Clean Slate

Image Processing Basics: The Background

Image processing in industrial applications often is much simplified when the lighting device provides an image with a homogeneous background. Such a situation allows for robust, stable segmentation of foreground and background. This article deals with some simple methods of image processing which may be useful for the examination of a lighting system.

The purpose of lighting in industrial image processing is to enhance the relevant features of objects and to mask those properties which are of no importance or might even produce unwanted effects. The simplest case would be a lighting device which produces a nearly binary image with clear contrast between objects and background. Figure 1a shows a typical example. Most application engineers are quite satisfied when the grey level image can be transformed into a proper binary image by means of a single global threshold which may be chosen from a broad interval without producing significant deterioration of the segmentation. Such a situation usually is evaluated by analysis of the grey level histogram. Figure 1b shows the histogram for figure 1a. This is a nice example for a bimodal distribution with two clearly separated features. One cluster around grey level 25 belongs to the pixels of the dark objects; the other cluster around grey level 215 is formed by the pixels of the background. Global thresholding with the grey level 104 results in the binary image in figure 1d with clear segmentation of objects and background.

Distribution of Grey Levels

We thus seem to look at an ideal lighting solution. In detail, however, the situation turns out to be a bit more complicated. Since figure 1a shows several coins placed on a backlight-device, the histogram should feature just two sharp lines corresponding to the dark coins and the bright background, respectively. What we observe, however, are two clusters with a width of about 20 grey levels. Figure 1c reveals even more structure in the grey level distribution. The ordinate shows the square-root of the number of pixels with the corresponding grey level rather than the number itself as in figure 1b. This representation shows that for every grey level between the two prominent clusters at least some pixels can be found in the image. One reason for the appearance of these grey levels is the special situation at the edge of the coins, where reflection, shadows and the optical properties of the lens contribute to a continuous intensity profile of the edge, which is sampled by the discrete grid of the detector in the image-plane of the camera. Signal noise as well as differences in sensitivity from pixel to pixel and the variation of the dark signal ("fixed pattern noise") also contribute to the scatter of the grey levels.

The grey level distribution of an image with objects on a background is a useful tool for the evaluation of the general situation, but it is not well suited to qualify the illumination. When the objects are removed from the scene, however, the properties of the lighting-device should show up more clearly. As an example, Figure 2a shows a small background region clipped from figure 1a. The main feature in the corresponding histogram is a bell-shaped cluster in the interval between the grey levels 206 and 225. There are no other grey levels in the

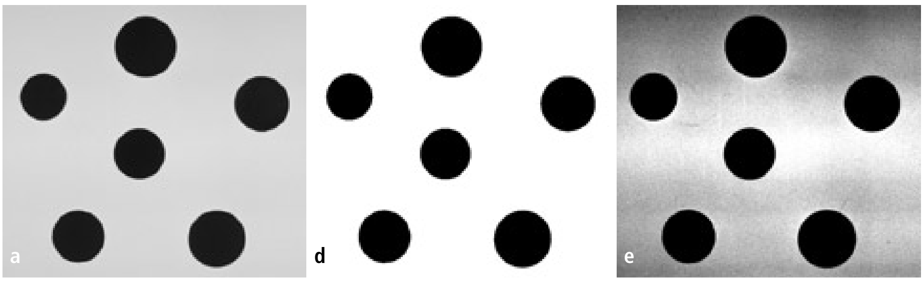
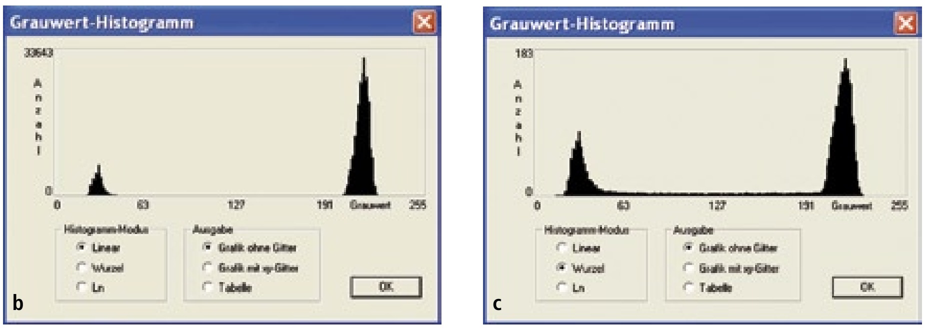


