Effects of empty bins on image upscaling in capsule endoscopy

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ABSTRACT

This paper presents a preliminary study of the effect of empty bins on image upscaling in capsule endoscopy. The presented study was conducted based on results of existing contrast enhancement and interpolation methods. A low contrast enhancement method based on pixels consecutiveness and modified bilinear weighting scheme has been developed to distinguish between necessary empty bins and unnecessary empty bins in the effort to minimize the number of empty bins in the input image, before further processing. Linear interpolation methods have been used for upscaling input images with stretched histograms. Upscaling error differences and similarity indices between pairs of interpolation methods have been quantified using the mean squared error and feature similarity index techniques. Simulation results demonstrated more promising effects using the developed method than other contrast enhancement methods mentioned.

Keywords: Bilinear, empty bins, enhancement, image, interpolation, upscaling

1. INTRODUCTION

Empty bins are bins corresponding to zero number of times of image pixels in a specific range. Such bins occur in the full range of image bins specified by the image type. For example, a grayscale image has 256 bins as a default value, while a binary image has only 2 bins. Many empty bins occur in an image with a very bad contrast and can affect badly the visual diagnostic viewing. Easier image viewing is crucial in clinical diagnosis as well as in many other domains. The capsule endoscopy (the newest endoscopic technology) yields small size images (about 300 x 300). Therefore, image upscaling is needed for easing the viewing of such small size images thus making accurate clinical decisions on bowel pathologies, such as polyps, inflammation, bleeding, etc. [1]. However, image upscaling is not an easy task. It involves solving many problems related to it. Some of the most known problems are upscaling/interpolation error artefacts, such as blurring, ringing, jaggies, etc. Reasons explaining the occurrence of such artefacts have been discussed extensively in the literature, and non-exhaustive solutions were proposed. Since effects of empty bins were not previously studied in image upscaling, this work focuses on such effects.

Figure 1. Two sample test images downloaded from the capsule endoscopy database for medical decision support [2]. From left to right: Capsule endoscope (MiroCam® Capsule Endoscope from Medivators [3]), TIM1 (input test image 1) and TIM2 (input test image 2).

Existing image contrast enhancement and linear interpolation algorithms have been used to study such effects. Image interpolation is frequently performed to upscale an image in the effort to get a closer view of small features or details, where optical zooming cannot be used.

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Many linear image interpolation algorithms are also found in the literature [4],[5],[6],[7],[8],[9],[10],[11]. Such algorithms are often chosen over non-linear image interpolation algorithms [12],[13],[14],[15], [16] due to their simplicity and acceptable visual image quality, especially when the processing time is not the main concern. Four selected interpolation algorithms/methods are the nearest interpolation, bicubic interpolation, and Lanczos interpolation. There exists also many image contrast enhancement methods in the literature [17],[18],[19], [20],[21],[22], [23]. In this study, three existing image contrast enhancement methods have been selected for empty bins assessment purposes before developing a new method.

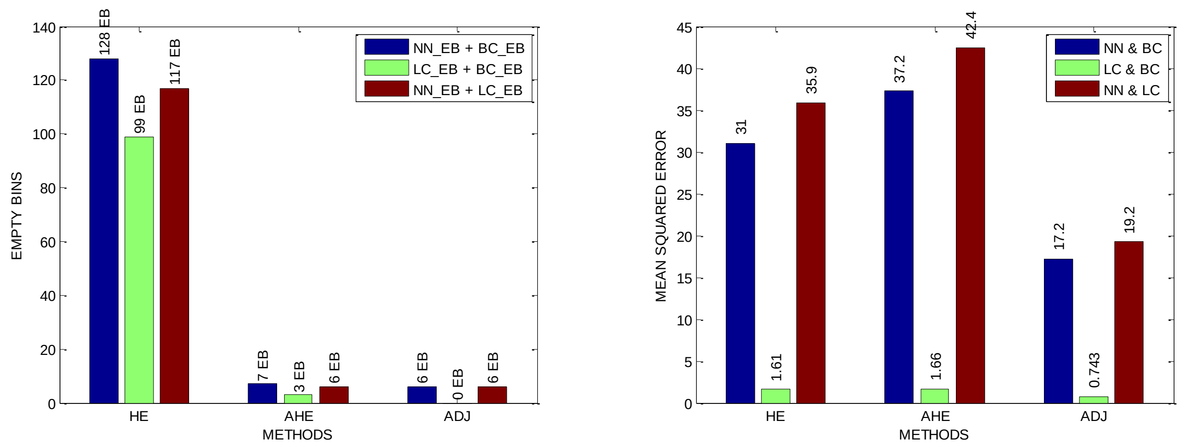

Figure 2. 3X-TIM1; NN: Nearest neighbor interpolation; BC: Bicubic interpolation; LC: Lanczos interpolation; HE: Histogram equalization method; AHE: Adaptive histogram equalization method; ADJ: Adjusting image intensity values method; EB: Empty bins.

