Illumination Insensitive Reconstraction and Pattern Recognition Using Spectral Manipulation and K-Factor Spatial Transforming

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Abstract: Image recognition under various changing illumination conditions is an important problem being frequently addressed. The paper presents a new approach based upon combination between spectral manipulation called the HSV and spatial transformation called the K-factor that is applied over the HSV components. Such manipulation allows composing image which is both insensitive to illumination and contains the significant spatial details of the original pattern. A useful application of this algorithm can be applied to pattern recognition problems under variable illumination. Numerical simulations as well as experimental results demonstrate the capability of the proposed algorithm to obtain reduced sensitivity to illumination variations and to increase probability of detection while maintaining the same level of false alarm rate.

Keywords: Pattern recognition, illumination invariance, color image processing.

1. INTRODUCTION

Change detection is a process of identifying the variations versus time. The most common applications using change detection algorithmic are related to surveillance, remote sensing, interactive gaming etc. Recent patents address this topic and propose various image processing decomposition approaches to be used for the shadow removal [1].

The most trivial way of doing change detection is by subtracting the intensities of two sequential video frames. The main disadvantage of such a simplified approach is its sensitivity to noises generated due to registration and illumination variation problems. The important question is how to determine a threshold that will prevent generation of undesired false alarms.

Basically the algorithms dealing with change detection in color images do it by applying two stages. The first stage is aimed to develop insensitivity to changes in illumination and the second one manipulates colors in order to improve the detection performance (probability of detection and false alarm rate).

Several approaches were previously introduced and discussed for illumination invariance (without involving colors) which include finding the ratio between two images with different illumination conditions [2] or performing the shadow extraction based upon the extraction of spatial gradients [3]. The implementation of change detection in colored sensors is not yet commonly used although several approaches from the recent years do exist in the computer vision literature.

Monochrome images are very sensitive to illumination changes since the change in illumination varies the only parameter in the image: its intensity. Jain and Chau [4] have reported on the usage of multi-sensor and statistical data fusion for change detection but they did not explore the relation between the different sensors which is equivalent to the statistical dependence between different colors. Due to the fact that color (albedo) of objects is separable from illumination and from relative orientation of objects (reflectance) there is a hope to distinguish changes arising from scene change (where albedo is changed) and illumination change (where the albedo is constant).

Rosin [5] has investigated the threshold selection process based on spatial distribution of the signal and the noise. Fisher [6] has presented the problem of optimal threshold selection in case of colored images. Such a threshold should be illumination change invariant and benefit from the multi spectral information in order to improve the overall detection performance. Fisher investigated the Euclidean distances in RGB and HSV image representation spaces for several image difference functions.

Since detection of simple changes which is based upon fluctuations in the intensity is subjected to false alarms, features that are more robust and insensitive to changes in the illumination conditions were suggested to be used:

- Pixel ratio [7] is used to detect structural changes by computing the ratio of intensities in two corresponding regions in two images. When intensities ratios are varied inconsistently a structural change in the region is found. This approach is computationally expensive and does not provide

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accurate contour although it is partially illumination insensitive.

- Level lines image representation [8] is a method with high computational complexity stating that the variation in global illumination does not change the geometry of the level lines structure but rather creates or removes some of the lines.
- Moving edge maps [9] is a technique having low computational complexity however limited for detecting a single simultaneously moving object due to the procedure of closing contours.
- Vector difference [10] is an approach based upon local characterization of structures. The approach exhibits low computational complexity but has also low accuracy in detection of object's contours.

Color edge change detection [11] is a procedure having low computational complexity and yet provides relatively good spatial accuracy in detecting real edges in the scenery. It may also deal with several moving objects simultaneously. The difference between the current and a reference colored image is used to detect edges while edge is defined not as only intensity discontinuity but also discontinuity in color. Change in the edges distribution is also used to detect change in the scenery.

The K-factor spatial transformation is a decomposition describing the image as contrast ordered harmonics whose joint product reproduces the original pattern [12]. Decomposition of the K-factor transformation shows that the first order factor harmonic contains mainly the shadow information while the higher orders are the rest of the image.

