

Wireless Capsule Endoscopy Video Enhancement using Modified Adaptive Gamma Correction Method

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Abstract

Wireless Capsule Endoscopy (WCE) has been widely used to diagnose the issues generated from the human Gastro Intestinal (GI) system. The following issues are occurred in small bowel such as bleeding, ulcer and tumor. Normally, the quality of video frame captured by WCE has been degraded due to non uniform luminance and inadequate illumination in the GI tract. During the diagnostic process of tumor subjects significant details like texture present in GI tract have been used. So far natural statistics of the WCE frames have not been preserved by the primitive form of Adaptive Gamma Correction (AGC). Hence in this article a modification in AGC has been proposed to preserve the originality of the frame. An arbitrary value $\alpha = 0.5$ have been used in order to hold the multiple WCE frames for analysis. The WCE frames have been enhanced using MAGC. It has also been compared with the WCE frames enhanced with Global Histogram Equalization (GHE), Contrast Limited adaptive Histogram Equalization (CLAHE), AGC and anisotropic diffusion for better visibility and quality. Gamma correction and algorithm design have been simulated using Matlab 2015a[®].

Keywords-Wireless Capsule Endoscopy (WCE), Luminance, Adaptive gamma correction (AGC), Global Histogram Equalization (GHE), anisotropic diffusion, Transformed intensity.

I. Introduction

Wireless Capsule Endoscopy (WCE) is an imaging technique meant for the examination of the midway regions of the GI tract, especially the small bowel, which are beyond the access of the conventional endoscopy and colonoscopy. Perhaps, this may be the only technique which can directly visualize the internal walls of the small bowel. In WCE, the subject is allowed to swallow a pillcam which continuously transmits images of the internal walls of the GI tract to the external receiver, during its passage through the tract. Inadequate illumination in the GI tract adversely affects the quality and visibility of WCE. The resolution of WCE is constrained by the channel bandwidth allotted for Medical Implant Communication Service (MICS) band, which is only 300 kHz [1]. Many image processing techniques [2-11] have been

employed to enhance the quality of WCE off-line to assist the manual and computer aided diagnosis.

A locally adaptive gamma correction to compensate the non-uniform illumination in WCE frames was developed in Alizadeh *et al.* [2]. A combination of geometric mean filter and gamma correction was adopted in Suman *et al.* [3] to enhance the quality of the WCE. Ramaraj *et al.* [4] investigated the Discrete Fourier Transform (DFT) and Discrete Wavelet Transform (DWT) based homomorphic filtering, in contrast space, to enhance the WCE. The Spectral Optimal Contrast-Tone Mapping (SOCTM) described in literature [5], for the enhancement of WCE is an extension of the Optimal Contrast-Tone Mapping (OCTM). In SOCTM, WCE image in Red Green Blue (RGB) space was transformed into Luminance and a and b color space and OCTM was applied on the intensity channel alone. Gaussian filter was employed in Shahril *et al.* [6] to smooth the WCE.

A tensor based anisotropic diffusion was described in B. Li and M.Q.H. Meng [7]. B. Li and M.Q.H. Meng [8-9] employed contrast driven forward and backward anisotropic diffusion to enhance the capsule endoscopy images. An adaptive contrast anisotropic diffusion which adjusts the scale space parameter locally, according to a Local Detail Descriptor (LDD) was put forth in Li *et al.* [10]. The Hessian matrix was used to represent the local contrast information in literature [8] and literature [10], whereas literature [7] employed Diffusion Tensor (DT). Based on the eigen values of the Hessian matrix of WCE image, the scale space parameter was adaptively chosen in the 'adaptive contrast diffusion' was described in B. Li and MQH. Meng [11]. A Fuzzy logic – based image enhancement method has been developed by Hanmandlu. M *et al.* [12] based on fuzzifying the color intensity property of the image. Hanmandhu. M *et al.* [13] suggested a Fuzzy based enhancement method where images are classified into underexposed and overexposed regions. Gaussian Median Filter (MF) was used for the fuzzification in underexposed region and Traingular MF for overexposed region. This method gave better results as compared with Genetic algorithm based and entropy based approaches. Naik.S *et al.* [14] suggested a grey scale image enhancement method to color images without encountering gamut problem. Pitas.I *et al.* [15] devised a multi channel methods for color image enhancement.