Those selected are histogram equalization, adaptive histogram equalization and adjusting image intensity values. The working principles of these existing methods are extensively found in the literature, they are not, therefore, replicated in this paper. Images taken by or from the capsule endoscope were used as test images. The selected error and similarity assessment techniques are mean squared error (MSE) and feature similarity index (FSIM). In general, the smaller the number of empty bins the better the visual quality, provided that each gray level difference can be perceived by the observer, and this, in turn, depends on the luminance levels of the display and on the illumination of the environment. For example, in Figure 2 and Figure 3, an enhancement method leading to achieving the smallest number of empty bins sum is generally prone to achieving the smallest value of MSE.

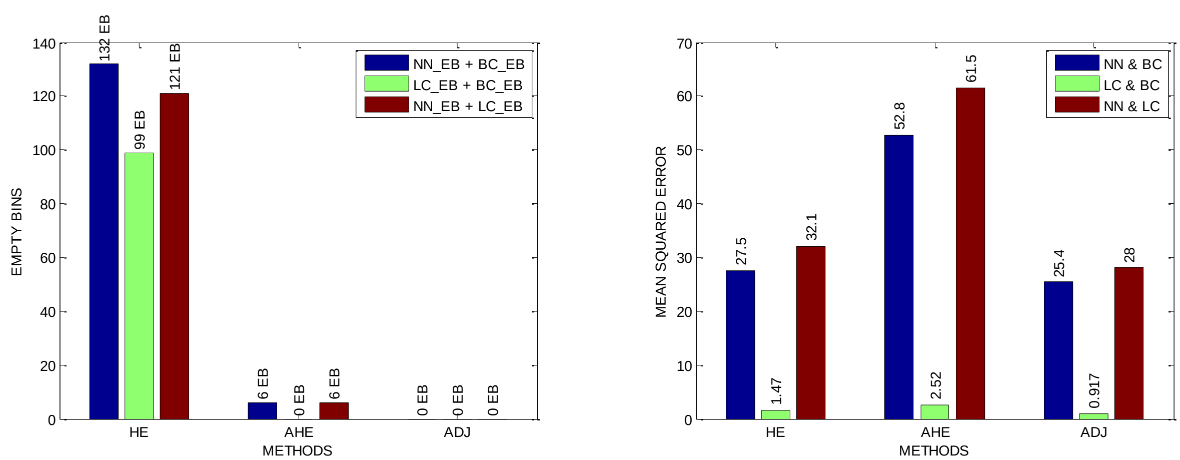

Figure 3. 3X-TIM2; NN: Nearest neighbor interpolation; BC: Bicubic interpolation; LC: Lanczos interpolation; HE: Histogram equalization method; AHE: Adaptive histogram equalization method; ADJ: Adjusting image intensity values method; EB: Empty bins.

In other words, that method is likely to produce the smallest image upscaling errors. However, this is not always the case, since in some image cases, empty bins are necessary for the most acceptable/preferable approximation/representation of that input image details. On top of that, existing contrast enhancement methods used (or mentioned in Figure 2 and Figure 3) do not technically take into account such a necessity. Therefore, a new enhancement method that can distinguish between necessary empty bins and unnecessary empty bins has been developed and comparative results are presented in the simulation part of this paper. This paper is organized as follows: Part 2 presents the enhancement method developed for minimization of empty bins. Part 3 presents simulation results. The conclusion is presented in part 4.

2. ENHANCEMENT METHOD SELECTIVELY MINIMIZING EMPTY BINS

The method developed is based on the bilinear interpolation weighting scheme and takes into account each four pixels group. Figure 4 shows each four pixels group as well as their corresponding weights.