In this paper we present a new approach based upon applying an HSV color transformation per each one of the pixels in the original image. HSV transformation is widely used in an image correction, manipulation and restoration systems. Recently some patents on these topics were issued [13-15]. We used the fact that the S-saturation component of the color transform is insensitive to illumination conditions, however it does not contain many spatial features of the original image (e.g. as might be seen from its gradient). The V component on the other hand resembles very much the grayscale representation of the image and thus is very sensitive to variation in the illumination.

Thus, basically the algorithm that is proposed in this paper includes applying the K-factor transform over the S and the V components. Then, we take the first order factor from the S (which is insensitive to illumination) and the rest of the factor harmonics from V (which contain the fine spatial details) and compose back the image (monochrome). The obtained result shows that shadowed regions become more brightened than in the original image. Thus, the last stage in the algorithm is to multiply the original image with the composed one. The obtained result is both insensitive to illumination conditions and resembles the original image.

Section 2 presents short background and the illumination change effect on the histogram of the R, G and B spaces. The algorithm and materials are described in section 3. The experimental results are discussed in section 4. Section 5 concludes the paper.

2. THEORETICAL BACKGROUND

K-factor image factorization reduces an image into a finite or infinite set of contrast-ordered images whose joint product reassembles the original image. The K-factor transformation [16] may be described mathematically as follows:

$$I(x,y)=\prod_{n=1}^{N} f_n=\prod_{n=1}^{N}\frac{1+k^n g_n}{1+k^n} \tag{1}$$

while k is a threshold less than 1, f_n are the K-factor harmonics, I is the decomposed image, (x,y) are spatial coordinates and g_n is a binary image computed as:

$$g_n(x,y)=\begin{cases} 1 & \dfrac{I(x,y)}{\prod_{j=1}^{n-1} f_j(x,y)}>\dfrac{1}{1+k^n} \\ 0 & elsewhere \end{cases} \tag{2}$$

$g_1(x,y)$ is determined according to:

$$g_1(x,y)=\begin{cases} 1 & I(x,y)>\dfrac{1}{1+k} \\ 0 & elsewhere \end{cases} \tag{3}$$

N is the number of harmonics. N=8 is sufficient to obtain a reconstruction with negligible residual error.

The HSV transformation is a nonlinear color transform, as defined by A. R. Smith [17] and which is given by Eq. 4 where (R,G,B) are the original image pixel values in the color space, MIN= min(R,G,B), i.e. the minimal value of a given pixel and MAX= max(R,G,B), i.e. the maximal value of a given pixel. H is defined for the values range of $0 \le H \le 2\pi$.

$$H=\begin{cases} undefined & ,if\ MAX=MIN \\ \dfrac{\pi}{3}\cdot\dfrac{G-B}{MAX-MIN}+0 & ,if\ MAX=R\ and\ G\ge B \\ \dfrac{\pi}{3}\cdot\dfrac{G-B}{MAX-MIN}+2\pi & ,if\ MAX=R\ and\ G<B \\ \dfrac{\pi}{3}\cdot\dfrac{B-R}{MAX-MIN}+\dfrac{2}{3}\pi & ,if\ MAX=G \\ \dfrac{\pi}{3}\cdot\dfrac{R-G}{MAX-MIN}+\dfrac{4}{3}\pi & ,if\ MAX=B \end{cases} \tag{4}$$

$$S=\begin{cases} 0 \quad , & if\ MAX=0 \\ 1-\dfrac{MIN}{MAX} \quad , & otherwise \end{cases}$$

$$V=MAX$$

Let us now examine how the illumination change affects the HSV space. The illumination change applied over RGB spaces results in intensity change as (R / I ; G / I; B / I;), where I (I>1) is related to the power of the illumination which scales the gray levels distribution and it is chosen to be uniform for all three RGB components of the color space. At first let us consider the HSV transformation according to the formulation of Eq. 4. Change in illumination causes (MAX; MIN) to be (MAX / I; MIN / I) respectively.

There is no effect of change in the illumination over H and S components of HSV since *I* is canceled in the mathematical division appearing in the expressions for H and S (see Eq. 4). Thus, illumination only affects the expression for the V component. Therefore, S space is preferable over V regarding the illumination sensitivity.

Replacing first K-transform harmonic of V by S decreases the illumination sensitivity of the scene (since S is illumination insensitive).

