# Local Contrast Enhancement for Improving Screen Images Exposed to Intensive External Light

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## Abstract

When a mobile device (notebook, smartphone, etc.) is used, the images on the monitor screen may be significantly distorted by a strong external light (for instance, sunlight) illuminating the screen surface. This additional illumination reduces all the local contrast values in the displayed images and leads to fading and deterioration of the subjective visual images thus impeding image recognition and analysis. A technique of processing the input digital video signal in such a way that, in presence of an additional external illumination, the local contrast values of the displayed image are made as close as possible to the original ones is described. The significant image enhancement due to this technique has been demonstrated in experiments with the illuminated monitor screen and has been estimated mathematically via the distributions calculated for local contrast values before and after processing video signal.

***Keywords:*** *Contrast enhancement, Displayed images, Local contrast, External illumination, Ambient light correction*

## 1. INTRODUCTION

The images on the monitor screen may be distorted by a strong light illuminating the screen surface. Such a situation occurs rather frequently when a mobile device (a notebook, a smartphone, etc) is used under conditions of bright natural light or artificial illumination of high intensity levels. This additional external illumination reduces all the local contrast values in the displayed images relative to those in the original images observed in the absence of such illumination. Since successful contrast detection is one of the most important conditions for an adequate visual perception, decrease of the local contrast values could result not only in a general deterioration of subjective image quality but also in failures and errors in visual performance.

Evidently, to improve recognition of details in the displayed image, it is necessary to compensate somehow for the loss of the perceived image quality. One of the possible ways is to employ some method of contrast enhancement. A lot of procedures for contrast enhancement have been proposed during the last thirty years, especially for the purposes of aviation, medical digital radiography, infrared imaging systems [Beghdadi and Negrate 1989, Dash and Chatterji 1991, Weeks 1996, Chang and Wu 1998, Zhu et al. 1999, Mukhopadhyay and Chanda 2000, Kim et al. 2001, Cheng et al. 2003, Branchitta et al. 2008] where the initial images could be of a poor quality. These procedures have been classified into two groups: direct methods implying modification of calculated contrast values by some functions, and indirect methods using modification of histograms, in particular, histogram equalization**.** In fact, many of these procedures are equivalent to low-pass and high-pass filtering for separating smooth and detail areas of an image and enhancing the detail components.

Despite essential differences, all these methods are so-to-say universal in the sense that they could be applied to any original image independently of the cause of its low quality. The task of image processing is formulated rather generally: to obtain the better image and, at the same time, to avoid over-enhancement and under-enhancement. Our study concerns a partial case, when the quality of the displayed image is poor due to the external illumination of the monitor screen surface. For this case, several variations of the general approaches could be found in the literature available: gamma correction with a lower value of gamma than in the absence of ambient light [Ware 2000], a novel remapping function including the measured value of the ambient light [Delvin et al. 2006], high-pass and low-pass filtering depending on the ambient light [O'Dea et al. 2004/2009]. However, in the case of distortion caused by the external illumination the task of image enhancement can be formulated more precisely.

Proceeding from the assumption that the quality of the original image is good enough and taking into account the crucial role of local contrasts in human perception, we suppose that to improve the quality of the displayed image washed-out by the ambient light, it is rational to find a transformation of the original input digital video signal into the signal that make the local contrast values as close as possible to those of the original image. A straightforward algorithm of such a transformation is described below. In this paper, we restricted ourselves to the simplest case: a *monochrome* original image and *smoothed* additional luminance of the screen.

## 2. THEORETICAL APPROACH TO FINDING THE LOCAL CONTRAST ENHANCEMENT ALGORITHM

### 2.1. Formulating the Problem

Let an original monochrome image be described by the luminance distribution on a monitor screen surface, $U(x,y)$, where $x, y$ are the coordinates of the surface points. Suppose that the coordinates are of discrete (integer) values and set in a rectangular region, $\mathbf{R}$: $x = 0,...,N-1,\ \ y = 0,...,M-1$. Then the image may be presented as the luminance array $\mathbf{U} = \{U(x,y),\ (x,y) \in \mathbf{R}\}$ consisting of $NM$ pixels. The original image is determined by *the input digital video signal*, that is, the array of brightness code words, $\mathbf{c}_{\mathrm{U}} = \{c_{\mathrm{U}}(x,y), (x,y) \in \mathbf{R}\}$, where the brightness code word, $c_{\mathrm{U}}(x,y) = 0, 1, ..., 255$. The luminance at the point $(x,y) \in \mathbf{R}$ is an increasing function of the corresponding brightness code:

$$U(x,y) = F(c_{\mathrm{U}}(x,y)).$$

The function $F(\ldots)$ is the *tone characteristic* of the monitor. Using this function, the original image may be expressed as

$$\mathbf{U} = \{U(x,y) = F(c_{\mathrm{U}}(x,y)),\ \ (x,y) \in \mathbf{R}\}.$$

Suppose that the monitor screen is illuminated by an external light source. It results in an additional luminance, $U_0(x,y)$, at every screen point. The new luminance distribution, induced *by the same input signal* in the presence of the external illumination of the screen, is the distorted image,

$$\mathbf{V} = \{V(x,y) = F(c_{\mathbf{U}}(x,y)) + U_0(x,y),\ (x,y) \in \mathbf{R}\}.$$

Due to the external illumination the visual quality of the distorted image on the monitor screen is lower than of the original one. Our task is to find a transformation of the original input video signal into another signal,

$$\mathbf{c}_{\text{opt}} = \{c_{\text{opt}}(x,y),\ (x,y) \in \mathbf{R}\},$$

inducing the screen image,

$$\mathbf{U}_{\text{opt}} = \{U_{\text{opt}}(x,y),\ (x,y) \in \mathbf{R}\},$$

that is *subjectively* as close as possible to the original image in spite of the presence of the external screen illumination.

## 2.2. Local Contrast

The measure of similarity of the two images used in this study was based on the differences of their local contrast values. It is natural to define the local contrast at the point $(x, y)$ of the original image, $\mathbf{U} = \{U(x,y),\ (x,y) \in \mathbf{R}\}$, as

(1) $$C_{\mathbf{U}}(x,y) = \frac{U(x,y) - \bar{U}(x,y)}{\bar{U}(x,y)},$$

where $\bar{U}(x,y)$ is a weighted average luminance of the points surrounding a given point $(x, y)$, that is

(2) $$\bar{U}(x,y) = \sum\nolimits_{i,j=-d}^{d} a_{i,j} \cdot U(x-i, y-j).$$

In this equation the parameter *d* characterizes the size of the surrounding area, and $a_{i,j}$, $i, j = -d, ..., d$, are positive normalized weight coefficients such, that $\sum\nolimits_{i,j=-d}^{d} a_{i,j} = 1$. The image

$$\bar{\mathbf{U}} = \{\bar{U}(x,y),\ (x,y) \in \mathbf{R}\}$$

may be treated as a smoothed copy of the given image.

It is obvious that Eqs (1) and (2) may be applied to any image. In particular, the local contrast at the point $(x, y)$ of the distorted image $\mathbf{V}$ is

$$C_{\mathbf{V}}(x,y) = \frac{V(x,y) - \bar{V}(x,y)}{\bar{V}(x,y)}.$$

Since $V(x,y) = U(x,y) + U_0(x,y)$, then $\bar{V}(x,y) = \bar{U}(x,y) + \bar{U}_0(x,y)$. In the case of smoothed additional luminance of the screen, the following approximation is valid: $\bar{U}_0(x,y) \approx U_0(x,y)$. Therefore,

$$C_{\mathbf{V}}(x,y) \approx \frac{U(x,y) - \bar{U}(x,y)}{\bar{U}(x,y) + U_0(x,y)}.$$

That is,

(3) $$C_{\mathbf{V}}(x,y) \approx C_{\mathbf{U}} \cdot \frac{\bar{U}(x,y)}{\bar{U}(x,y) + U_0(x,y)}.$$

Thus, the additional illumination of the screen *decreases the local contrast value at any point.* The darker is the image region, the more is contrast decreasing (cf. **Figure 1**, A, and B).

