

L. Yaroslavsky. Fundamentals of Digital Image Processing. Course 0555.3230

Lecture 11. Image enhancement

11.1. Image enhancement as an image processing task. Classification of image enhancement methods

Image enhancement is a processing aimed at assisting image visual analysis. In visual image analysis, the user that observes images plays a role of a decision making machine while images may be regarded as sets of features that are needed for the decision making and that are represented in a special way perceivable to the machine.

Human visual system has certain limitations in its capability to perceive information carried by images. Visual system can not detect brightness contrasts that are lower than a certain contrast sensitivity threshold. It has also a limited resolving power. It fails to analyze images corrupted by noise, especially by impulse noise or highly correlated noise patterns. From the other side, visual system perceives colors, it has 3-D capability through stereo vision, it is capable of efficient detecting changing images in time. One can say that visual system has five channels per pixel to perceive information: three for RGB colors and additional two for stereo and for dynamical vision. Image enhancement is intended to convert images into a form that makes use of capabilities of human visual system to perceive information to their highest degree.

Theoretically, image enhancement methods may be regarded as an extension of image restoration methods. However, in contrast to image restoration, image enhancement frequently requires intentional distorting image signal such as exaggerating brightness and color contrasts, deliberate removing certain details that may hide important objects, converting gray scale images into color, stereo and movie ones to display three-four-five component features, etc. In this sense image enhancement is image preparation or enrichment in the same meaning these words have in mining.

An important peculiarity of image enhancement as image processing is its interactive nature. The best results in visual image analysis can be achieved if it is supported by a feedback from the user to the image processing system.

Image enhancement methods date back to the beginning of the last century photography and microscopy methods such as unsharp masking, solarization, phase contrast. Electronic television enabled using more sophisticated methods for manipulating image contrasts, brightness, color and geometry. However only digital computers equipped with appropriate display devices enabled implementation of truly interactive image processing. Flexibility of programmable digital computers make them the ideal vehicle for image enhancement.

From the point of view of implementations, image enhancement methods can be classified into four categories: gray scale, or histogram manipulation methods, image spectra manipulation methods, geometrical transformation methods and display methods.

Gray scale, or histogram manipulation methods implement different modifications of image display transfer function. We will review them in Sect. 11.2. Image spectra manipulation methods implement modification of image spectra in different bases, most frequently DFT and DCT ones. They are reviewed in Sect. 11.3. Special information display methods for image enhancement are briefly outlined in Sect. 11.4.

11.2 Gray level histogram modification methods

One of the features that determine the capability of vision to detect and analyze objects in images is contrast of objects in their brightness with respect to their background. While globally image may utilize the entire dynamic range of the display device, locally, within small windows image signal has very frequently much lower dynamic range. Small local contrasts may make it difficult to detect and analyze objects.

The simplest and the most straightforward way for amplification of local contrasts is stretching local dynamic range of image signal in a sliding window to the entire dynamic range of the display device. The two computationally inexpensive methods for stretching local contrasts are max-min stretching and local dynamic range normalization by local mean and variance. They are described correspondingly as

$$\hat{a}_{k,l} = \frac{a_{k,l} - \min_{k,l}}{\max_{k,l} - \min_{k,l}}, \quad (11.1)$$

and

$$\hat{a}_{k,l} = \begin{cases} a_{\max}, & \text{if } \hat{a} \geq a_{\max} \\ \hat{a}, & \text{if } a_{\min} \leq \hat{a} \leq a_{\max} \\ a_{\min}, & \text{if } \hat{a} \leq a_{\min} \end{cases}, \quad (11.2)$$

where

$$\hat{a} = g \frac{a_{k,l} - \text{mean}_{k,l}^{(w_1, w_2)}}{\text{stdev}_{k,l}} + \frac{a_{\max} - a_{\min}}{2}, \quad (11.3)$$

$a_{k,l}$ and $\hat{a}_{k,l}$ are input and output image samples in the window position (k, l) , $\max_{k,l}$, $\min_{k,l}$, are maximal and minimal signal values within the window, a_{\max} and a_{\min} are boundaries of the display device dynamic range,

$$\text{mean}_{k,l}^{(w_1, w_2)} = \frac{1}{(2w_1 + 1)(2w_2 + 1)} \sum_{m=-w_1}^{w_1} \sum_{n=-w_2}^{w_2} a_{k-m, l-n}, \quad (11.4)$$

is local mean value and

$$\text{stdev}_{k,l} = \sqrt{\frac{1}{(2w_1 + 1)(2w_2 + 1)} \sum_{m=-w_1}^{w_1} \sum_{n=-w_2}^{w_2} (a_{k-m, l-n} - \text{mean}_{k,l}^{(w_1, w_2)})^2}, \quad (11.5)$$

is local standard deviation within the window. Local dynamic range normalization by local mean and variance is illustrated in Fig. 11.1, upper row.