Anisotropic Diffusion Filter [7 &10-11] is basically an edge preserving restoration technique. Forward and Backward diffusion [9-10] does restoration and edge enhancement together. But the reason for poor image quality in WCE is low and non-uniform illumination and low contrast, rather than the presence of noise. WCE frames furnished in Fig. 1: make it justified that frames are devoid of inhomogeneous and noisy pixel intensity transitions in the homogenous regions. Diffusion blurs the image beyond tolerable limits if the number of iterations is not judiciously chosen, even if the threshold of gradient modulus is adaptively computed. Varying the threshold of gradient modulus locally is not appreciable as it significantly alters the intensity, textural and geometric features of the frame. R, G and B channels cumulatively decide the colour composition. Investigations on natural images [12-13] reveal that enhancing these channels individually hampers the natural colour composition of the WCE frames and produce colour artefacts.

Smoothing degrade the visibility of structures in the WCE frames and hinders fine texture on the GI tract wall. Enhancing the RGB channels separately, hinders the natural colour composition of the WCE frames and induce colour artefacts. This article proposes a modification in the adaptive gamma correction method. It helps to effectively correct the non-uniform luminance on the WCE frames. The MAGC is employed on the 'Value' component in Hue Saturation Value (HSV) space, preserving the hue and saturation to keep the original colour composition intact. In MAGC, to incorporate the merits of the histogram specification into the adaptive gamma correction, a weighting function is employed on the discrete probability density values, before computing the Cumulative Probability Density (CPD) function. The method of modifying the transformation curve in AGC is detailed in the immediately following section. The effectiveness of the MAGC is evaluated by comparing the WCE frames enhanced with MAGC with the frames enhanced with GHE, CLAHE, AGC and anisotropic diffusion filter, in section 3.



Fig. 1: WCE frames

II. Methodology

The WCE is of make Given Imaging Ltd and model number is Pillcam SB2 has been used for the acquisition of images. The WCE videos segments are of MPEG RGB24 format with frame rate 25 frames/second, comprising typically 450-550 frames. The specimens belong to sub-mucosal tumors, Ulcer, normal etc.

As enhancement in RGB space is not appreciable, the WCE frame is transformed into HSV model. In HSV colour model, the achromatic as well as chromatic information of the original WCE frame get decomposed into three component

spaces, hue (H), saturation (S) and value (V). Wherein, hue and value account for colour and luminance, respectively. Even a small change in hue causes significant influence on the colour of the WCE frame. Perhaps, this may degrade the quality of the frame. Visual artefacts may be induced if the continuous variation of the saturation is disturbed during enhancement. Simultaneously enhancing both luminance and saturation may produce unnatural colour. Following the intuitions from the experiments [14-16] conducted on natural images in HSV space, for enhancing the contrast of WCE frame; only value is enhanced, preserving saturation and hue. The hue and saturation components are preserved to keep the original colour composition intact. The overall block schematic of the enhancement procedure is shown in Fig.2. Decomposed H, S and V components of an RGB WCE frame are furnished in Fig. 3 a-Fig. 3 c.