3. ALGORITHM AND MATERIALS

In the proposed algorithm we use the K-factor transformation as well as the HSV representation to dispose the shadows from an image. The R, G and B components of an image are transformed into H, S and V images. S and V are then decomposed into the K-factor transform. A gray image is recomposed back by applying the inverse K-factor decomposition based upon the first harmonic of the S image and all the other harmonics from the V image. The obtained result is like an inverse filter having re-emphasis of the shadowed regions in the picture. Thus, the result is multiplied by the original image. This multiplication is important also in order to increase the amount of spatial details within the resulted image. Step-by-Step summary of the proposed algorithm appears below (new notations given in brackets):

- Obtain initial color image (Img1).
- Transform Img1 from RGB to HSV coordinates.
- Perform K-factor decomposition for S and V spaces.
- Gray image construction: choose first harmonic from the S space (S1) and all other as V harmonics (V2 to V8).
- Recompose S1 and V2 to V8 into one gray image (G1).
- Optional: Multiply original (reduced to gray level) image by the reconstructed gray image (G1).

This algorithm was tested on a various scenario images. A face phantom was tested with various illumination angles. A real outside scene was shot in different daylight times with changing shadow oblique. Deeper discussion on the test images is presented in Section 4.

4. EXPERIMENTAL RESULTS

Let us now apply the algorithm described in section 2 on images taken under different illumination conditions. Following Matlab simulation we verified the assumption that the S and the H coordinates of the HSV plane are insensitive to changes in illumination conditions. The Matlab definition for the HSV decomposition follows the one presented in Eq. 4.

Fig. (**1**) shows two Gaussian images that differ by their illumination power, which affects the images as an intensity multiplicative factor. Fig. (**1a**, **b**) present the images. Fig. (**1c**, **d**) show the distribution density of the Gaussian pixels of the first and the second image, respectively. One can see that the second distribution is shifted and stretched comparatively to the first one. The illumination change factor that was chosen here for the simulation was 2.

Fig. (**1e**, **f**) are the distributions of the H coordinate of the first and the second image, respectively. One can see that they are similar which means that the H coordinate is illumination insensitive.

Fig. (**1g**, **h**) depict the S coordinate distribution of the HSV space for the two images, respectively. One can see that they are similar which means that the S coordinate is illumination insensitive as well.

Fig. (**1i**, **j**) depict the V coordinate distribution of the HSV space for the two images, respectively. One can see that the second distribution is shifted and stretched in comparison to the first one just as obtained in the RGB distribution.

Our algorithm takes the first K-factor harmonic of S and use the rest of the N-1 (e.g. 7) harmonics of V to compose

