Brightness spatial stabilization in the LIP framework

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Introduction

The LIP (Logarithmic Image Processing) Model derives from the transmittance law and offers a rigorous mathematical framework for image processing [1]. The ability of its operators to simulate variations of illumination or exposure time, is particularly interesting. We propose here a new method to perform image spatial stabilization in presence of lighting changing. The technique consists of simulating local variations of exposure time and produces realistic results. In a first step, we will apply the method to local lighting corrections, which may be considered as a pre-processing. Then we will adapt it to process High Dynamic images and compare the results to those obtained by the classical Tone Mapping approach.

LIP model

The present section is devoted to short recalls about the LIP Model. For more details, the interested reader is invited to refer to [1], and more recently [2]. A grey level image f is defined on a spatial support D, with values in the grey scale [0,M[. The LIP model was created initially to process images acquired in transmission (observed object between the source S and the sensor) [1]. For that reason, the grey scale definition is inverted: in the LIP context, 0 corresponds to the « white » extremity that is to say to the source intensity I(S). In the following, f denotes either the image or the observed object.

The transmittance $T_{f(x)}$ of an image f at $x \in D$ is defined as the ratio of the out-coming flux at x by the in-coming flux (corresponding to the source intensity I(S)). The « addition » of two obstacles f and g generates the image $f \triangle\!\!\!\!\!+ g$. Its expression is derived from the well-known transmittance law $T_{f \triangle\!\!\!\!+ g} = T_f \times T_g$. The link between the transmittance $T_{f(x)}$ and the grey level f(x) is expressed according to: $T_{f(x)} = 1 - f(x) / M$, from which is deducted the LIP addition law:

$$f \triangle\!\!\!\!\!+ g = f + g - f.g / M$$

From this formula derives the logarithmic subtraction between two images f and g, when $f \geq g$. It is noted $f \triangle\!\!\!\!\!- g$ and represents the function we must add to g (in the logarithmic sense) to obtain f:

$$f \triangle\!\!\!\!\!- g = (f - g) / (1 - g / M)$$

Now let us recall the notion of Logarithmic Additive Contrast, noted LAC(x,y)(f), of a grey level function f at a pair (x,y) of points lying in D^2. It corresponds to the LIP subtraction between the maximum and the minimum of a compared pair of grey levels, according to the formula:

$$LAC(x,y)(f) = |f(x)-f(y)| / (1- Min(f(x), f(y))/M)$$

From this logarithmic additive contrast, a lot of metrics have been defined and applied to various situations [2]. An interesting property of the LAC concerns its independence to brightness variation, for example in case of exposure time changes [3].

Brightness correction with the mean intensity stabilization

It has been demonstrated that logarithmic addition or subtraction of a uniform image (i.e. a constant grey level) allows simulating variations of sensor's sensitivity for images acquired in reflection (see fig.1) [3]. The solution we propose here aims at stabilizing images to a given mean value. For an image f acquired under variable lighting, it consists of replacing f by an image whose grey levels mean value equals a given constant, this last corresponding to a "reference" lighting. Let μf denote the mean value of f and μg the mean value of the stabilized image g. Then the constant C which must be subtracted from f to obtain g is computed as follows: we need $\mu f \triangle C = \mu g$ then $C = \mu f \triangle \mu g$. Figure 1 shows a stabilization applied to a sequence of images acquired under variable exposure times.

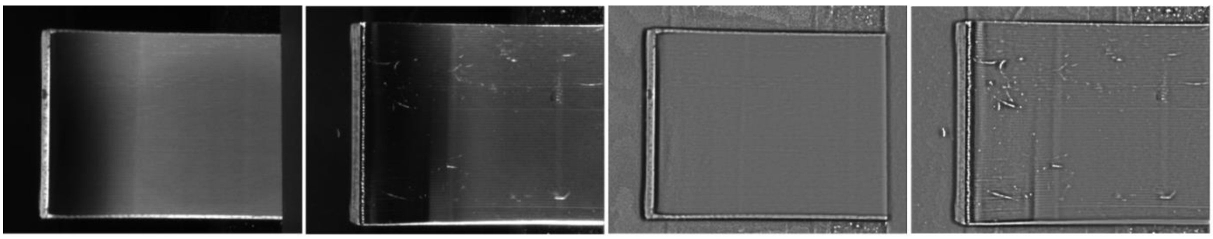
Figure 1. Sequence stabilization. Top line: images under variable exposure times. Bottom line: corresponding images after stabilization

Spatial stabilization

In the previous section, the method has been applied to the whole image. This kind of correction may be algorithmic, as in our case, or material (automatic gain, automatic exposure time…). Both situations have a common limitation, due to their « global » nature. If the studied scene includes a bright region and a dark one, a same correction will be unable to produce a good rendering for both regions. Such scenes are very usual: shadow zones inside an image, back-light acquisition, night scene with isolated light sources… Thus it appears necessary to perform local corrections.

The proposed method consists of applying locally the LIP stabilization to a mean value. The correction computed on each pixel x corresponds to the subtraction from f(x) of a grey level computed from the local mean value and the reference mean. The algorithm can be decomposed into two steps. First a mean filtering is applied to the image. Then for each pixel a grey level is calculated from the filtered image and a chosen mean value. This grey level is finally added or subtracted to the original image.