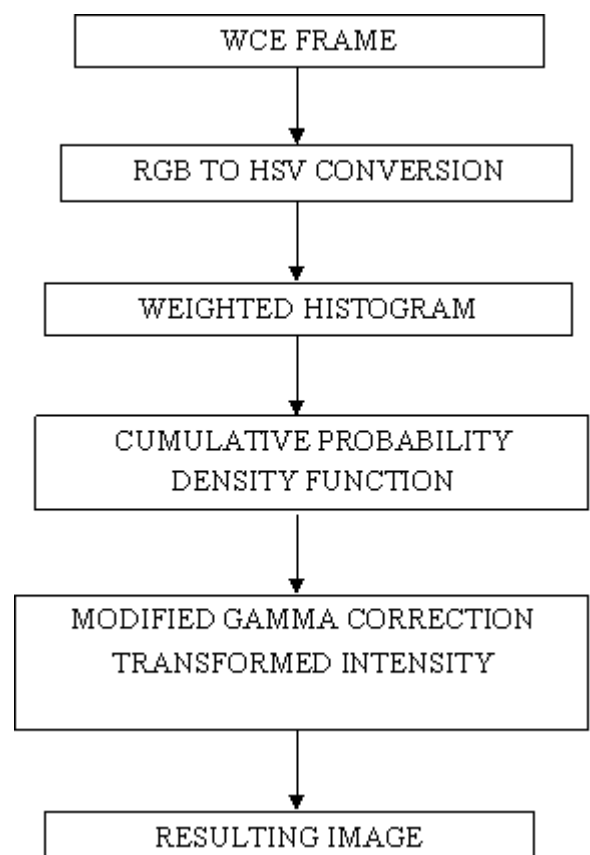


Fig.2. Block schematic of enhancement procedure

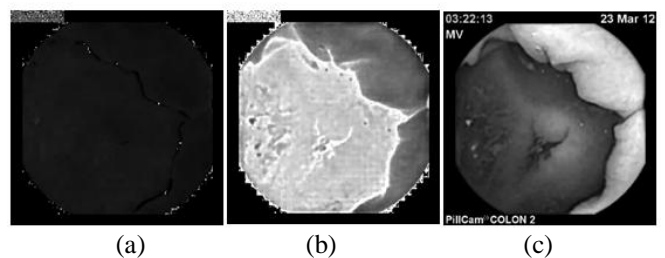


Fig.3. HSV WCE frame decomposed into 'H', 'S' and 'V' components (a) Hue (b) saturation (c) Value

Generally, gamma transformation is meant to selectively stretch the contrast in the low and high intensity regions in the image. In gamma transformation, the transformed intensity is represented in Eq. (1),

$$T(k) = k_{\max} \left(\frac{k}{k_{\max}} \right)^\gamma \quad (1)$$

where, 'k' is the original intensity and 'k_{max}' is the maximum intensity, present in the original image. For $\gamma < 1$, the contrast in the low intensity or dark region get stretched and high intensity region get compressed. The effect is vice versa for $\gamma > 1$. In WCE, the reason for poor frame quality is the low illumination in the GI tract and non-uniform luminance of different regions in the frame. Hence, for WCE frames, 'γ' value less than unity are appreciable to enhance contrast in the darker regions of WCE frames. The primitive form of AGC in Eq. (1) does not have the capability to preserve the natural statistics of the original image. Therefore, to preserve the natural histogram statistics of the WCE frames, the transformation in Eq. (1) is modified in Eq.(2) as,

$$T(k) = k_{\max} \left(\frac{k}{k_{\max}} \right)^{1-C(k)} \quad (2)$$

where, 'C(k)' is the Cumulative Probability Density Function (CDF) of the intensity, 'k', given by Eq.(3) & Eq.(4),

$$C(k) = \sum_{i=0}^k P(i) \quad (3)$$

and,

$$\sum_{k=0}^{k_{\max}} C(k) = 1 \quad (4)$$

The discrete probability density of the intensity, 'k' is described in Eq. (5),

$$P(k) = \frac{n_k}{MN} \quad (5)$$

where, 'n_k' is the number of occurrence of the intensity, 'k' and M*N is the total number of pixels in the frame. To incorporate the merits of the histogram specification into the adaptive gamma correction, a weighting function is employed on the discrete probability density values, before computing the cumulative probability density function. The weighted histogram,

$$P_w(k) = P_{\max} \left(\frac{P(k) - P_{\min}}{P_{\max} - P_{\min}} \right)^\alpha \quad (6)$$