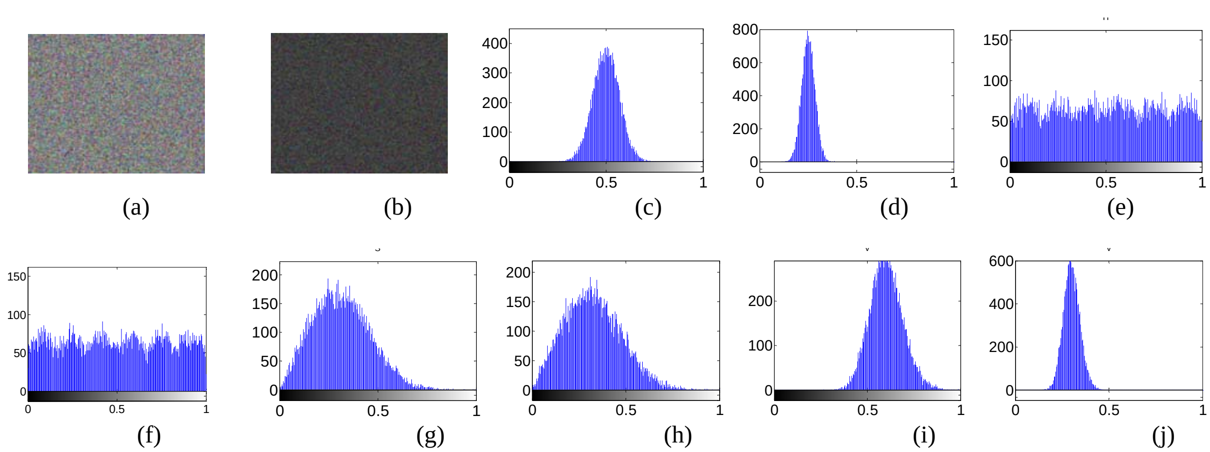


Fig. (1). Two Gaussian images with different illumination factors and their HSV and RGB probability distribution densities: (**a**) Gaussian image, (**b**) Gaussian image, but multiplied by illumination factor change of 0.5. (**c**) Distribution density identical for R,G,B coordinates of the image in (**1a**). (**d**) The same as 1c for the image of 1b. (**e**) Hue (H) distribution of HSV decomposition of the image of (**1a**). (**f**) The same as 1f but for the image of (**1b**). (**g**) Saturation (S) distribution of HSV decomposition of the image of (**1a**). (**h**) The same as 1g but for the image of (**1b**). (**i**) Value (or brightness) distribution of HSV decomposition for the image of (**1a**). (**j**) The same as 1i but obtained from the image of (**1b**).

back the image which is both insensitive to illumination and yet whose gradient resembles the original pattern. In order to enlarge the weight of the first harmonics, in our computations we took this harmonic in a power of 1.8.

Results demonstrating the de-shadowing of faces are depicted in Fig. (**2**). In Fig. (**2a**) shadowed face image is presented. The left part of the face is very dark in comparison to the brightness of the right part.

Fig. (**2b**) presents the image obtained after decomposing according to the K-factor transform, multiplexing the harmonics for the S and the V images and then recomposing back the image. After multiplying it by the original image one may obtain Fig. (**2c**). Since Fig. (**2b**) brightened the shadowed regions of Fig. (**2a**), the result obtained after the multiplication of Fig. (**2c**) is more or less uniformly illuminated image of a face.

To obtain a more quantified estimation, a set of 2 frames was taken (while pictures of Fig. (**3**) were the samples of this frame sequence). The RGB images were converted both to gray and to HSV coordinates while the S coordinate was selected to obtain the illumination invariance using K-transform as discussed before. The first of the K-harmonic of V decomposition was replaced by the first K-harmonic of S-decomposition and then the image was back constructed to obtain gray level image (see Fig. **4**). The computation was performed over the temporal set of 8 original gray images and reconstructed images using the above algorithm (in the meanwhile without applying the final multiplication with the original image). For the discussion we present only two out of the eight images.

Two parameters were compared and analyzed. The first parameter which is denoted by C_1 was the spatially averaged contrast ratio of the target and the background region that surrounds the target in the image:

$$C_1 = \frac{\sum_x \left[I_t(x)\right] - \sum_x \left[I_b(x)\right]}{\sum_x \left[I_b(x)\right]} \tag{5}$$

where x is the spatial coordinate, I_t is the region of the target in the image and I_b is the region that surrounds the target in the image. The second parameter that is denoted as C_2 is the spatially averaged contrast ratio between the enlightened spatial region of a background and shadowed background region in the image:

$$C_2 = \frac{\sum_x \left[I_s(x)\right] - \sum_x \left[I_b(x)\right]}{\sum_x \left[I_b(x)\right]} \tag{6}$$

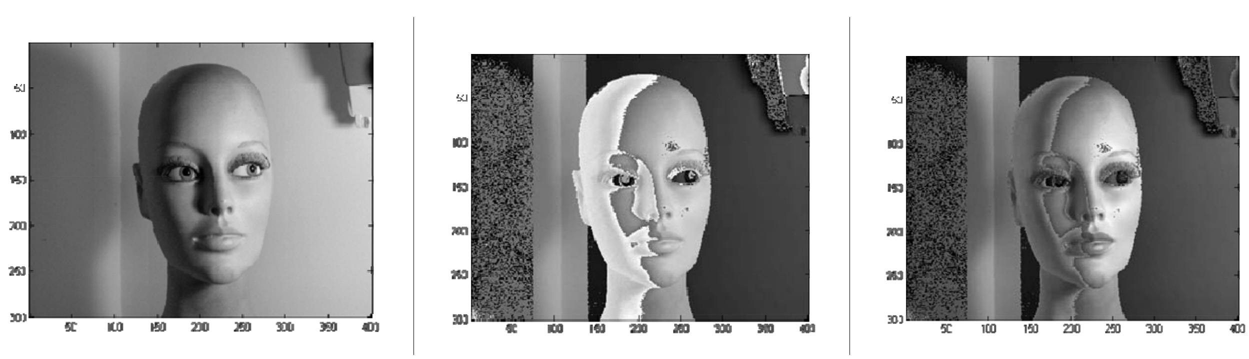
where x is the spatial coordinate, I_s is the enlighten region of the background in the image and I_b is the shadowed region that surrounds the target in the image.