Fig. 1: An image of coins on a back-lighting device, the corresponding grey level histogram with linear and square-root scaling, the resulting binary image and the result of a stretching operation for contrast enhancement



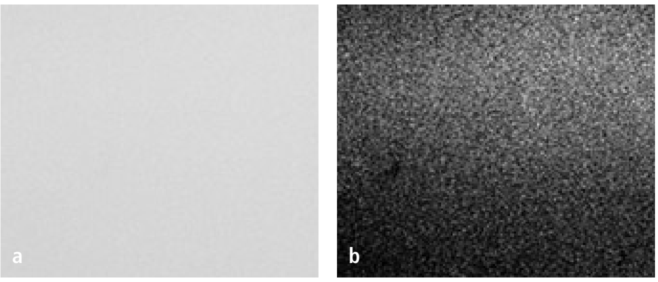


Fig. 2: A small section of the background from figure 1 and the result of a grey level stretching

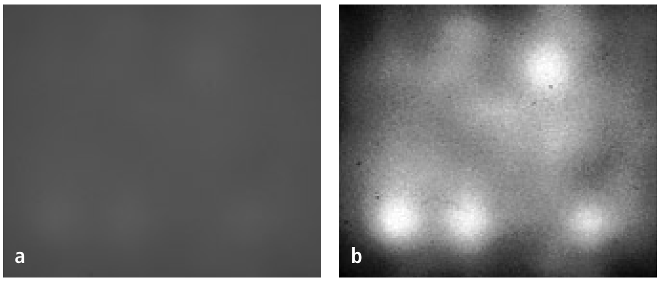


Fig. 3: An image of a commercial back-lighting device and the result of a grey level stretching

whole clipping outside of this interval. The range is only 20 grey values, the median is 216, and the standard deviation is 2.7. These global statistical parameters or rather these values normalized to the centre of the distribution may thus be very well suited for the quantitative characterization of the lighting solution.

Local Structures

Local structures in the image, however, often have no direct influence upon the values of global parameters. Even for images like figure 2a with seemingly very favorable statistical parameters a closer look may reveal surprising features. Figure 2b shows the result of a simple contrast enhancement operation, a so called window-leveling or stretching. In this example, the grey levels between 210 and 225 are stretched to the full range available, that is all values smaller than 211 are set to 0, all values larger than 224 are set to 255, and the values in between are linearly mapped to the range from 0 to 255. Small differences between grey levels thus become more distinct for a human observer. The illumination is by no means homogeneous, and there are not only granular statistical fluctuations in the background, but also some dark spots and broad darker and brighter zones. The whole extent of these variations shows up when the contrast enhancement is applied to the whole image like in figure 1e, where the grey level interval between 190 and 220 has been stretched to the full range available. A number of unwanted effects and structures appear, and global statistical parameters will most probably not be sufficient to characterize such features. A further, quite spectacular example is the commercial back-lighting device producing the image shown in figure 3a. Grey levels range from 59 to 93 with a standard deviation of 5.1. These values seem to be not very alarming, but the stretching-operation for the interval from 70 to 90 shows some quite strange structures as can be seen in figure 3b.