where, 'α' is an arbitrary parameter which determines the shape of the CDF and thereby, the shape of the transformation function. P_{max} and P_{min} are the maximum and minimum values of the probability density functions in the statistical histogram. In the Modified Adaptive Gamma Correction, the CDF is computed from the normalized weighted histogram in Eq. (6) as,

$$C_w(k) = \sum_{i=0}^k \frac{P_w(i)}{\sum_{i=0}^{k_{\max}} P_w(i)} \quad (7)$$

In contrast to AGC in MAGC, the enhanced intensity is computed from the modified CPD in Eq. (7) as,

$$T(k) = k_{\max} \left(\frac{k}{k_{\max}} \right)^{1-C_w(k)} \quad (8)$$

where T(k) in Eq.(8) shows the enhanced intensity of MAGC.

III. Results and Discussions

To evaluate the performance of the modified adaptive gamma correction, the enhanced WCE frames with MAGC have been compared qualitatively with the frames enhanced with AGC, CLAHE, GHE and anisotropic diffusion.

Both AGC and MAGC make use of the CPD of the original WCE frame. The adaptive gamma correction uses the original CPD without modifying it, different from the modified adaptive gamma correction. Cumulative Probability Density of the original WCE frame in Fig.6. (a) is illustrated in Fig.4. In adaptive gamma correction there is no flexibility for the user to modify the CDF and to define the shape of the desired transformation curve. In contrast to adaptive gamma correction, the modified adaptive gamma correction offers the freedom to the user to define the desired shape of the transformation curve by simply varying the arbitrary parameter, 'α' in Eq. (6). The shape of the CPD for different values of 'α' is depicted in Fig. 6. When α value is close to unity, the CPD tends to be linear and the transformation curve become an exponentially increasing smooth curve. So that the transformation curve (Fig.7.) resembles the transformation curve of an ideal adaptive gamma correction furnished in Fig.5. At lower values of α, the modified adaptive transformation preserve the histogram statistics of the original frame. The WCE frame enhanced by the modified adaptive gamma correction with different values of α is furnished in Fig.8. (a) to Fig.8. (d). The fine textures on the GI tract wall and features of the original WCE frame is preserved better in Fig.8. (c) and Fig.7. (d) i.e. for α=0.1 and α=0.5 than when α=1, in Fig.8. (b). The best selection of 'α' should allow the tradeoff between degree of enhancement and the preservation of fine texture on the GI tract wall and frame features. Original and enhanced WCE frames in Fig.9. (a) and Fig.9. (b), respectively, justifies that an arbitrary value of 'α' equal to 0.5 holds equally good for multiple WCE frames.

WCE frame enhanced with adaptive gamma correction in fig. 10 (a) has appreciable visual quality better than the frame enhanced with CLAHE (Fig.10. (b)), GHE (Fig.10. (c)), and anisotropic diffusion (Fig.11. (a)-Fig.11. (e)). But, when compared to the WCE frames enhanced with modified adaptive gamma correction, the fine details are not preserved to the extent possible with the MAGC.

The parameter setting of CLAHE is as; clip-limit equal to 0.01, histogram specification of the tile-'Uniform', dynamic range of the enhanced image: 0-255, number of histogram bins equal to 256, tile size as 8*8 and the distribution parameter as 0.4 (both for Rayleigh and uniform). From the WCE frame enhanced with CLAHE, furnished in Fig.10. (b), it can be noticed that the natural texture of the original frame get completely disturbed during enhancement. In CLAHE, the neighboring tiles after enhancement are combined using bilinear interpolation to eliminate artificially induced boundaries. But the enhanced WCE frame with CLAHE in Fig.10. (b) shows that fine textures in the frame get over-enhanced and deteriorate the visual quality of the frame. In the WCE frame enhanced with GHE, (fig. 10 (c)), it can be observed that at the boundaries, spurious artefacts and distortions are introduced.

