Automatic Detection and Concealment of Specular Reflections for Endoscopic Images

Gevorg Karapetyan
Institute for Informatics and Automation Problems of NAS of RA
Yerevan, Armenia
gevorgka@gmail.com

Hakob Sarukhanyan
Institute for Informatics and Automation Problems of NAS of RA
Yerevan, Armenia
hakop@ipia.sci.am

ABSTRACT

Endoscopic images usually contain specular reflections occurred because of light reflection from distributing light. For many important analysis algorithms the specular reflections may become a source of errors. In this paper we present an approach of automatic detection and concealment of specular reflections from digital images. Our presented method allows fast identification of reflection areas via analyses of lightness histogram of the image fragments. The specular reflections are being segmented based on adoptive threshold for each image fragment. Then we apply efficient predictive concealment algorithm on areas containing the specular reflections. The method has been tested on large set of endoscopic images.

Keywords

Computer vision, image processing, endoscopic images, concealment, specular reflections, medical images

1. INTRODUCTION

Endoscopy is a diagnostic procedure, which lets the physician look inside the human body. The endoscope usually consists of camera attached to thin tube and light source. During the endoscopy procedure the physician can observe the humans inside organs in monitor. Moreover, the video with observing material can be saved for further analysis and processing. Because of frontal light source usually specular reflections occur on surfaces of human organs. The specular reflection is a classification of light reflection from surfaces when the angle of reflection is equal to the angle incidence. The specular reflections are noticeable in images as strong highlighted regions. These reflections are not desirable, since in many visual analysis algorithms they may become a significant source of error [1].

Colonoscopy is a video endoscopy which is used for colorectal cancer screening. One of the main research topics of colonoscopic imaging research is the temporal segmentation and summarization of colonoscopy procedures [2-4]. Segmentation of specular reflections may be very useful in this topic. An example is automatic detection of colorectal polyps (see Fig. 1), which can develop into cancer if they are not detected and removed. The color reflections on polyps may affect the surface texture and may negatively impact on robust detection [5].

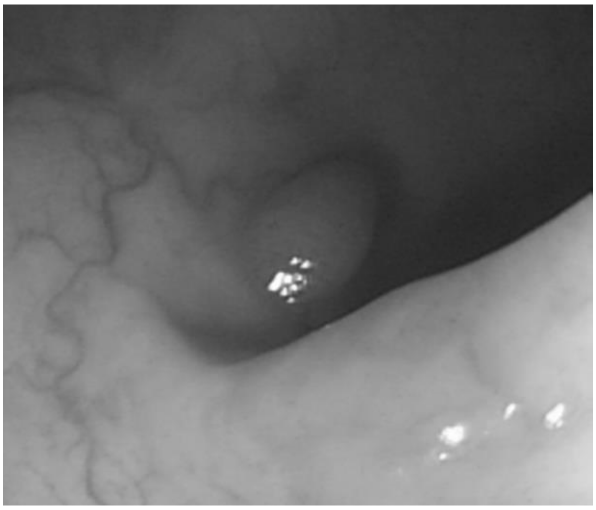


Fig.1 Colonoscopic image showing colonic polyp which has specular reflections on its surface

The paper presents a framework for automatic detection and concealment of specular reflections. The framework consists of two parts. The first is the segmentation of the specular reflections. And the second is the concealment of the regions containing the specular reflections.

The paper is organized as follows: In the section 2 the segmentation and concealment methods of the specular reflections are described. Then in section 3 the results of the experiments are shown. The work is completed in section 4.

2. METHODS

In the existing approaches of segmentation of the specular reflections is widely used the thresholding technique, when the histogram of entire image is analyzed and the image is segmented based on the peak of high intensity pixels [6]. But segmenting entire image with one threshold does not provide an accurate result for wide range of endoscopic images, moreover, if the image contains large amount of light areas (close to white) it is hard to define the threshold value. Our method for segmentation divides the images into windows and then each window analyzes the histogram of the window and defines the areas with rapid intensity change to very high.