Manifold Influencing Factors

It should be noted that these procedures do not characterize the lighting solution as such, but rather the combination of lighting, optical imaging and the influence of the detector and its electronic signal processing. Optical distortion, e.g., may result in different detector signals for different regions of the object plane even if the illumination is perfectly homogeneous. Furthermore, several lenses routinely used for industrial image processing show a significant drop of efficiency towards the outer regions of the image plane compared to the centre. In the long run, you will always have to deal with the optimization of the image formation as a whole. A holistic view at the problem thus seems to be quite efficient as long as experience provides some hints to the reasons for and consequences of specific effects. A continuous variation of the intensity through the image plane, e.g., sometimes will cause no trouble at all. Image processing based on edge detection, e.g., will usually not be sensitive to such deviations from an ideal intensity distribution. Most image processing methods just need local contrast, since algorithms usually utilize local differences

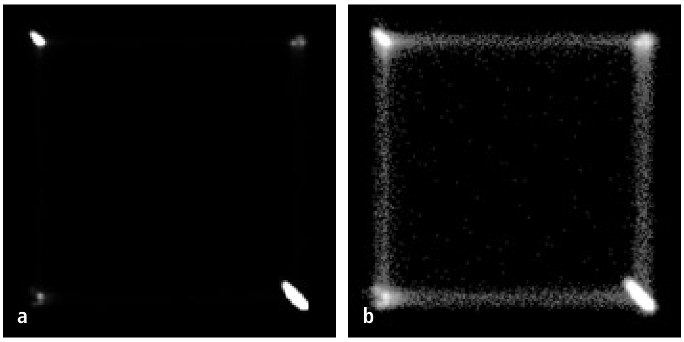


Fig. 4: The co-occurrence matrix for the image in figure 1 and a non-linear mapping for enhancement of further structures in the matrix

between grey levels rather than long-range properties.

Lighting thus must not produce artifacts which may be interpreted as local contrast although there is no corresponding feature in the real scene. Such artifacts, however, may appear in numerous variations, similar to the situation in surface control with its huge number of different scratches, craters and other faults which can not be completely described in advance.

Systematic Analysis Methods

As a systematic approach, a gradient-image may be well suited, which maps the local slope between the grey levels of adjacent pixels. Methods borrowed from texture analysis also may be appropriate for this purpose. As an example, figure 4a shows the so-called co-occurrence matrix for the image in figure 1a. On both axes, the available grey levels are plotted, in this case the range from 0 to 255. To construct the matrix, the grey levels of every pixel and its neighbor are determined. If the actual pixel has the value 100 and its neighbor has the value 120, e.g., the counter for the position (100,120) in the matrix is incremented by 1. A perfectly homogeneous distribution, where all the pixels in the source image have the same grey level, will thus result in a co-occurrence matrix where a single element only will be different from zero, showing up as a bright spot on a black background in a representation of the matrix as an image. The matrix shown in figure 4a, however, is a bit more complicated. There are two bright regions on the diagonal, corresponding to the homogeneous dark regions of the objects and the bright background, respectively. On the other diagonal, there are two weaker regions corresponding to the edges of the objects, produced by the paths from the background into the object and vice versa, respectively. This matrix was not constructed by analysis of the grey level of the direct neighbor of a pixel, but of the pixel 16 steps to the right and 16 steps downwards. The influence of the edges is enhanced by this modification. In figure 4b, the matrix has been modified by a non-linear stretching operation. The intensity of the regions thus is no longer a linear mapping of the number of counts in the matrix. This procedure emphasizes further structures in the matrix which in turn reflect the existence of further local grey level steps in the image. This representation may be useful for the determination of a tolerance region for a grey level threshold in a binarization operation, for the design of an adaptive threshold or for considerations concerning edge detection. The local variations of a background image may also be further characterized on the basis of these data. The co-occurrence matrix, however, is a complex construction. It is reasonable to try to extract some parameters which might be suited to evaluate the grey level distribution in the background of an image in the context of a specific application. A simple procedure would be to define a region around a certain area of the diagonal and to check whether all non-zero elements of the matrix are within this area. Other useful parameters have been developed for texture analysis and are described in the literature [1].

Reference

[1] Gonzales, R.C., Woods, R.E., Digital Image Processing, Addison-Wesley 1993, p. 508 ff.

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