Alternative methods of amplification of local contrasts are methods of the direct modification of image histograms: global and *local histogram equalization* and *P-histogram equalization*. Histogram equalization converts an image $\{a_{k,l}\}$ with histogram $h(q)$ into an image $\{\hat{a}_{k,l}\}$ with a uniform histogram by means of the following gray level transformation:

$$\hat{a}_{k,l} = (q_{\max} - q_{\min}) \frac{\sum_{q=q_{\min}}^{a_{k,l}} h(q)}{\sum_{q=q_{\min}}^{a_{\max}} h(q)} + q_{\min}, \quad (11.6)$$

where q_{\min} and q_{\max} are minimal and maximal quantized values of image signal (for 256 quantization levels these are 0 and 255).

It follows from Eq. 11.6 that the slope of the histogram equalization transfer function $\hat{a}_{k,l}(a_{k,l})$ is proportional to the histogram value:

$$\frac{\Delta \hat{a}_{k,l}}{\Delta a_{k,l}} \propto h(q)_{q=a_{k,l}}. \quad (11.7)$$

This means that histogram equalization results in amplification of contrasts that, for each gray level, is proportional to its histogram value, or to the gray level *cardinality*.

P-histogram equalization defined by the equation

$$\hat{a}_{k,l} = (q_{\max} - q_{\min}) \frac{\sum_{q=q_{\min}}^{a_{k,l}} [h(q)]^P}{\sum_{q=q_{\min}}^{a_{\max}} [h(q)]^P} + q_{\min}, \quad (11.8)$$

is a natural generalization of the histogram equalization that makes it more flexible through the use of a user-defined parameter P . If $P = 0$, *P-histogram equalization* is equivalent to the automatic stretching image dynamic range from (a_{\min}, a_{\max}) to (q_{\min}, q_{\max}) . $P = 1$ corresponds to histogram equalization. Intermediate values $0 \leq P \leq 1$ result in more soft contrast enhancement that is frequently better perceived visually.

The described histogram modification techniques can be applied both globally and locally. In the latter case, the modification is local adaptive.

Image unsharp masking, histogram equalization and *P-histogram equalization* are illustrated in Fig. 11.1 and Fig 11.2 compares global histogram equalization and *P-histogram equalization* and

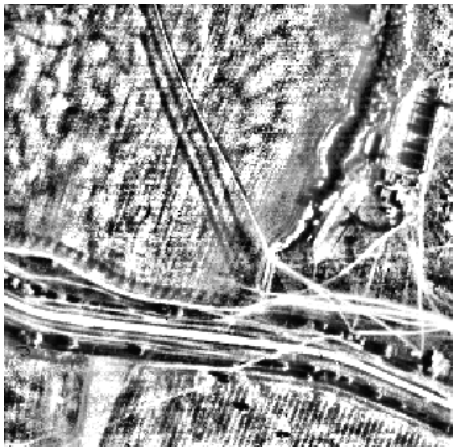
their corresponding transfer functions (compare them with the image histogram). Note that the P -histogram equalization may be regarded as an implementation of the nonlinear pre-distortion for optimal compander quantization (Lect. 5).