## 2.3. Algorithm

We define the similarity of two images, $\mathbf{U}$ and $\mathbf{W}$, as the square of *Euclidean distance* between the corresponding arrays of local contrasts:

$$\rho(\mathbf{U},\mathbf{W}) = \sum\nolimits_{x=0}^{N-1}\sum\nolimits_{y=0}^{M-1}(C_{\mathbf{U}}(x,y) - C_{\mathbf{W}}(x,y))^2.$$

Using the definition of the local contrast (Eq (1)) one may rewrite this expression as

(4) $$\rho(\mathbf{U},\mathbf{W}) = \sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\left(C_{\mathbf{U}}(x,y) - \frac{W(x,y)}{\bar{W}(x,y)} + 1\right)^2$$

It is evident that the *optimal enhanced image* $\mathbf{U}_{\text{opt}}$ is a solution of the following equation:

$$\rho(\mathbf{U},\mathbf{U}_{\text{opt}}) = \min_{\mathbf{W}} \rho(\mathbf{U},\mathbf{W}).$$

The straightforward technique of solving the problem is 'the simple iteration method'. Let one know the *m*-th approximation to the enhanced image,

$$\mathbf{U}_{\text{opt}}^{(m)} = \{U_{\text{opt}}^{(m)}(x,y),\ (x,y) \in \mathbf{R}\}.$$

The first step is calculating the *m*-th average luminance according to Eq (2):

(5) $$\bar{U}_{\text{opt}}^{(m)}(x,y) = \sum_{i,j=-d}^{d} a_{i,j} \cdot U_{\text{opt}}^{(m)}(x-i, y-j),\ (x,y) \in \mathbf{R}.$$

Substituting $\mathbf{U}_{\text{opt}}^{(m)}$ and $\bar{\mathbf{U}}_{\text{opt}}^{(m)}$ into Eq (4) one obtains

$$\rho(\mathbf{U},\mathbf{U}_{\text{opt}}^{(m)}) = \sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\left(C_{\mathbf{U}}(x,y) - \frac{U_{\text{opt}}^{(m)}(x,y)}{\bar{U}_{\text{opt}}^{(m)}(x,y)} + 1\right)^2.$$

The next approximation $\mathbf{U}_{\text{opt}}^{(m+1)}$ should decrease the distance $\rho(\mathbf{U},\mathbf{U}_{\text{opt}}^{(m)})$. It is reasonable to find the approximation as the solution of the following equation:

$$\sum_{x=0}^{N-1}\sum_{y=0}^{M-1}\left(C_{\mathbf{U}}(x,y) - \frac{U_{\text{opt}}^{(m+1)}(x,y)}{\bar{U}_{\text{opt}}^{(m)}(x,y)} + 1\right)^2 = 0.$$

It is evident that the solution is

(6) $$U_{\text{opt}}^{(m+1)}(x,y) = (C_{\mathbf{U}}(x,y) + 1) \cdot \bar{U}_{\text{opt}}^{(m)}(x,y),\ (x,y) \in \mathbf{R}$$

If the conditions $\mathrm{Min} \le U_{\text{opt}}^{(m+1)}(x,y) \le \mathrm{Max}$, where $\mathrm{Min} = U_0(x,y)$, $\mathrm{Max} = \mathrm{Min} + F(255)$, are violated, then it is necessary to replace the calculated value (6) with one of the extreme values:

(7) $$U_{\text{opt}}^{(m+1)}(x,y) = \begin{cases} \mathrm{Min}, & \text{if calculated value less than Min} \\ \mathrm{Max}, & \text{if calculated value more than Max} \end{cases}.$$

As an initial approximation, $\mathbf{U}_{\text{opt}}^{(0)}$, one could use the distorted image $\mathbf{V}$.

After obtaining the final (*n*-th) approximation, $\mathbf{U}_{\text{opt}}^{(n)}$, it is necessary to find the transformed input digital signal

$$\mathbf{c}_{\text{opt}} = \{c_{\text{opt}}(x,y),\ (x,y) \in \mathbf{R}\}.$$

Since $U_{\text{opt}}^{(n)}(x,y) = F(c_{\text{opt}}(x,y)) + U_0(x,y)$, then

(8) $$c_{\text{opt}}(x,y) = F^{-1}(U_{\text{opt}}^{(n)}(x,y) - U_0(x,y)),$$

where the function $F^{-1}(...)$ is the inverse function to the tone characteristic of the monitor. An example of the enhanced image is shown in **Figure 1**, C.

It is evident that without external light video signal $\mathbf{c}_{\text{opt}}$ would produce the image

$$\mathbf{U}^* = \{U_{\text{opt}}^{(n)}(x,y) - U_0(x,y),\ (x,y) \in \mathbf{R}\}.$$

The local contrast of this image exceeds the original one at any point (see **Figure 1**, D).