For each window an adoptive threshold value is being selected. After segmentation of the specular reflections, the corrupted areas are being concealed via modification of Frequency Selective Extrapolation [7-9] where the size of support area for each missing area is being chosen content aware with respect to the homogeneity of adjacent areas. It is very important that the pixels of not related areas are not participating in estimation of missing area. In sections 2.1 and 2.2 the brief description of segmentation and concealment algorithms is presented.

2.1. Detection of specular reflections

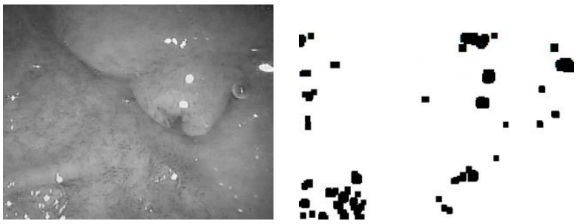
The segmentation of highlighted regions has been done with usage based on analyses of luminance component of image in YUV color space. The conversion from RGB to YUV color space is shown below:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \bullet \begin{bmatrix} R \\ G \\ B \end{bmatrix}.$$

The specular reflection areas have high luminance value in comparison to adjacent areas. For segmenting the specular reflections we use window of 128x128 size. In image area which is in window is being analyzed and if the window contains bright areas, the threshold is being calculated. The window fragment is being analyzed with the help of histogram of the image. Because of specular reflections there is peak in high intensity region. The threshold is being selected in a region where the derivative of the image from right, changes from significant high value to the value near zero.

For each window an adoptive threshold is being used. Thus, the specular reflections are being segmented not with one threshold for entire image which may lead to false positive detections. The adoptive threshold gives higher level of true positive detection of specular reflection regions.

Before applying the concealment algorithm we should generate the binary mask, where the pixels corresponding to specular reflections have 0 values.



(a) (b)

Fig 2. (a) Image with specular reflections, (b) Binary mask of specular reflections

The obtained binary mask images Fig. 2 (b) is used in concealment algorithm for showing the corrupted regions.

2.2. Concealment method

Image concealment is the process of concealing missing data in digital images, via interpolation of the missing pixels using information of the adjacent areas. As a concealment method we have used a modification of powerful Frequency Selective Extrapolation (FSE) Algorithm, where the size of support area is being chosen content aware. The FSE is widely used in applications for concealing transmission errors in digital images and videos. Since the specular reflections have a relatively small size and can be inpainted with the same technique as for block losses.

Fig. 3 shows the part of the endoscopic image which contains specular reflections which should be inpainted via adjacent areas.

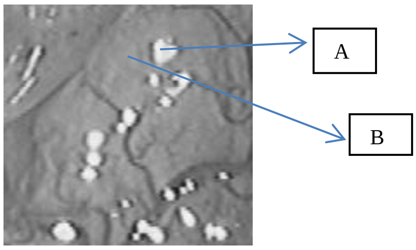


Fig 3. A - Specular reflection which should be concealed with the help of B supporting area.

We choose α area, which is composed of corrupted region A and support areas elements from B. The image in α we denote $f[m,n]$, $m = \{0,..,M\}$, $n = \{0,..,N\}$, where M and N are the width and height of area α. For estimation of corrupted regions the samples in support area B will be approximated by weighted linear combination of two-dimensional DFT basis functions, which are defined over area α. The approximation will be done with the usage of $g[m,n]$ parametric model.

$$g[m,n] = \sum_{(k,l)\epsilon K^v} c_{k,l}\varphi_{k,l}[m,n],$$

where K^v is the set of basis functions, $c_{k,l}$ is the expansion coefficient, $\varphi_{k,l}$ 2D DFT basis function which is defined in entire area α.

