turning the conventional digital camera into multi-angular colourimeter [7]. The flexibility of ANNs allowed the position of the camera and the light source to be fixed. Namely, it was possible to estimate colours for different viewing angles based on the shoot made in one geometry – the aspecular angle of 45° [8].

Image processing steps depend on which sensor/camera is used, and it normally implies using the RAW data from a sensor, without white balancing and gamma correction, where further processing may include demosaicking, noise removal, non-uniformity and linearity corrections etc. RGB signals for certain colour patch are obtained by averaging data over the area of the patch in an image and are transformed by using the chosen transformation function to obtain CIELAB values.

The best-reported accuracy of such measurement is around 2 ΔE_{ab}, and it depends on many factors such as the type of sensor used, light source, ambient light, camera settings, colours used for the training set, image processing etc. Multi-spectral camera systems with appropriate image processing have been shown to provide better accuracy.

For evaluating the "within the run" variations it is not necessary to estimate absolute CIELAB data, but the ΔE_{ab} difference between the OK sheet and the rest of the print run. Since the absolute accuracy is not a goal, the transformation function does not need to be very complex. Transformation can be done by lookup tables or even a simple matrix, depending on the desired accuracy [3].

The biggest drawback of empirical characterisation method is the fact that the transformation function is valid only for the specific substrate-ink combination. If paper or ink changed in the printing process, the transformation function had to be re-established. Another solution is the model-based approach explained in [6].

Many industrial solutions use digital cameras as a part of closed-loop in-line control systems [9, 10] in sheet-fed and web-fed printing. Cameras can be used to estimate not only colourimetric values but also density [10] which allows direct correction of the ink amount in the printing process.

Uniformity

Uniformity of printed products' large areas is an important factor that influences the overall impression of print quality. The non-uniformity is usually defined as any variation in density over the area of interest. Variation can be periodic (banding, jitter) or aperiodic (mottle, graininess). The goal of image processing is to detect, distinguish and quantify the possible deviation from the solid area. It can be done in the spatial or frequency domain. To obtain digital images, prints can be photographed or scanned, where the second option prevails in practical application.

Evaluation of the uniformity of printed products is defined in [11] as the assessment of large area graphic image quality attributes. These attributes include background darkness, graininess, mottle, large area void and banding etc. The standard defines procedures and processing techniques for evaluating each one of the attributes.

In digital printing (especially electrophotography) special attention should be placed on mottle evaluation. It falls into the class of aperiodic macro non-uniformity since it represents the change in lightness over the large area of a print. In [12] authors compared three methods for evaluating print mottle, with an aim to define the method which correlates the best with perceived non-uniformity. The parameters obtained from the Gray-Level Co-occurrence Matrix, a matrix that records how often different combinations of pixel intensity values occur in an image in a specific spatial relationship and distance, performed the best [12]. The analysis was done using the lightness component of an image (L* in CIELAB colour space).

Another approach for characterising mottle can be found in [13]. The image is first transformed to the frequency domain and then filtered with contrast sensitivity function to simulate the response of the human visual system. Discrete wavelet analysis was used in [14], where the index of print mottle is based on the coefficient of variance of the wavelet-filtered image. In [15] total noise amount obtained from the noise power spectrum was proposed as a metric of overall non-uniformity of a printed image.

Wavelet filtering was also used for detecting banding, jitter and ghosting [16]. For banding and jitter detection, the authors used wavelet filtering in conjunction with 2-D spectral analysis. Such an approach allowed the characterisation of the defects regardless of their orientation [16]. Ghosting can be detected by Fourier or spectral analysis, or by wavelet filtering and a template matching technique as in [16].

Character and Line Reproduction

Another group of quality attributes is directly related to characters and lines, and it includes line width, character darkness, blurring, raggedness, character surround area haze and extraneous marks [11], dot size etc. Image processing for characterizing these parameters relies on various types of image segmentation techniques (thresholding, edge-detection, region-based approaches etc.) with an aim to isolate and analyse specific areas of an image.

Analysis of line width and dot size is performed to determine the amount of dot gain. To accomplish this, lines/dots of specific colour have to be isolated from the rest of the image, where different segmentation methods can be used depending on the complexity of a background. Bergman et al. [17] present two-stage segmentation for measuring an average ink dot size in halftone pictures. The method presented in their work can be used to determine the dot size on the printing plate as well.

The sharpness of printed image is determined by evaluating edge blurriness or the average edge profile transition width in the direction perpendicular to the edge. It can be performed in the spatial domain by calculating line spread function (LSF) or, more common, in the frequency domain by obtaining modulation transfer function (MTF). Additional filtering concerning contrast sensitivity of the human visual system can be applied. On the other hand, edge raggedness indicates the amount of wicking, and it is a measure of the average edge profile variation (50%) in the direction parallel to the edge [18].

The measures of all the abovementioned parameters are defined within [11] together with the procedures for sampling and test charts preparation.

Quality of Finishing

When it comes to the quality of finishing, image processing was successfully applied to evaluate the degree of surface damaging when folding the coated paper [19]. In the mentioned work, authors evaluated different ways of sample preparation, digitisation techniques and proposed an algorithm based on transformation, segmentation and feature extraction in order to quantify cracking of a coated surface after folding.

Image analysis finds a special role in assessing coatings and special effect coatings. The uniformity/distortion of the coating is usually described by the distinctness of image (DOI for abbreviation), which can be analysed the same way as blurring. Nowadays, almost all gloss meters are equipped with CCD cameras in order to quantify DOI [20, 21].

The appearance of special effect coatings highly depends on the distance, angle and type of illumination, as well as the position of a viewer, additional characteristics such as graininess and sparkle had to be considered. These characteristics can be evaluated using images obtained from digital cameras. Analysis of graininess implies using a diffuse light source and assessing the uniformity of a captured patch. On the other hand, sparkle evaluating encompasses capturing an image of the sample under different light conditions and further segmentation (usually thresholding) and analysis of area and intensity of isolated pixels. BYK-mac series of (gonio)spectrophotometers use the approach described above to quantify both graininess and sparkle [22]. The method for assessing spatial non-uniformity of special effect coating is recently presented in [23].

Possible Issues

Possible issues related to image analysis and processing for determining quality parameters in printing may be inaccurate sampling or selection of the region of interest. Also, some of the abovementioned methods had to be improved in order to provide a better correlation with visual perception.

If the printing is not performed on flat surfaces, the texture of a surface has a strong impact on the results. This is the case in textile printing, for example. Tse and Brigs [24] suggested averaging more images prior analysing any of the quality parameters in case of digitally printed textiles in order to isolate the printed information from the fabric structure. In the case of the fabrics of lower thread count, the detected colour will highly depend on the background on which the fabric is placed during digitising.

Summary

In this work, we present an overview of image analysis methods for evaluating print quality attributes. Digital image of the printed product is used as a base for further analysis and processing, where each one of the presented methods characterizes certain quality attribute. Results can be used not only to describe the corresponding attribute, but also to monitor print production.

It is to be noted, however, that the overall impression of printed products is based on the combination of quality factors. Some of the attributes, such as colour and sharpness, contribute to a greater extent to the perceived quality of a product. That is why many image quality metrics were proposed over time, taking into account different quality attributes and their correlation with perceived print quality. If the goal is to objectively describe the overall impression of the printed product quality, image quality metrics can be a good choice.

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