Multi-Resolution Enhancement of Photographic Images

Koen Vande Velde and Paul A. Delabastita
Agfa-Gevaert
Mortsel, Belgium

Abstract

Multi-resolution enhancement provides a powerful tool for enhancing photographic images. These images are acquired with a large dynamic range and a good signal-to-noise ratio. A problem arises in reproducing such images on a medium (CRT, paper...). There are the restrictions of the recording apparatus (number of reproducible intensity levels, color gamut, and color resolution...) as well as environmental factors (flare, light level...). Apart from these technical restrictions, there are also fundamental limitations to the capabilities of the human visual system.

We present a multi-resolution method that adjusts the image such that it uses the available dynamic range in a more efficient way and faint image details are visualized better, even in dark and light portions of the image.

The enhancement is done in a way that preserves the natural look of the image. The algorithm is robust enough to process photographic images in batch, without tweaking the processing parameters per image. The main message of this paper is that multi-resolution image enhancement, originally developed for radiological imaging, can be applied successfully on photographic color images.

Introduction

Traditional methods for image enhancement are unsharp masking and histogram equalization. Plain unsharp masking adds a certain percentage of the image details to the image, to make these details more visible in the output image. The image details are obtained by subtracting from the image an unsharp image, calculated by applying a low-pass filter to the image. Depending on the kernel size of the filter, we are boosting details with high spatial frequency (for a small kernel), or details with lower spatial frequencies (for larger kernels). The crucial concept in this method is therefore the spatial frequency band containing the details that need to be enhanced. The method does not take into account the detail amplitude. Details of small amplitude and details of large amplitude are scaled in the same way. Doing so, one does not use the dynamic range of the image in an optimal way. Large contrasts that fall into the right frequency band are enlarged, leaving less space in the available dynamic range for details of smaller amplitude. It was already recognized in a Fuji patent[1] dating from 1980 that it is better not to multiply the details by a constant factor, but to let the enhancement depend on the detail amplitude.

In this way a more sophisticated unsharp masking is obtained. When unsharp masking is presented in this way, unsharp masking with a larger kernel is very close to histogram equalization with a sliding window.

The drawback of these methods is that one has to choose a particular kernel size. The consequence is that details will be enhanced in a particular frequency band. Because the available dynamic range is limited, this will inevitably mean that details that do not fall into this particular band are suppressed. This gives a nice result when most of the relevant image information resides in the chosen frequency band, but makes it hard to set good processing parameters for a large set of images. For some images it is even not possible to select an optimal kernel size, since they combine appreciable contrasts in both high and low frequencies. A multi-resolution approach gives us a way to escape the *optimal kernel problem* and makes it possible to manipulate image details in different spatial frequency bands at the same time. In this way we can let amplitude detail alone govern the enhancement, irrespective of spatial frequency. The multi-resolution method enlarges small contrasts, bringing subtle contrasts above the perception threshold, and diminishes large contrast, which are visible anyhow. This is done in all spatial frequency bands. The result is an image visualizing the acquired image information in a better way. These ideas have proven to be useful for enhancing medical grayscale images. They can be useful for photographic color images as well.

Multi-Resolution Image Representation

To obtain the image details of a grayscale image at different resolution levels, we use the following iterative scheme. An image I is successively brought to lower resolutions by low-pass filtering (smoothing) and subsampling:

$$I_0 = I$$
$$I_n = \downarrow (f * I_{n-1})$$

f is a low-pass filter and $\downarrow$ stands for subsampling, i.e. deleting 1 in 2 pixels in both the horizontal and vertical direction. Therefore, I_n is 4 times smaller than I_{n-1}. At each resolution level n, the details D_n of the image I_n are extracted, e.g. by subtracting from In the lower resolution image I_{n+1} (after interpolating the last one to resolution n):

$$D_n = I_n - P(I_{n+1})$$

P stands for an interpolation operation (= zooming the image by a factor of 2 in both the horizontal and vertical direction). The multi-resolution image representation consists of the detail images of the different resolutions and a residual low-resolution image:

$$D_0, D_1, \ldots , D_{K-1}, I_K.$$

D_n contains the image details of the spatial frequency band corresponding to resolution n.

Typically, we take K=8 resolution levels for the decomposition. Because D_n is smaller in size than D_{n-1} it is called a pyramidal decomposition.

The image can be reconstructed in an exact way from this representation, by repeating

$$I_n = D_n + P(I_{n+1}) \text{ for } n = K\text{-}1 \text{ to } 0.$$

This image representation is known as the laplacian pyramid.[2] Several other multi-resolution representations exist, but all combine the steps of resolution lowering with detail extraction, see e.g. Ref. 3.

Image Enhancement

The multi-resolution image enhancement will manipulate the image details from the multi-resolution image representation, to make details of small amplitude larger and details of large amplitude smaller. To this end, the image details D_n are mapped in a pixelwise manner by a sigmoid function σ_n, to obtain the modified image details:

$$D_n' = \sigma_n(D_n)$$

The sigmoid function may take the following form:

$$\sigma_n(x) = \alpha_n x \text{ for } x < t_n$$
$$\beta_n x^\gamma \text{ for } x \geq t_n$$

with $\gamma < 1$. The value of γ controls the strength of the enhancement, t_n is a threshold value preventing unwanted over enhancement of small details at the highest resolution levels (i.e. noise).

The output image is then reconstructed from the modified image details and the residual image.

The scheme of this image enhancement is depicted in figure 1. It has been used with success for enhancement of radiological images.[4]

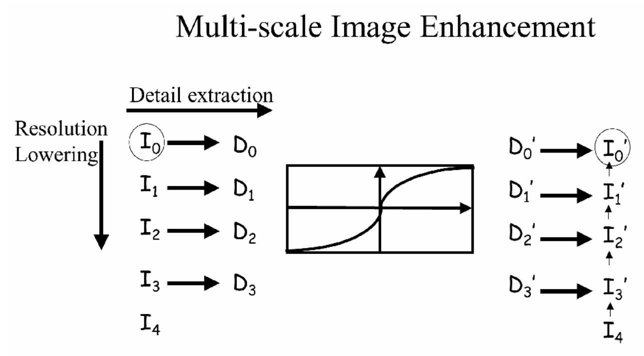

Figure 1.Scheme of the algorithm

Color Images

To apply the algorithm to color images, the color image is converted to a representation of color using a brightness or luminance channel, and two opponent color channels. The algorithm is then performed on the luminance channel only. Modifying the luminance however requires a correction on the saturation to obtain colors resembling closely the colors of the input image.

A modest boost of the saturation, depending on the enhancement parameter γ is generally quite satisfactory. This simple approach has proven more robust than more complex manipulations in color space.

The robustness of the algorithm makes it possible to process photographic images in batch, without tuning the parameters per images. This makes it especially fit for photo-finishing applications.

Figures 2 and 3 show examples of unprocessed and processed images captured with a consumer digital camera. The unprocessed images are shown at the top, the processed images are shown at the bottom.

References

1. EP32237
2. P. Burt and E.H. Adelson, *The Laplacian Pyramid as a Compact Image Code,* IEEE Transactions on Communication, COM-31: 532-540 (1983)
3. Fan J., Laine A.F., *Contrast enhancement by multiscale and nonlinear operators*, in *Wavelets in medicine and biology*, Akram Aldroubi and Michael Unser eds., CRC Press (1996)
4. P. Vuylsteke and E. Schoeters, *Multi-scale Image* Contrast *Amplification (MUSICA),* Proceedings of SPIE Vol. 2167, 551-560 (1994)

Figure 2 and 3: Examples