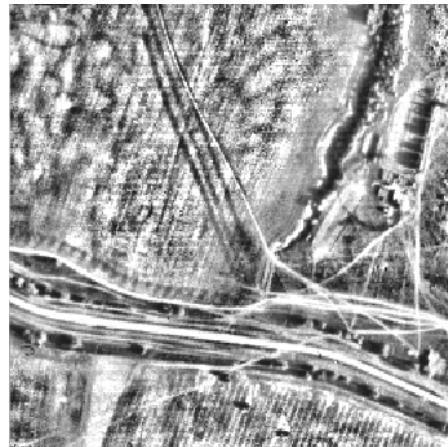
Initial image (256x256)



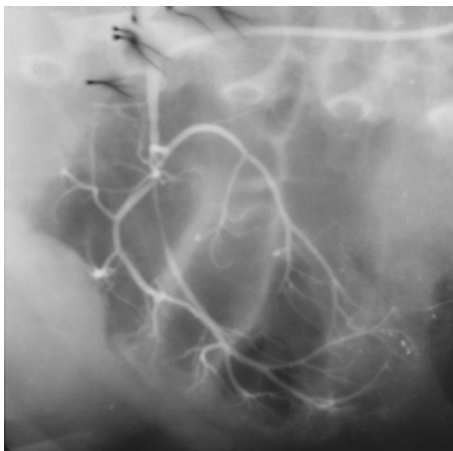
Normalization of local mean and standard deviation in the window 33x33



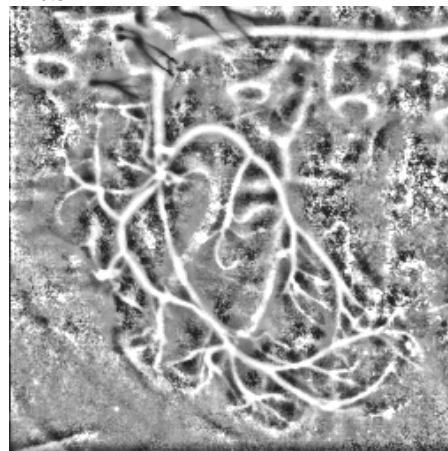
Local histogram equalization, SzW=33x33



Local histogram P -equalization, SzW=33x33; $P=0.5$

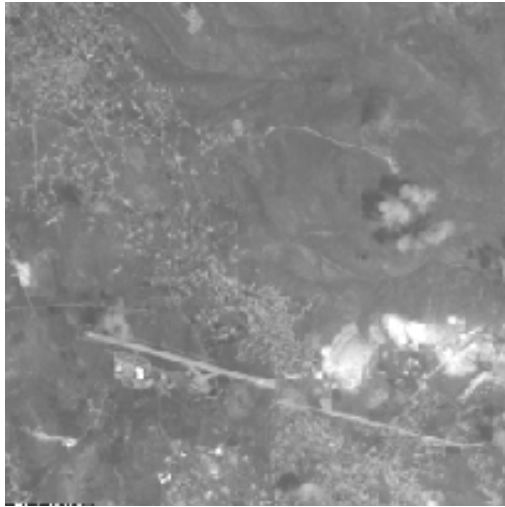


Initial image (256x256)

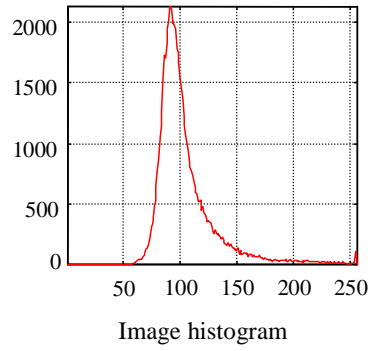


Local histogram equalization, SzW=15x15

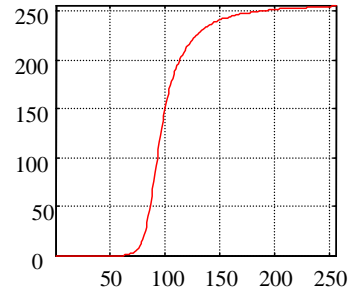
Figure 11.1. Local histogram modification by means of standardization of local mean and variance (upper row) and by P -histogram equalization (middle and bottom rows)