The obtained results were as follows: Regarding the first parameter C_1 the result at the gray image was 0.24 and in the reconstructed image it was 12.1, i.e. **50 times smaller** in the gray image. Regarding the second parameter C_2 the result for the gray image was 0.53 and for the reconstructed images 1.14, i.e. both numbers are of the same order of magnitude. The meaning of those results is that the reconstructed decomposition increases the variation of the contrast by a factor of 50 which means that it increases the probability of detection. The second parameter which was about the same value for the gray and for the reconstructed images means that the constructed decomposition does not vary significantly the background intensity and thus does not change the false alarm rate. The ratio between C_1 and C_2 for the gray image and the reconstructed image, further divided by each other, actually describes the overall improvement of the suggested approach in an integrated sense which combines both false alarm rate and probability of detection. In our example for the first frame the improvement factor:

$$\mu = \frac{C_1^S \times C_2^{gray}}{C_1^{gray} \times C_2^S} \tag{7}$$

was 23.4 where C_1^S and C_2^S correspond to the C_1 and C_2 parameters for the reconstructed image and C_1^{gray} and C_2^{gray} correspond to the C_1 and C_2 parameters for the gray image.

The second frame was not much affected by sun's illumination, thus the background did not vary much, and the result for it is as following: C_1 was 10.0 and 0.11 for the reconstructed and the gray images respectively. C_2 was 0.12 and 0.11 for the reconstructed and the gray images respectively. Therefore, μ equals to 83.3. Table **1** summaries the parameters of these images.



(a) (b) (c)

Fig. (2). (**a**). Gray scale image. (**b**). Applying the algorithm of conversion to HSV coordinates and multiplexing their K-factor transform harmonics. (**c**). Applying the algorithm of conversion to HSV coordinates and multiplexing their shadow harmonics and eventually multiplying the result with the original gray scale image.

If the above algorithm is used with the final stage of multiplication of the reconstructed image by the original gray level image (Fig. **5**), it yields enhanced spatial details in the image; however it reduces the contrast ratio. For example, the μ parameter in this case for the first frame was equal to 17.5.

Table 1. Summary of the Test Images' Statistics

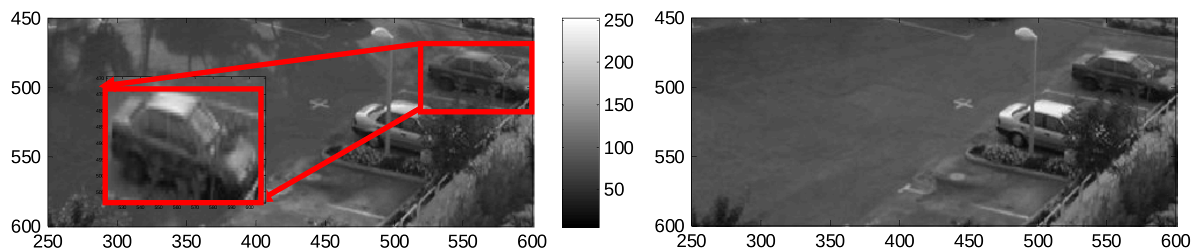
Image/ Param.	1st Initial	1st Reconstructed	2nd Initial	2nd Reconstructed
C_1	0.24	12.1	0.11	10
C_2	0.53	1.14	0.11	0.12
μ	23.4		83.3	

Another test was conducted in order to discover which K-factor transform harmonic of S domain, if inserted instead of K-factor transform harmonic of V domain, has the most significant effect on the C_1 ratio and thus on the probability of detection. The results are shown in Fig. (**6**) where they clearly point out that the first harmonic is the optimal choice. This justifies the choice of this harmonic for the decomposition in our algorithm.