The iteration procedure described by Eqs (5)-(7) converges. However, the convergence is rather slow. Nevertheless, it is possible to obtain considerable enhancement of the displayed image after a reasonable number of iterations. The further improving of the similarity by means of increasing the iteration number is not often noticed by observers.

Some results of the algorithm application to the real pictures are presented in the next section.

## 3. EXPERIMENT

As it follows from the theoretical analysis presented in Section 2, to apply the proposed algorithm for contrast enhancement under conditions of the external illumination, one has to know: (i) the tone characteristic of the monitor, $F(\dots)$, and (ii) the level of the equivalent luminance $U_0(x, y)$ produced by the external illumination of the screen surface.

### 3.1. Monitor Tone Characteristic

Description of the tone characteristic might be presented in the form of the tables containing screen luminance values for all values (0-255) of the input digital video signal. Such tables should be created for all the monitor settings selected by the user. Instead of the tables, one could use appropriate mathematical formulas.

The tone characteristic of the LCD monitor ACER AL1751W used in our experiments was based on the measurements of the screen luminance for the discrete signal values separated by 10 units. In the course of measurements, it is not rational to use smaller intervals since the luminance increments/decrements will be too small. However, for the purposes of signal processing it is necessary to know luminance for each input signal value. Taking into account natural assumption about a good smoothness of monitor tone characteristic, it is reasonable to use some kind of interpolation instead of measurements of the luminance values for each of 256 input values. In our study, the simplest cubic spline interpolation technique was implemented.

### 3.2. Equivalent Luminance Produced by the External Illumination

In order to evaluate the effect of the external illumination on the perceived luminance of the monitor screen, it was divided into two equal parts and one of them was *uniformly* illuminated by the external source. Thus, the luminance of one part was determined solely by input video signal while the luminance of the adjacent second part was determined both by the input signal and the external illumination. The physical luminance of the screen was varied by varying input signals designed to both parts of the screen and the level of the external illumination. Since the optical density of the liquid crystal elements depend on input signal, a priori, one could not exclude the possibility that, in the LCD monitor, the effect of illumination would be dependent on the screen luminance.

The task of the subject was to make the two screen parts visually identical in perceived luminance by controlling the input signal to the screen part that was not illuminated. The results were presented as the relationship between the two input signals. Comparing these data with corresponding tone characteristic, one could estimate the equivalent constant luminance added to the own screen luminance due to certain external illumination. Since the details of the physical measurements have no direct relation to the subject matter of the conference, they are omitted here.

The experiments with luminance matching made us sure that the equivalent luminance due to an external illumination was not dependent on the own luminance of the LCD monitors. In other words, in order to find the equivalent luminance caused by a given external illumination, it is really enough to determine the input signal value $c_e$ that provides the screen luminance equal to the luminance caused by the external illumination alone (i. e. when the input signal value applied to the illuminated part is equal to 0).The value of the equivalent luminance $U_0$ that has to be used in calculation of contrast (see Section I) should be $U_0 = F(c_e)$

### 3.3. Application of the Algorithm to Real Pictures

The algorithm described by Eqs (5) - (8) was applied to some real pictures. The additional luminance, $U_0(x, y)$ , was set equaled to 100 cd/m$^2$ at every screen point. It corresponds to ca. 5000 lx of the screen external illumination. The normalized weight coefficients in Eq (2) were chosen as follows:

$$a_{i,j} = a(i) \cdot a(j),\ \ i, j = -2, \dots 2;\ \ a(0) = 6/16,$$

$$a(-1) = a(1) = 4/16,\ \ a(-2) = a(2) = 1/16.$$

The luminance of the original pictures was converted to the range [2..275] cd/m$^2$ so that the luminance of distorted pictures belong to the range [102..375] cd/m$^2$. For the used monitor ACER AL1751W with selected brightness/contrast settings these ranges correspond to the video signal ranges [0..223] and [145..255].