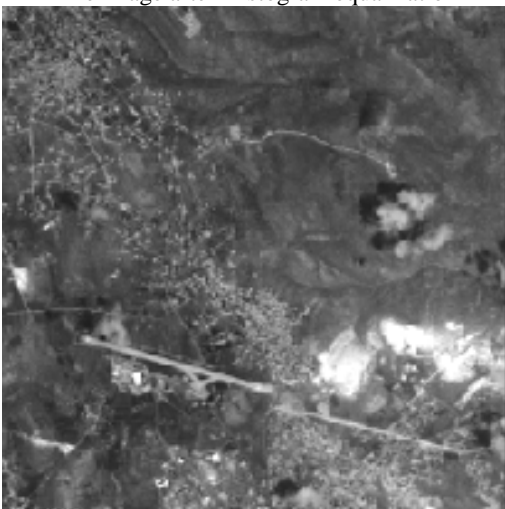
Initial image



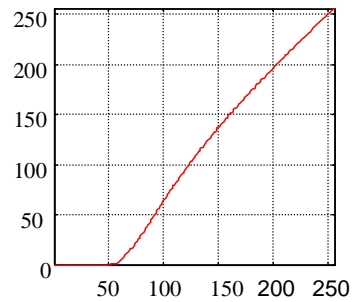
The image after histogram equalization



Histogram equalization transfer function



The image after P-histogram equalization (P=0.1)



Histogram P -equalization transfer function (P=0.1)

Figure 11.2 Global histogram modification by means of histogram equalization and P-histogram equalization. Left column (from top to bottom): initial image, result of histogram equalization and P-histogram equalization (P=0.1). Right column, from top to bottom: histogram of the initial image and corresponding gray level transformation transfer functions

11.3 Image spectra modification methods

Two image spectra manipulation methods for local contrast enhancement are the most simple in the implementation: unsharp masking and nonlinear spectra coefficients transformations. They are implemented, respectively, in signal domain and transform domain filtering.

Unsharp masking is defined by the equation:

$$\hat{a}_{k,l} = a_{k,l} + g(a_{k,l} - \text{mean}_{k,l}^{(w_1, w_2)}), \quad (11.9)$$

where $\text{mean}_{k,l}^{(w_1, w_2)}$ is the image local mean in the window of $(2W_1 + 1)(2W_2 + 1)$ pixels defined by Eq. 11.3 and g is a user defined local contrast amplification parameter. Window size parameters W_1 and W_2 are also user defined parameters that are commensurate with the size of the objects to be enhanced.

Modification of image spectra that results from applying unsharp masking is determined by the unsharp masking frequency response. As it follows from Eq. 11.9, it is, for image of $N_1 \times N_2$ samples, equal to:

$$\eta_{r,s} = 1 + g[1 - \text{sincd}(2W_1 - 1; N_1; r) \text{sincd}(2W_2 - 1; N_2; r)] \quad (11.10)$$

where $\text{sincd}(\cdot; \cdot; \cdot)$ is the discrete sinc-function. Fig. 11.3 illustrates 1-D sections of unsharp masking frequency responses for windows of 3 and 15 pixels.

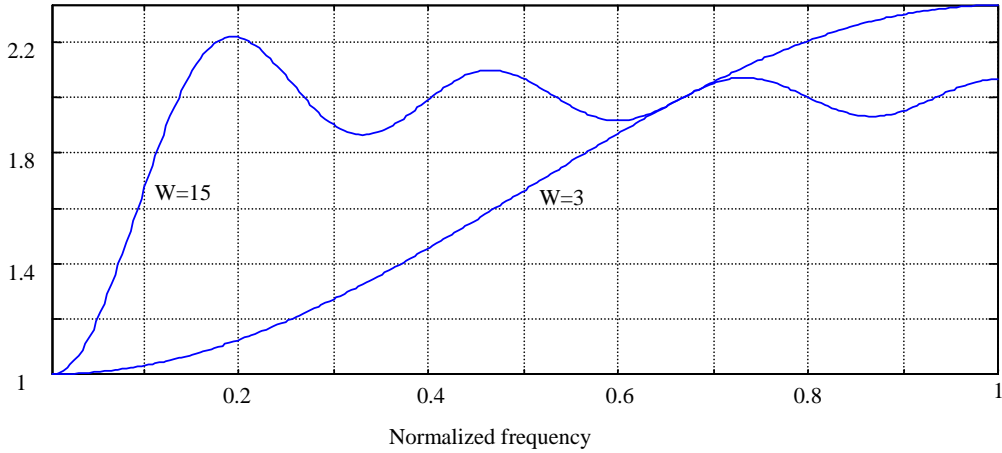


Figure 11.3. 1-D sections of unsharp masking frequency responses for window sizes 3 and 15 pixels with amplification coefficient $g=1$

Unsharp masking is a non-adaptive local contrast enhancement procedure. With unsharp masking, the degree of amplification of image high frequencies is the same for any image. An alternative and adaptive method for modification of image spectra that results in local contrast enhancement is P -th law nonlinear modification of absolute values of image spectra coefficients. It is described by the equation

$$\hat{\alpha}_{r,s} = \frac{\alpha_{r,s}}{|\alpha_{r,s}|} |\alpha_{r,s}|^P, \quad (11.9)$$

where $\{\alpha_{r,s}\}$ and $\{\hat{\alpha}_{r,s}\}$ are initial and transformed image spectral coefficients in a selected basis, respectively, and P is a user defined parameter. As a transform, usually DFT or DCT are used. When $0 \leq P < 1$, this modification redistributes energy of spectral coefficients in favor of low energy coefficients. The degree to which individual coefficients are amplified depends now on the image spectrum.