We assume that in any iteration v the signal is being approximated by $g^{(v)}[m,\ n]$ parametric model, which is calculated below:

$$g^{(v)}[m,n] = \sum_{(k,l)\epsilon K^v} c_{k,l}^{(v)}\varphi_{k,l}[m,n],$$

where $c_{k,l}^{(v)}$ is the expansion coefficient calculated in iteration v.

The quality of extrapolation is controlled by calculation of the residual error signal in area α, which is calculated by

$$r^{(v)}[m,n] = \left(f[m,n] - g^{(v)}[m,n]\right)w[m,n],$$

where $w[m,\ n]$ is the window function, which is 0 in highlighted area and is 1 in support area.

$$w[m,n] = \begin{cases} 0, (m,n)\epsilon A \\ 1, (m,n)\epsilon B \end{cases}$$

For each iteration $E_B{}^{(v)}$ the error criterion is being calculated

$$E_B{}^{(v)} = \sum_{(m,n)\epsilon\alpha} \left(f[m,n] - g^{(v)}[m,n]\right)^2$$

The iteration stops, when the E drops below pre-defined threshold.

After termination of the iterative process the corrupted pixels in area A of $f[m,\ n]$ are being replaced with the corresponding pixels from $g[m,n]$ parametric model.

The algorithm is working in frequency domain and the algorithm steps are the following:

1) Initially the $g[m,n]$ parametric model is equal to 0.

$$g^{(0)}[m,n] = 0, \forall(m,n) \in \alpha$$

And the residual error is equal to the input signal multiplied with the window function,

$$r^{(0)}[m,n] = f[m,n]w[m,n], \forall(m,n) \in \alpha$$

Since the algorithm works in frequency domain, one DFT is applied on $g^{(0)}[m,n], f[m,n]$ and $r^{(0)}[m,n]$:

$$F[m,n] = DFT(f[m,n]\}$$

$$G^{(v=0)}[m,n] = DFT\{ g^{(v=0)}[m,n]\}$$

$$R^{(v=0)}[m,n] = DFT\{ r^{(v=0)}[m,n]\}$$

2) Calculation of $\Delta E_A{}^{(v+1)}$energy decrease computation, the difference of error criterion between v *and* $(v+1)$ iterations.
3) Selection of (u,v) basis function indices value pair, for which $\Delta E_A{}^{(v+1)}$

$$(\mathrm{u}, \mathrm{v}) = \mathrm{argmax}\, \Delta \mathrm{E_A}{}^{(\mathrm{v}+1)}$$

4) Update of $c_{k,l}^{(v+1)}$ expansion coefficient update
5) Repeat steps 2 – 4 until the $\Delta E_B{}^{(v+1)}$ drops predefined threshold E_{min}=15 or the number of iteration becomes more than max number of iterations. We used max number of iterations 100.
6) After termination apply Invers Discrete Fourier Transform on parametric model:

$$g[m,n] = IDFT\{ G^{(v)}[m,n]\}.$$

Then replace the element from $f[m,n]$ which contain specular reflections with the corresponding elements from $g[m,n]$

$$f[m,n] = g[m,n],\ where\ [m,n] \in A$$

3. EXPERIMENTAL RESULTS

The experiments have been done on the set of endoscopic images. The algorithms described above were implemented on C++ language. As we have mentioned above the first step is the detection and segmentation of heighted regions. We use window of 128x128 for analyzing histogram of the Y component of the image. Then an adoptive threshold is being chosen for each window containing color specular reflections. The average value of the threshold in our experiments is from 190-230 for Y component. After detection of specular reflections areas we use 7x7 size erode for binary mask to make the areas larger. This is done because the highlighted regions usually contain dark circles or color artifacts. The concealment of enlarged areas which include the color artifacts is more accurate. The size of erode has been chosen based on our experiments, but if the color artifacts have large sizes even after enlargement they may negatively impact on the concealment result.