5. CONCLUSION

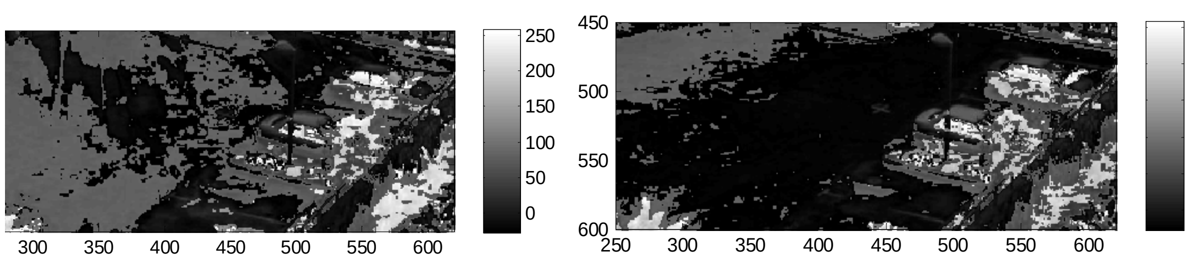
In this paper we have presented a new approach based upon spectral manipulation and K-factor decomposition to construct an illumination insensitive algorithm. In our approach we have shown that the S as well as the H components of the HSV manipulation can be combined using K-transforming to produce illumination insensitive result. Using the K-factor decomposition of the S and the V components we managed to demonstrate significant enhancement of the resulted features in the reconstructed image and yet have it insensitive to changes in the illumination intensity and orientation.

An improvement of more than an order of magnitude was experimentally obtained in pattern recognition (target



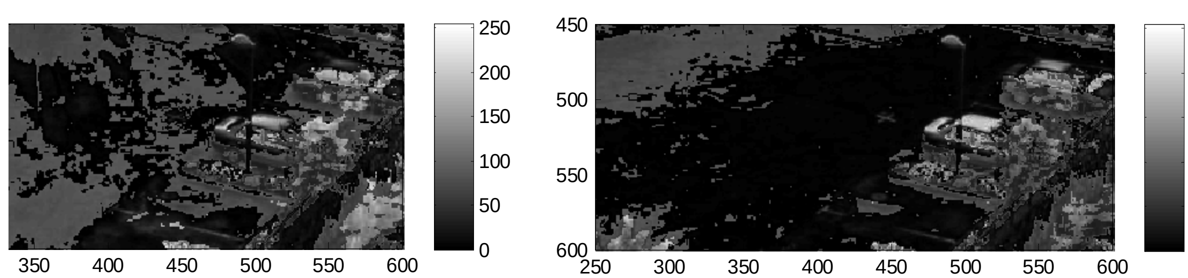
(a) (b)

Fig. (3). Two input images taken in different times along the day. (**a**) A day scene with shadows due to sunlight. The target is zoomed in lower corner of the image. (**b**) Same scene in different time along the day, mostly without shadows.



(a) (b)

Fig. (4). Two input images as shown in Fig. (**3**) after being processed by the proposed algorithm (without applying the final multiplication with the original image). (**a**) A day scene with shadows due to sunlight. (**b**) Same scene in different time along the day, mostly without shadows.



(a) (b)

Fig. (5). Two input images as shown in Fig. (**3**) after being processed by the proposed algorithm and finally being multiplied by the original gray level image. (**a**) A day scene with shadows due to sunlight. (**b**) Same scene in different time along the day, mostly without shadows.

detection) probability while remaining the same level of false alarm rate.

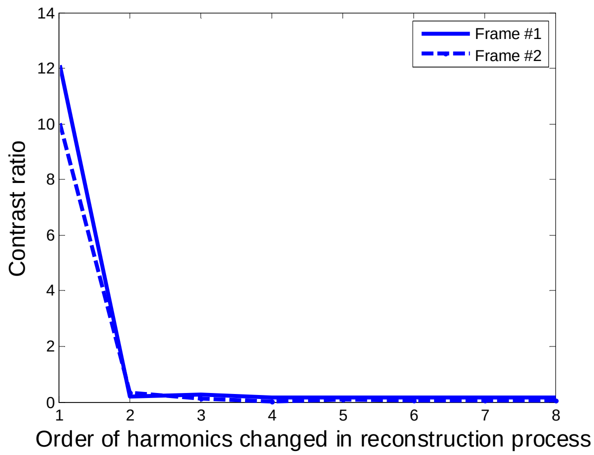


Fig. (6). Contrast ratio of the target and the surrounding background versus the order of the K-factor transform of the S domain used in the algorithm. Frame #1 is given in solid line and Frame #2 is plotted in dotted line.

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