Such a spectrum modification may be applied globally to the spectrum of the entire image and locally in a user specified sliding window to spectra of the window samples in each position of the window. In the latter case, the modification is local adaptive. In Fig. 11.4 one can compare image local contrast enhancement by means of unsharp masking and global and local nonlinear modification of image DCT spectrum.

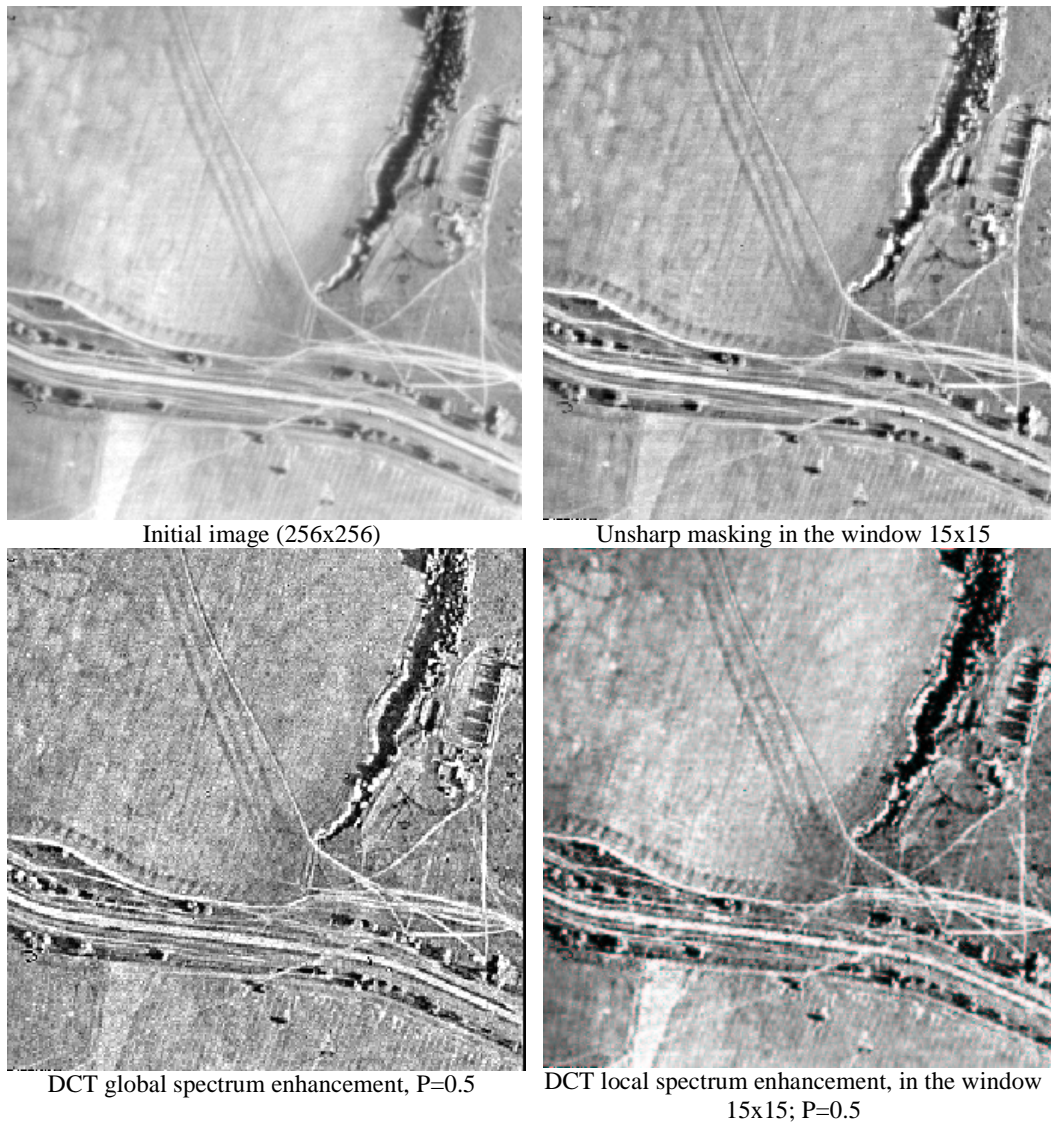
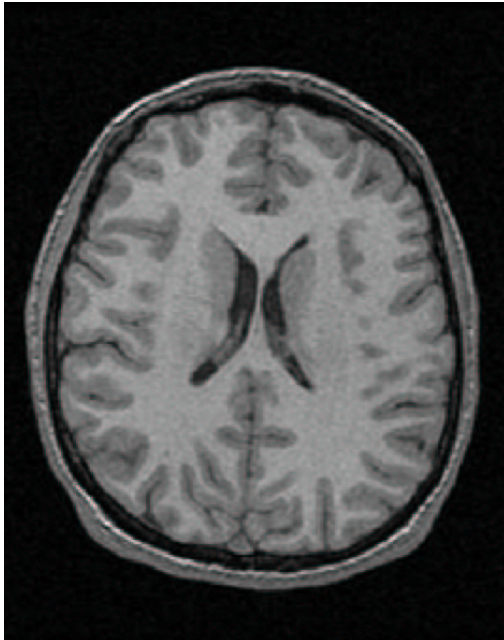


