Fused logarithmic transform for contrast enhancement

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Presented is a new version of logarithmic transform for image enhancement: fused logarithmic transform (*fLog*). Based on multi-resolution spline fusion technology, a composite image with a significant improvement in image contrast can be synthesised by fusing the source image and its logarithmic version. Cascaded with other image enhancement techniques, such as histogram equalisation, the fused logarithmic transform could turn the enhanced contrast into more visible details.

Introduction: Logarithmic transform (Log) is one of the most commonly used image enhancement methods [1]. A great advantage with Log transform is its consistency with the logarithmic sensitivity of the human visual system to light. Today, the Log transform has been widely embedded in mainstream digital cameras for capturing high dynamic scenes. Although Log transform increases contrast very well at low range, it is also known that it compresses the contrast at high range. An illustration of this effect with 1D images is shown in Fig. 1. In this Letter, we propose a new logarithmic transform, fused logarithmic transform (*fLog*), which could enhance image contrast at both low and high ranges.

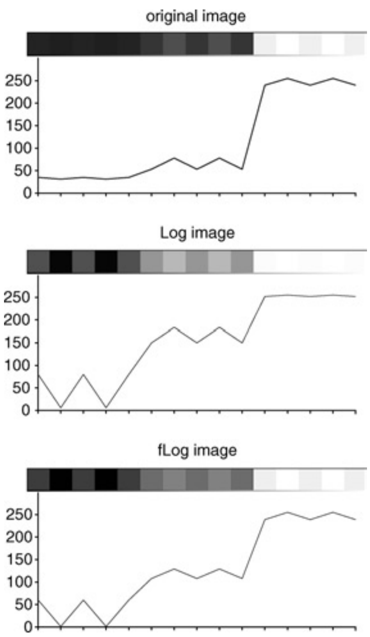

Fig. 1 *Illustration on 1D images*

Fused logarithmic transform: Comparing an image with its Log transform version, one may observe that they expose good contrast at different ranges: the Log version reproduces better visual details at low range while the original image has better contrast at high range. The basic idea here is to synthesise a composite image that will inherit good contrast from both the source image and its Log image. In this Letter, we report a new Log transform: fused logarithmic transform (*fLog*) by fusing the source image with its Log image. The proposed *fLog* transform works as follows:

Given an intensity image $A(i, j)$, where i and j are the row and column index, respectively, in the dynamic range of $[m{:}M]$, the image is first quantised to the typical range of [0:255] as:

$$Q(i, j) = \lfloor 255 \times F(A(i, j)) \rfloor \tag{1}$$

where the function F: $[m{:}M] \rightarrow [0{:}1]$ is a linear mapping function, and $\lfloor \cdot \rfloor$ denotes the floor function.

Its Log image is computed as [2]:

$$B(i, j) = \left\lfloor F\left(\left[\frac{\log(1 + p \times Q(i, j))}{\log(1 + p \times M)}\right]^{1/q}\right) \times 255 \right\rfloor \tag{2}$$

where $p \in [0, \infty)$ and $q \in [1{:}3]$.

The *fLog* transform is performed by fusing the source image A and its Log version B into a composite image C. Our fusion scheme is based on the multi-resolution spline fusion technique [3], which has been successfully used for combining two arbitrary source images into a composite image [3], as shown in Fig. 2, or for fusing two images having either different ranges or different focuses [4]. Note that, different from previous approaches, our fusion is performed on one single image.

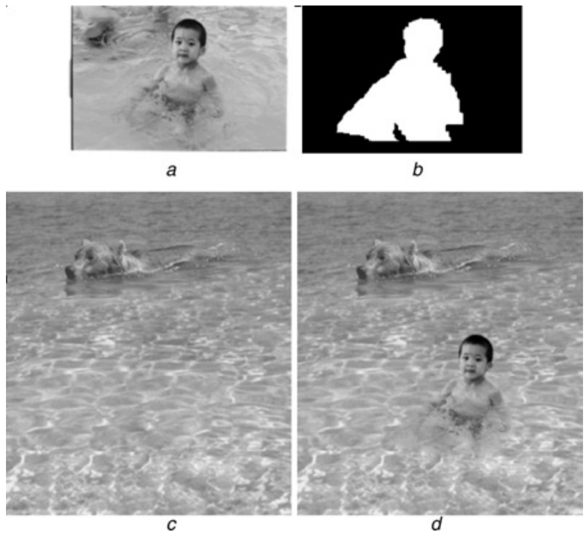

Fig. 2 *Fusion of two arbitrary images*

Fusion is used to combine oddly shaped regions of very different images: portion of (*a*) within the region indicated by the mask in (*b*) is inserted in the portion of (*c*) which is outside this mask region, to produce a composite (*d*)

To employ the multi-resolution spline fusion technique, we need to specify two terms: (i) two input images, and (ii) a binary image mask. The first one is solved by taking the source image and its Log version as the input images. The function of the binary image mask in the fusion processing is illustrated in Fig. 2. In this Letter, the image mask R is initialised as a linear mapping of the gamma-corrected versions of A and B:

$$R = F(A^{\gamma_1} + B^{\gamma_2}) \tag{3}$$

where γ_1 and γ_2 are two predefined exponents. Empirically we found that it works well with setting $\gamma_1 = 1$ and $\gamma_2 \in [2{:}3]$.