An example in a context of industrial control is presented (Fig.2). The shape of the controlled object is a metallic half cylinder and thus possesses a strongly specular surface. In such conditions, it is quite impossible to obtain a uniform lighting of it. Figure 2 shows two objects, one without defects (a), the second presenting small sized imperfections (c). In both cases the brightness spatial stabilization suppresses the lighting drift (Fig. 2 (c),(d)), while preserving the defects (Fig. 2 (d)).



(a) (b) (c) (d)

Figure 2. LIP spatial stabilization (obtained with a mean value of 128 and a neighbourhood size of 11x11 on images of 450x360px). (a): initial image of a first controlled object; (b): initial image of a second controlled object; (c): stabilization of(a); (d): stabilization of (b)

Tone mapping approach

Now let us see how simple changes in our method permit the processing of natural scenes presenting high illumination variations (high dynamic images). The previous computation of a local grey level mean value will be replaced by a more sophisticated calculus taking into account potential heterogeneous zones in the considered neighbourhood while avoiding the edges effects.

Bilateral Filter

This filtering technique introduced by Tomasi et al. [4] permits to smooth the image, while preserving the strong grey level transitions (contours). It consists of a non-linear combination of the neighboring pixels, taking into account the spatial distance between the neighboring pixels to the central one and the distance between their grey levels. In our method, such a smoothing produces a model of the local scene brightness, from which the adapted corrections are derived.

Our contribution to the Bilateral Filter concerns the computation of grey level distances between the studied pixel and its neighbors: we replaced the classical metrics commonly used by the LIP Additive Contrast. Such a metric produces a constant filtering, independent of lighting variations. In fact, it has been proved that the LIP Additive Contrast adapts to the lighting level of pairs of compared pixels [3].

Correction strength

After the filtering step, the second step of the method consists of applying to each pixel of the initial image a LIP stabilization from the filtered image and the reference mean. In the case of natural high dynamic images, the choice of enhancing only the dark parts of the image can be done. We suppose that the bright parts of the images are correctly balanced. In this case, only pixels whose levels (on the filtered image) are inferior to the reference mean will be changed.

Besides, a parameter controlling the strength of the correction has been added and consists in a scale factor applied to the grey levels finally subtracted (in the LIP sense) from each point of the initial image. This scale factor lies in the interval [0, 1]. For the value 0, the image remains unchanged and the correction is maximal for the value 1. The choice can be done by the observer, depending of the wished rendering. Also, this value can be set automatically in order to stabilize the dark areas to a percentage of the reference mean, in the case of a sequence of images for example.

Application examples

The following Figure 3 shows the interest of our method for color images. In fact, the computation of the grey level to be subtracted is done in the luminance plane and the LIP subtraction is performed on each channel R,G,B of the initial image.

(a) (b) (c) (d)

Figure 3. Dark zones enhancement, case of a color image (obtained with a LIP bilateral filtering, a mean value of 128 and a scaling factor of 0,8). (a): image of a well; (b): spatial stabilization of (a); (c): street scene; (d): spatial stabilization of (c)

Comparison with tone mapping algorithms

The proposed method obviously deals with *Tone Mapping* algorithms which aim at reducing the contrast range present in a high dynamic scene, while preserving the details of each region. Such techniques are commonly used in various domains: photography, television, video games…Thus it seemed us interesting to compare our algorithm to two well-known Tone Mapping algorithms.

The "Photographic Tone Reproduction" method (Reinhard [5]) first applies a scaling to the image grey levels, compared by the authors to a variation of exposure time. In a second step, the contrast is locally adjusted by means of a *dodge and burning* technique. This method, used in photography during the development, consists of exposing some zones to the light during a variable time. On this point, the principle of our method is similar, the local variation of exposure time being simulated.

Another classical Tone Mapping algorithm is proposed by Durand and Dorsey [6]. We are particularly concerned by this approach, which is based on the use of a "*Fast Bilateral Filter*". Nevertheless, the general principle digresses from ours: the image is separated in a low frequency image (lfi) and a high frequency one (hfi). The lfi is compressed and the hfi is kept unchanged in order to preserve details. Then the two images are merged. Application examples are presented in Figure 4.

Figure 5. Comparison with tone mapping methods. On the left, 3 images of the radiance map (Jack Tumblin [7]). On the right, the resulting images, respectively for Durand method [6], Reinhard method [5] and our method.

The rendering of our results is (subjectively) realistic and close to that of Reinhard. The explanation may be that Reinhard algorithm and ours are justified by a physical interpretation of the problem, while it is not the case for Durand and Dorsey.

Conclusion

The proposed algorithm addresses spatial brightness stabilization and presents a decisive advantage: its strong physical interpretation simulating local variations of exposure time, due to the chosen framework (LIP Model). A direct application has been presented in the field of industrial control, performing automated corrections of lighting drift. Based on the same principle, a more elaborated method has proved its efficiency for high dynamic images. The value subtracted to the image, in the LIP sense, is determined thanks to a bilateral filter evaluating the local illumination while preserving the boundaries in order to avoid possible artifacts. A LIP distance, based on the concept of LIP Additive Contrast, is used in this filter to make it insensitive to lighting variations.This kind of correction shares the same objectives than classical Tone Mapping algorithms.

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