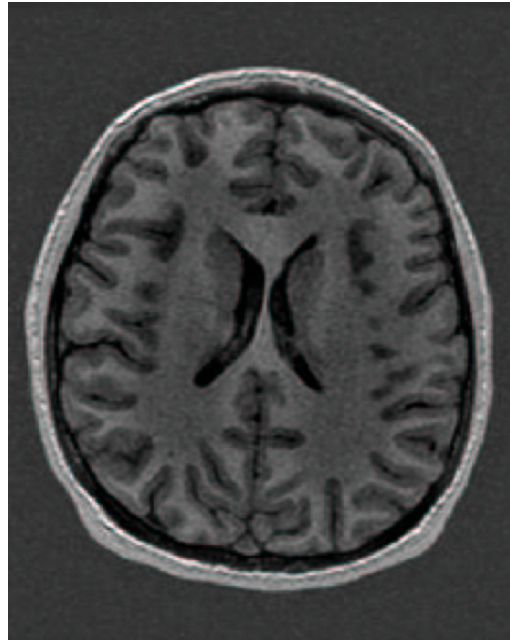
Figure 11.4 Unsharp masking and nonlinear spectrum modification for image enhancement

8.4 Using color, stereo and dynamical vision for image enhancement

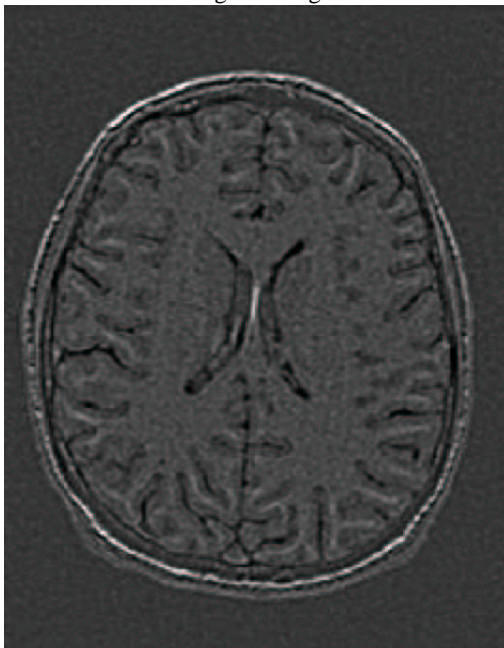
The basic principle of using color, stereo and dynamic capabilities of vision is straightforward. Image is processed to produce several output images that represent certain several features of the input image. For instance, this processing may be image sub-band decomposition, image local histogram P -equalization using several different window sizes, edge enhancement and extraction with different algorithm parameters, object detection, to name a few. The obtained set of images may then be used to generate animated artificial movie by using generated images as movie frames, or to generate artificial color images by representing combination of three generated images as red, green and blue components of the color image that is displayed for visual analysis (Fig. 11.5), or to generate artificial stereoscopic images for left and right eyes from couples of the obtained images. In the latter case, one of the processed images or the initial image is treated as a “reflectance map” of an artificial 3-D surface and another as its “depth map”. Using the reflectance map and the depth map, one can generate a pair of images for right and left eyes by introducing to every pixel of the “reflectance map” a horizontal shift proportional the value of the “depth map” for this pixel. Fig. 11.6 illustrates an example of such an artificial stereo image generated from air photograph of 256x256 pixels treated as a “reflectance map” and an image of its local means in the window of 45x45 pixels treated as a “depth map”.