In **Figure 1,** A**,** one of the original images, “Cupola” (512x635 pixels, http://www.photoforum.ru/photo/315333, author: Alexander Kolesnikov), is depicted. The image in **Figure 1,** B is faded due to the external light. The image enhanced by two iterations is shown in **Figure 1**, C. One could see that many details of the original which had disappeared from the faded image reappeared again after the enhancement (pay attention to the dark areas). The last image (**Figure 1,** D) is reproduced by means of the transformed video signal $\mathbf{c}_{opt}$ defined by Eq.(8) in the absence of the external light, and looks as somewhat over-enhanced.

### 3.4. Quantitative Estimation of Image Fading and Image Enhancement

The external illumination inevitably leads to some narrowing the range of the local contrast values since all of them decreases in the absolute magnitude (see Eq.(3)). On the other hand, application of any effective algorithm for image enhancement should automatically increase the contrast range of the image.

Taking this into account, we propose to estimate image fading/enhancement in parallel with image processing. As a measure of the image contrast range we propose to use the standard deviation of the local contrast values. **Figure 2** illustrates this approach. It contains 3 histograms of contrast values obtained for the images shown in **Figure** 1, A, B, C. The overall range of the contrast values [-1, 1] is divided in bins of 0.02 width and the percentages of the values in each bin are calculated. For each histogram corresponding peak value (the zero bin percentage) and the local contrast standard deviation are indicated. A significant narrowing of the contrast distribution due to the external illumination and its essential widening due to processing the video signal for image enhancement are well expressed.