Then, after obtaining the binary mask for each region containing specular reflections the modification of frequency selective extrapolation algorithm is applied. In FSE algorithm the block size is 16x16 px. The neighbor area has been from 3 to 16 px for each direction. The size is changed based on homogeneity of adjacent pixels. The size of FFT matrix is 64. Maximum interactions count per block is 100.

Fig.4 shows an endoscopic image which contains specular reflections. We can the see isolated and grouped reflection areas.

Fig.4. Endoscopic image with specular reflections

Fig. 5 shows the image after applying the proposed method. We can see that almost all the reflections have been detected and concealed. Only small areas in left corner which have low brightness level have not been detected.

Fig.5. Endoscopic image where specular reflection areas are concealed with proposed method.

The results shown below show that modification FSE algorithm can be applied for concealing specular reflections in endoscopic images and provide competitive results.

4. CONCLUSION

The method described above provides good results in automatic detection and concealment of specular reflections in endoscopic images. But the large size of corrupted area can be the cause of not accurate concealment, where the structure of tissue of the inside organ will be damaged, moreover, sometimes even after enlarging the specular reflection regions in binary mask, the color artifacts may be cause of erroneous concealment. The color artifacts may lead to change of the color of tissue after concealment. The tissue with different color may be wrongly understood as disease. Taking into account issues shown above the research continues for improving the algorithm.

The future work will include improvement of the reflection detection algorithm as well as we will try to apply this method on video sequence of using data from the adjacent frames in concealment procedure.

5. ACKNOWLEDGEMENT

Gevorg Karapetyan would like to thank the State Committee of Science of Armenia for supporting this work.

REFERENCES

[1] F. Vogt, D. Paulus, B. Heigl et al., "Making the invisible visible: highlight substitution by color light fields," in *Proceedings of the 1st European Conference on Colour in Graphics, Imaging, and Vision (CGIV '02)*, pp. 352–357, April 2002.

[2]Y. Cao, W. Tavanapong, K. Kim, J. Wong, J. Oh, and P. C. de Groen, "A framework for parsing colonoscopy videos for semantic units," in *Proceedings of the IEEE International Conference on Multimedia and Expo (ICME '04)*, vol. 3, pp. 1879–1882, June 2004.

[3] J. Oh, M. A. Rajbal, J. K. Muthukudage, W. Tavanapong, J. Wong, and P. C. de Groen, "Real-time phase boundary detection in colonoscopy videos," in *Proceedings of the 6th International Symposium on Image and Signal Processing and Analysis (ISPA '09)*, pp. 724–729, September 2009.

[4] D. Liu, Y. Cao, W. Tavanapong, J. Wong, J. Oh, and P. C. de Groen, "Mining colonoscopy videos to measure quality of colonoscopic procedures," in *Proceedings of the 5th IASTED International Conference on Biomedical Engineering (BioMED '07)*, pp. 409–414, February 2007.

[5] Mirko Arnold, Anarta Ghosh, Stefan Ameling, and Gerard Lacey, "Automatic Segmentation and Concealment of Specular Highlights for Endoscopic Imaging", EURASIP Journal on Image and Video Processing, pp. 0-12, December 2010

[6] T. Stehle, "Removal of Specular Reflections in Endoscopic Images ", Acta Polytechnica, Vol. 46, pp. 33-36, 2006.

[7] Kaup, A., Meisinger, K., Aach, T.: "Frequency Selective Signal Extrapolation with Applications to Error Concealment n Image Communications", *International Journal of Electronic Communication* (AE), Vol. 59, p. 147–156, 2005.

[8] G. Karapetyan, "Modification of FSE method based on coefficients of homogeneity", Mathematical Problems of Computer Science 35, pp. 109--115, 2011.

[9] G. Karapetyan, H. Sarukhanyan, "*On a Modification of the Frequency Selective Extrapolation Method*" Information Models and Analyses Vol.2 pp.139-145, 2012