The WCE frame processed with anisotropic diffusion with different values of number of iterations and threshold of

gradient modulus are furnished Fig.11. (a) to Fig.11. (d). The WCE frames in Fig.11. (d) and Fig.11. (e), diffused with equal number of iterations, but with different values of threshold of gradient modulus, do not differ much in visual appearance. The threshold of gradient modulus does not have as much influence as the number of iterations on the quality of the diffused WCE frame. When the number of iterations is more, the WCE frames become significantly over-blurred as seen in Fig.11. (a) to Fig.11. (c). It is conclusive that regardless of the parameter setting, anisotropic diffusion significantly removes fine textures and edges in the WCE frame. Anisotropic diffusion filter is not capable of enhancing the region-wise contrast.

It is evident from the above observations that the MAGC provides better visual quality than the CLAHE, Anisotropic diffusion, AGC and GHE. The unfavorable artifacts have been avoided by using the weighting function in MAGC.

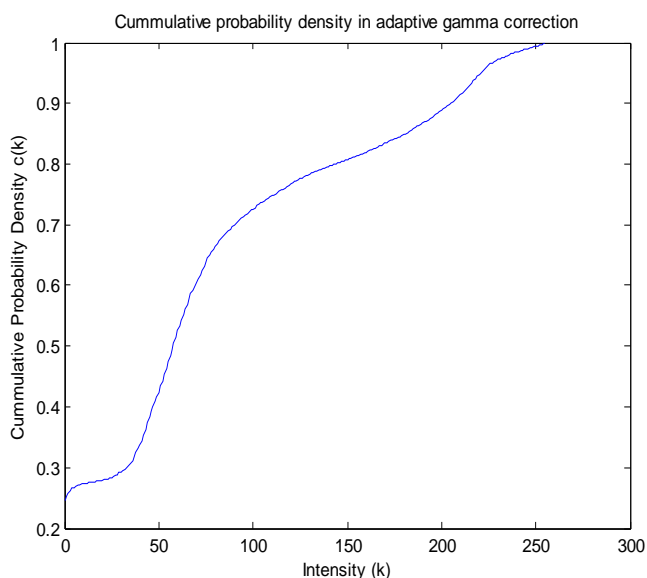


Fig.4. Cumulative probability density curve for adaptive gamma correction

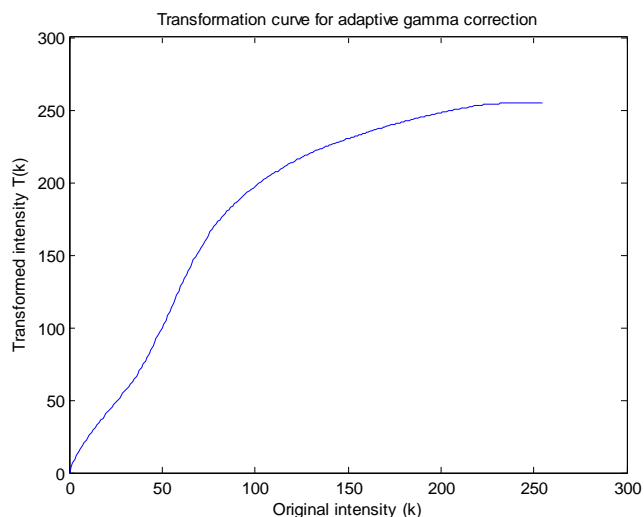


Fig.5. Transformation curve for adaptive gamma correction

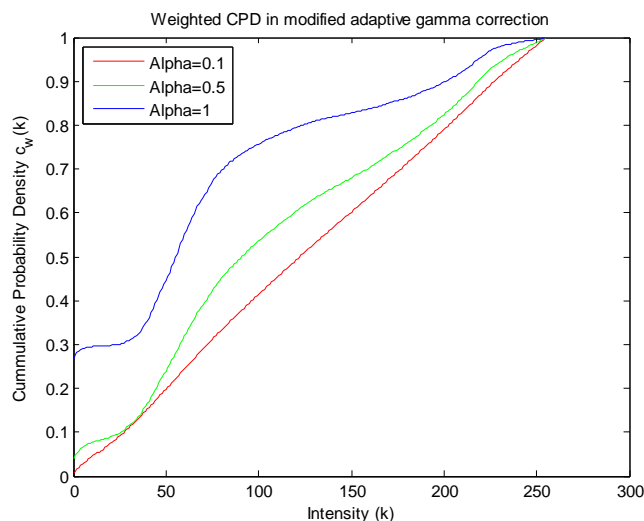


Fig.6. Cumulative probability density curve for modified adaptive gamma correction for different values of alpha