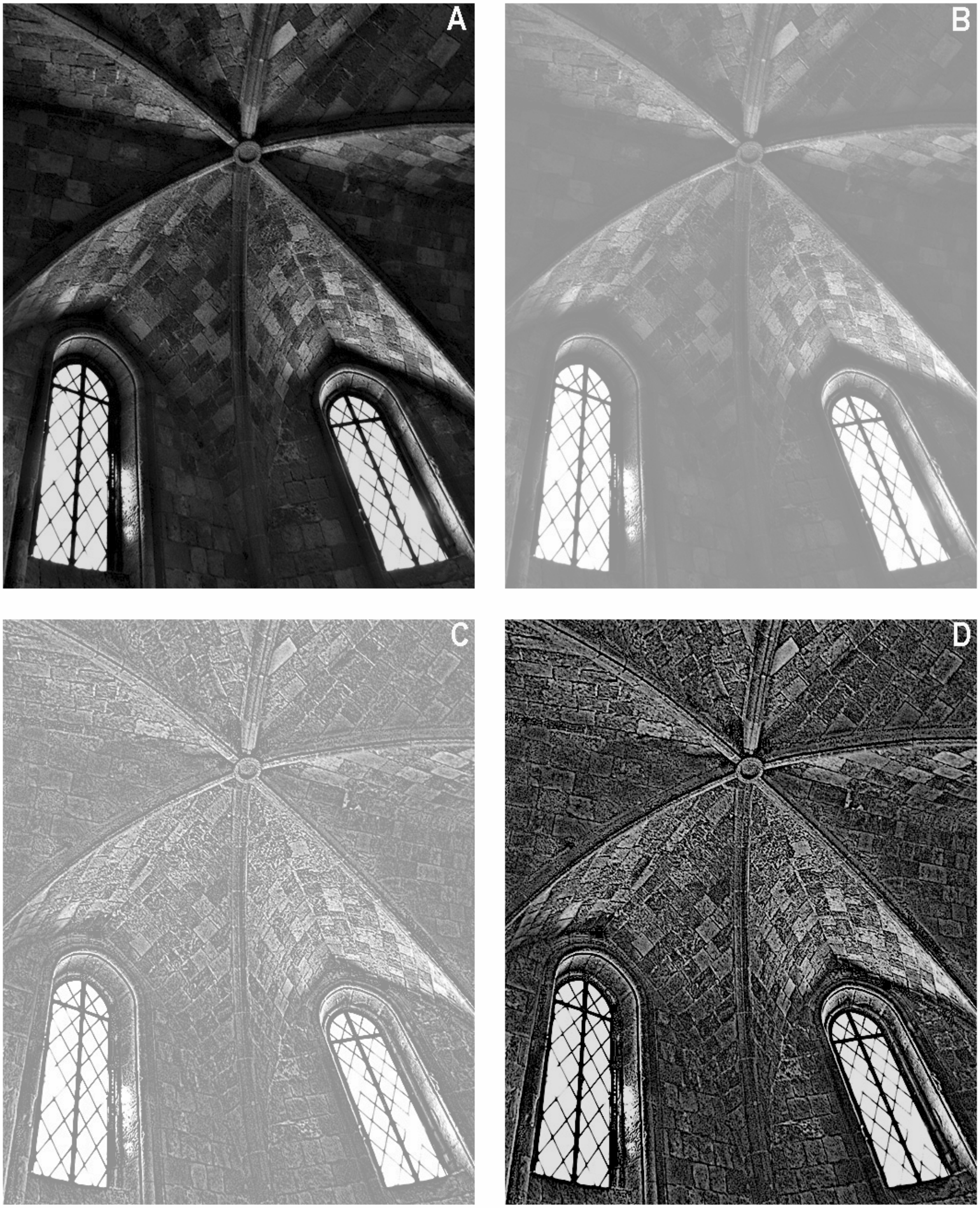


**Figure 1:** Result of the local contrast enhancement of a real image. A – Original image "CUPOLA" (512 x 635 pixels); B – the image distorted by external illumination; C, D - the enhanced images *with* (C) and *without* (D) external illumination.

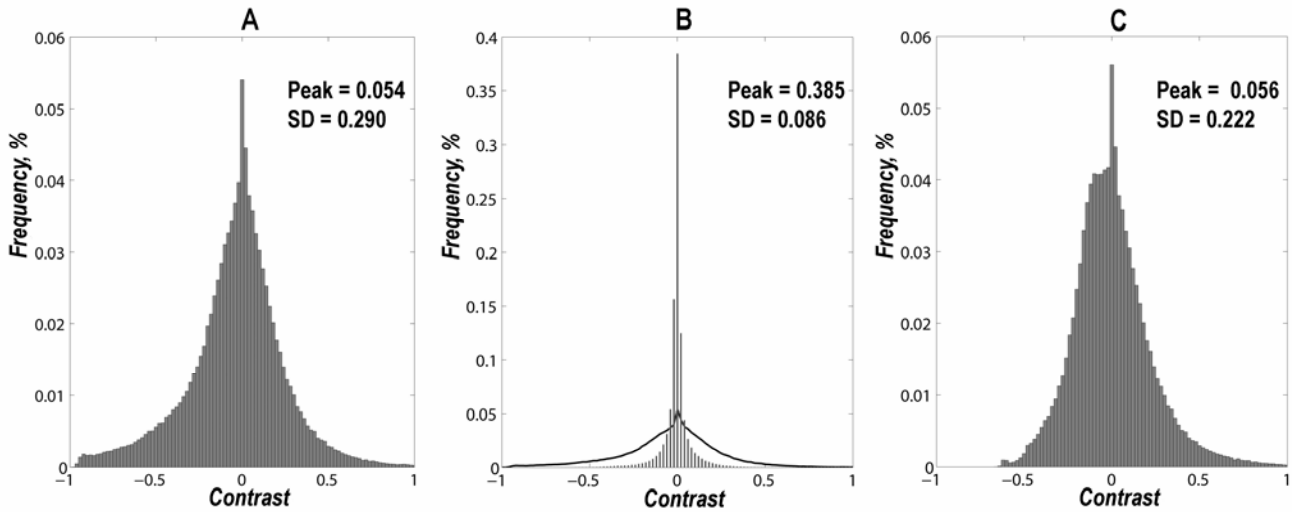


**Figure 2:** The histograms of the local contrast values. A – for the original image; B – for the image distorted by external illumination (the black line is the histogram A envelope curve); C – for the enhanced image with external illumination.

## 4. CONCLUSIONS

An effective method of image improvement has been proposed for a partial case when a low quality of displayed images is caused by intensive ambient illumination of a screen.

The method is based on restoration of the local contrast values and implies a transformation of the original video signal depending on the monitor tone characteristic and the level of the external illumination. However, the method is rather robust and does not require knowing of the precise values of these parameters.

The proposed approach to restoration of the local contrast values may find wide application for enhancing variety images of different types (including X-rays, infrared and so on).

The investigation has been carried out in the framework of the Research and Development Agreement (2004) between Institute for Information Transmission Problems RAS and Samsung Electronics Co. Ltd.

Our patent application to US, **Method of, and Apparatus for Image Enhancement Taking Ambient Illuminance Into Account,** was accepted 2006.02.15. Application number: 20060187242.

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