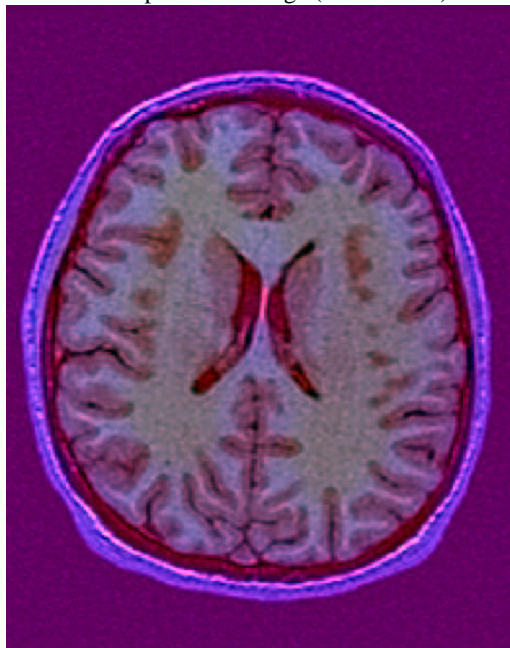
Original image



Unsharp masked image (medn35x35)



Unsharp masked image (medn7x7)

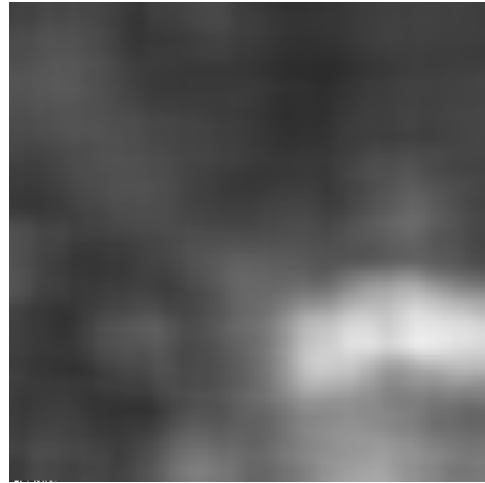


Colored image of the above 3 components

Fig. 11.5 Image colorization



Input image (256x256)



Input image local mean in the window 45x45 pixels (image size is 256x256)



Artificial stereoscopic images for left and right eye generated using the image local mean as a depth map.

Figure 11.5. Stereo visualization of an image and its local mean. One can observe 3_d image using a stereoscope or by looking at the images with squinted eyes. In the latter case, one should try to squint eyes until two pairs of images seen with each eye overlap into 3 images. Then the central of those three images with be seen as a 3-D image.

Summary

Image enhancement in image processing aimed at assistance to human operator in visual image analysis.

Image enhancement methods can be classified into four groups:

- histogram modification methods
- image spectra modification methods
- “unsharp” masking methods
- visualization methods

Histogram modification methods, image spectra modification and unsharp masking methods allow enhancing image local contrasts. Visualization methods aimed at exploiting all capabilities of visual system to perceive visual information.

Questions for self-testing

1. Explain what is image dynamic range stretching.
2. Explain what is histogram equalization and in what sense it improves image visual quality.
3. Explain what is P -histogram equalization and in what sense it improves image visual quality
4. Explain why local histogram modification is advantageous to the global one.
5. Explain basic principle of image “unsharp” masking. How unsharp masking modifies image spectrum?
6. Describe methods of image spectrum nonlinear modification and explain when and why they improve image visual quality.

Home work: Demonstrate, using Matlab functions **conv2** and **fft2**, image enhancement by unsharp masking and by nonlinear spectrum modification.