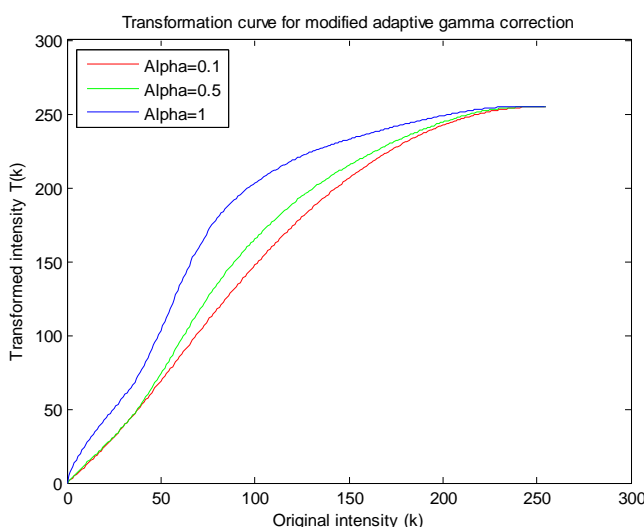
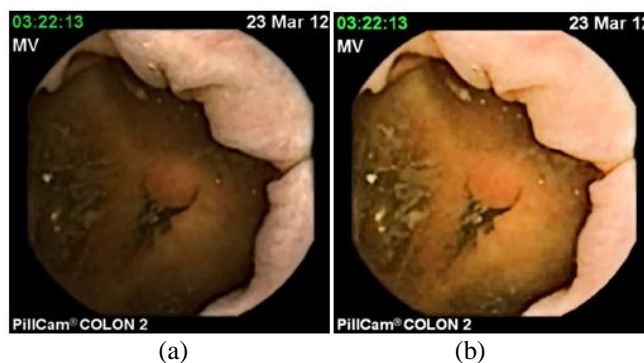


Fig.7. Transformation curve for modified adaptive gamma correction for different values of alpha



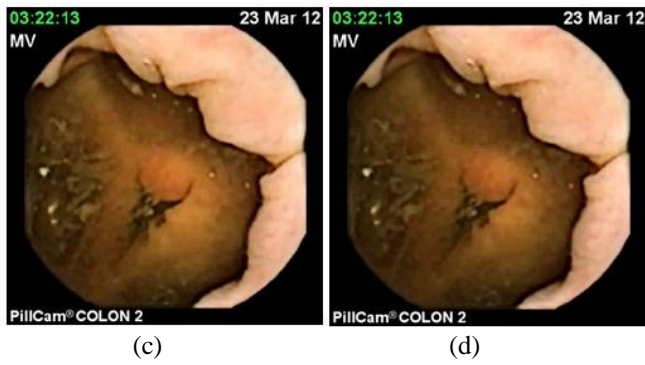


Fig.8. Original and enhanced WCE frames with modified adaptive gamma transformation for different values of alpha (a) Original WCE frame (b) Enhanced frame for $\alpha=1$ (c) Enhanced frame for $\alpha=0.5$ (d) Enhanced frame for $\alpha=0.1$