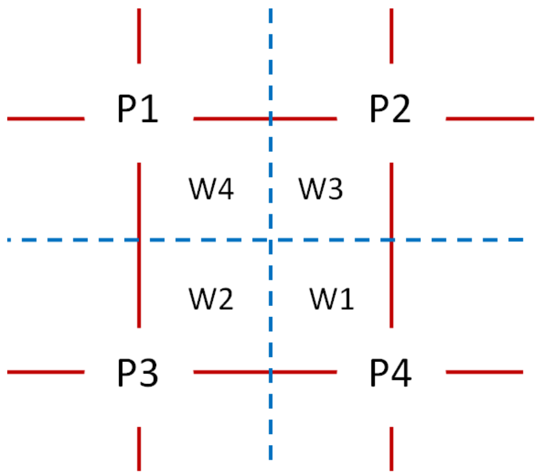

Figure 4. P represents image pixels. W represents the bilinear weighting function.

At the beginning, a destination image of the same size as the source image is created. Next, a group of each four pixels is selected, and, the sum of absolute difference from each pair of pixels is calculated using Eq.1. This sum is very important since it determines whether or not the new pixels values calculated using Eq.2, are to be used. If it is determined that new pixels are not going to be used, the output Eq.4 (with its the old pixels, P1, P2, P3 and P4) is used, or else, the output Eq. 3 is used.

$$S = |P1 - P2| + |P2 - P3| + |P3 - P4| + |P4 - P1| \tag{1}$$

where P1, P2, P3 and P4 represents original/input image pixels or simply old pixels. The idea is that if S is greater than four (S>4) the difference of at least one pair of two adjacent pixels (horizontally or vertically) is greater than one which suggests the possibility of having at least one empty bin between them. In this case, Eq.1 and Eq.2 formula have been developed to selectively deal with such possible empty bins.

$$P_x^* = round\left(\frac{P_x}{2}\right) + md \tag{2}$$

where x replaces pixels order number (from one to four), md means mean difference, and, an asterisk indicates the new pixel. Each old pixel is divided by two in order to avoid the influence of the round-off operation while creating a new group of four pixels. Here, the mean of each four pixels group (i.e. old and new) is calculated as well as the mean difference between the old group and new group pixels. Eq.3 gives the output function (of) with new pixels and weights. Note that Eq.3 is used only when S is greater than four, otherwise Eq.4 is used.

$$ofnew = \sum_{x=1}^{4} P_x^* \times W_x \tag{3}$$

$$ofold = \sum_{x=1}^{4} P_x \times W_x \tag{4}$$

where W_x represents each weight assigned to each pixel (old or new). However, the weight has been made equivalent to the normal bilinear weight only when the new pixel is greater than the old mean, otherwise, it is equivalent to a half of maximum weight values. To avoid possible pixelation in the results, the old mean can be divided by any number ranging between a half and zero.

3. SIMULATION RESULTS

Simulation results of this preliminary study are presented. Creating and using unoriginal reference images matching the size of upscaled images were not done here since that would increase upscaling errors.

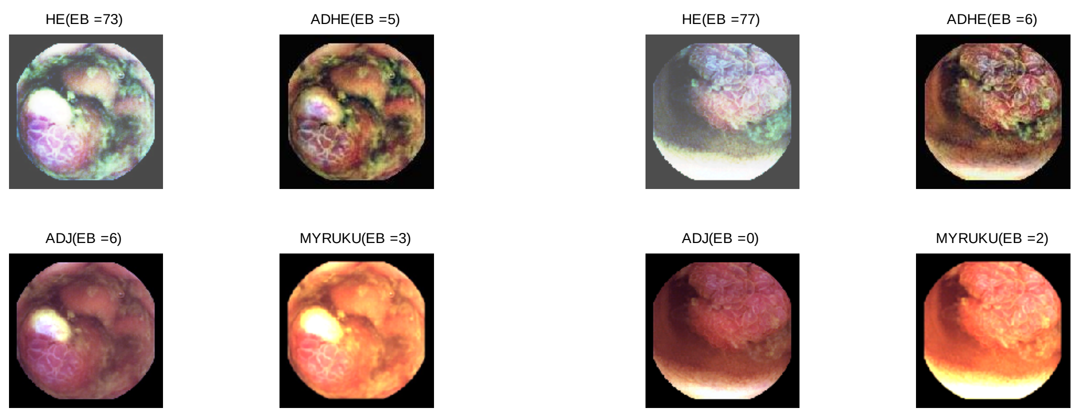

Figure 5. From left to right: Enhanced TIM1 and TIM2. myruku: the enhancement method developed.

To quantify the upscaling error difference and similarity between pairs of interpolation methods the mean square error and feature similarity index were only used.