The following steps showing how to fuse two images A and B [3]:

- Build Laplacian pyramids L_A and L_B for images A and B, respectively.
- Build a Gaussian pyramid G_R for the mask R.
- Form a combined pyramid L_S from L_A and L_B using nodes of G_R as the weights. That is, for each decomposition level l, row i and column j:

$$L_{S_l}(i, j) = G_{R_l}(i, j) \times L_{A_l}(i, j) + (1 - G_{R_l}(i, j)) \times L_{B_l}(i, j) \tag{4}$$

- Obtain the spline image C by expanding and summing the levels of L_S.

From (4) and (3) one can see that pixels from the source images are weighted differently depending on their intensity. As it is the Log image, B is typically brighter than A. There might be some over-bright areas in B, which make corresponding areas in the mask R very close to white (with a pixel value close to 1). Equation (4) gives a lower weight to those over-bright areas in B and relies more on the corresponding areas in A. Hence the composite image C inherits more details from A rather than from B in over-bright areas. This explains why the proposed *fLog* transform can reproduce more visual details than the Log transform.

Results: The proposed fused logarithmic transform *fLog* has been tested on a variety of images. To quantitatively evaluate the performance of contrast enhancement, we use the well known benchmark for image contrast measure, the Tenengrad value (TEN) [5], which is considered as one of the most robust and functionally accurate image quality measures.

TEN is simply calculated from the gradient of image $I(i, j)$, $\nabla I(i, j)$, at each pixel (i, j). The gradient magnitude is computed as:

$$\|\nabla I(i,j)\| = \sqrt{(S_i * I(i,j))^2 + (S_j * I(i,j))^2} \tag{5}$$

where S_i and S_j are the horizontal and vertical Sobel operator, and $*$ denotes the convolution operator. The Tenengrad value of an image is formulated as follows:

$$T = \frac{1}{n}\sum_i \sum_j \|\nabla I(i,j)\|^2, \quad \text{for} \quad \|\nabla I(i,j)\| > h \tag{6}$$

where n is the number of pixels and h is a threshold.

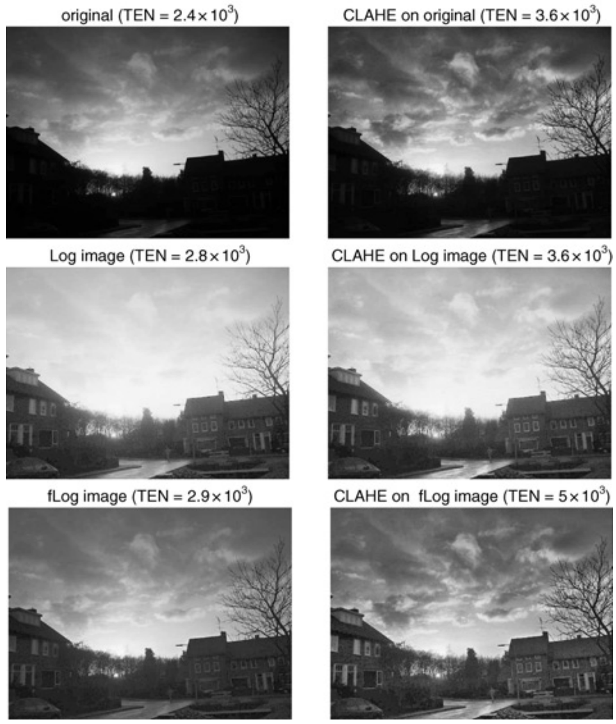

Fig. 3 *Enhancement on a colour image*

fLog image inherits good contrast from both source image and its Log image

We have calculated the TEN of all images in this Letter, and list them in the Figures. Note that the composite images from our *fLog* transform have significantly larger Tenengrad values. This agrees well with our visual inspection. We also show that further processed with other image enhancement technique(s), like histogram equalisation (HE) or contrast-limited adaptive histogram equalisation (CLAHE), the composite images will expose more visible image details than ones without use of the proposed *fLog* transform, as shown in Fig. 3. More resulting images in both grey scale as well as colour at a higher resolution can be found at our webpage: http://www.medialab.tfe.umu.se/members/hung-son.le/ienhance/index.html.

Conclusions: We have introduced a new version of logarithmic transform, fused logarithmic transform, to enhance image contrast. The *fLog* transform can be applied directly to any single images for contrast enhancement without need of any prior information on 3D scene geometry or knowledge of underlying light sources. The fusion algorithm is based on the multi-resolution spline technique, which is computationally efficient. We believe that, owing to its significant advantage in contrast enhancement, the proposed *fLog* transform has a high potential to replace the traditional Log transform as a default image processing component embedded in future digital cameras.

25 July 2007
Electronics Letters online no: 20082182
doi: 10.1049/el:20082182

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