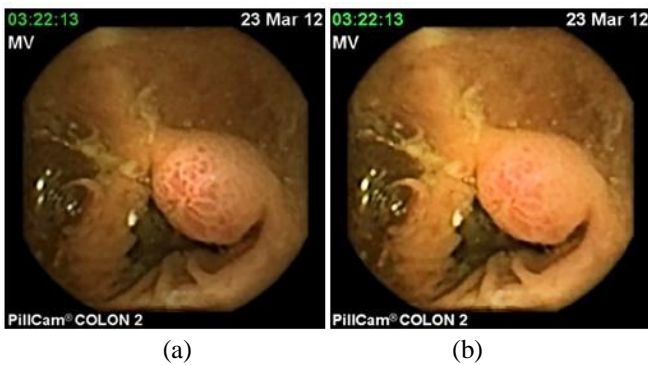


Fig.9. Original and enhanced WCE frames with modified adaptive gamma transformation (a) Original WCE frame (b) Enhanced frame for $\alpha=0.5$

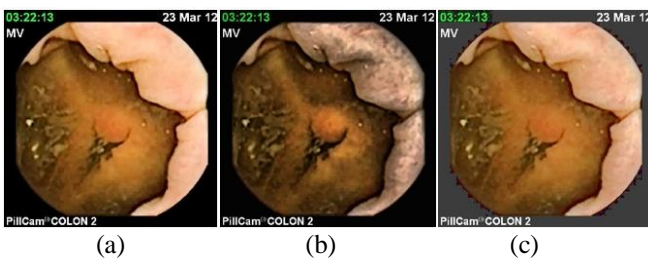


Fig.10. WCE frame enhanced with different techniques (a) adaptive gamma transformation (b) CLAHE (c) GHE

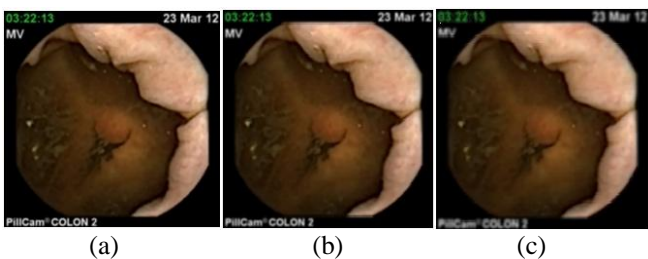


Fig.11. WCE frame enhanced with anisotropic diffusion at different values of threshold of gradient modulus and number of iterations (a) threshold of gradient modulus =15 and number of iterations=5 (b) threshold of gradient modulus =15 and number of iterations=10 (c) threshold of gradient modulus =15 and number of iterations=20 (d) threshold of gradient modulus =5 and number of iterations=5 (e) threshold of gradient modulus =30 and number of iterations=5

IV. Conclusion

Wireless Capsule Endoscopy (WCE) is the only imaging technique which directly visualizes the midway regions of the GI tract, which are beyond the access of the conventional endoscopy and colonoscopy. Inadequate illumination, possible with the small Light Emitting Diodes on the PillCam and the non-uniform luminance at different locations of the individual WCE frames reduce the overall quality of the WCE video.

An efficient modification of the conventional AGC was proposed in this article. The proposed MAGC was employed on the ‘Value’ component in HSV space, preserving the hue and saturation to keep the original colour composition intact. The weighting function, employed on the discrete probability density values helped to integrate the merits of the histogram specification into the AGC. The WCE frames enhanced with MAGC was compared with the WCE frames enhanced with GHE, CLAHE, AGC and anisotropic diffusion.

Regardless of the number of iterations and the value of the threshold of gradient modulus, the anisotropic diffusion was not capable of preserving fine textures and edges in the WCE frame and for improving the region-wise contrast. Natural texture of the original frame get completely disturbed during enhancement with CLAHE and fine textures became over-enhanced. In the WCE frame enhanced with GHE, at the boundaries, spurious artefacts and distortions were introduced. In AGC the fine details were not preserved to the extent possible with the MAGC. In contrast to AGC, MAGC offers the freedom to the user to define the desired shape of the transformation curve by simply varying the arbitrary parameter, ‘ α ’. Thus, the proposed MAGC over rides other conventional techniques in terms of its capability to enhance region-wise contrast and the ability to preserve the original histogram statistics.

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