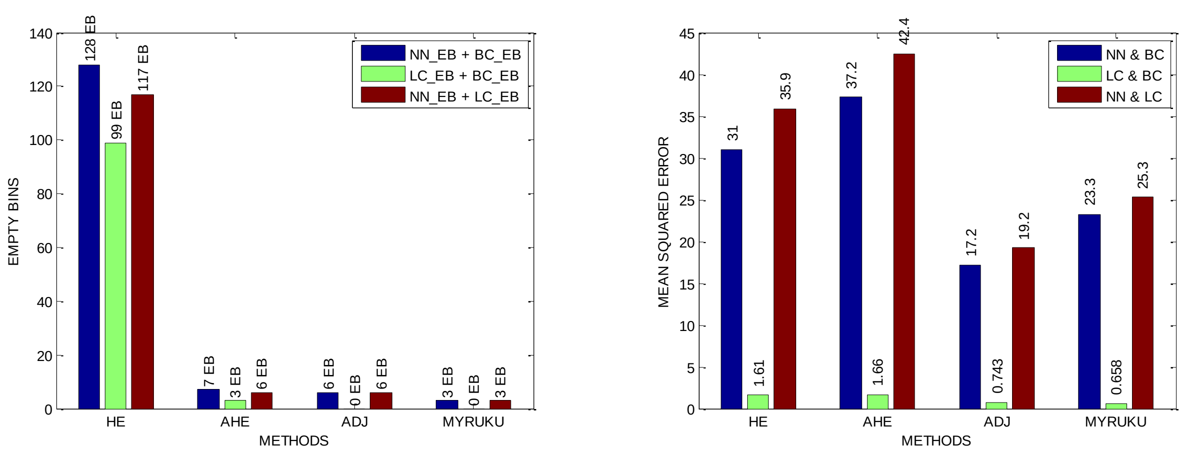

Figure 6. After interpolating each enhanced TIM1.

Other IQA metrics, especially those requiring 'strongly' 'original' reference images were not used in this simulation experiment. Comparing each pair of interpolation methods using MSE and FSIM techniques demonstrated how similar/dissimilar were outputs of interpolation algorithms. Figure 5 shows Figure 1's TIM1 and TIM2 input images enhanced using the methods mentioned as well as empty bins produced in each case. As can be seen, in Figure 5, developing an enhancement method that only produces the smallest number of empty bins is not a guarantee of achieving the most acceptable representation of input image details.

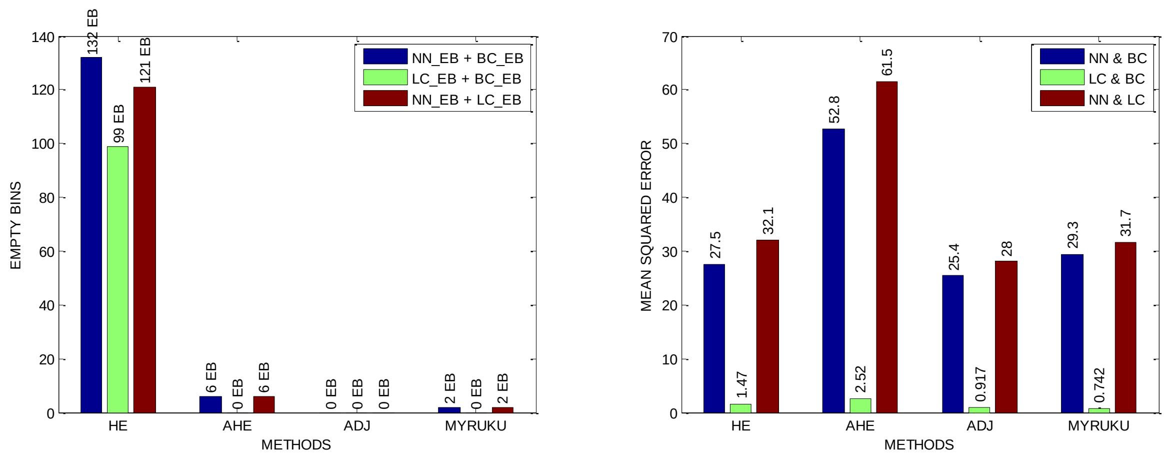

Figure 7. After interpolating each enhanced TIM2.

For example, in Figure 7, with the TIM2 image, the ADJ produced a smaller number of empty bins than the developed method but changed considerably the original hue of the input image, TIM2. The input color also changed too much with the HE and AHE. This demonstrates how necessary is to selectively remove empty bins. In all the cases presented in Figure 5, it can be seen, a preferable representation of the input TIM1 and TIM2 can be that provided by the developed method, referred to as 'myruku'.

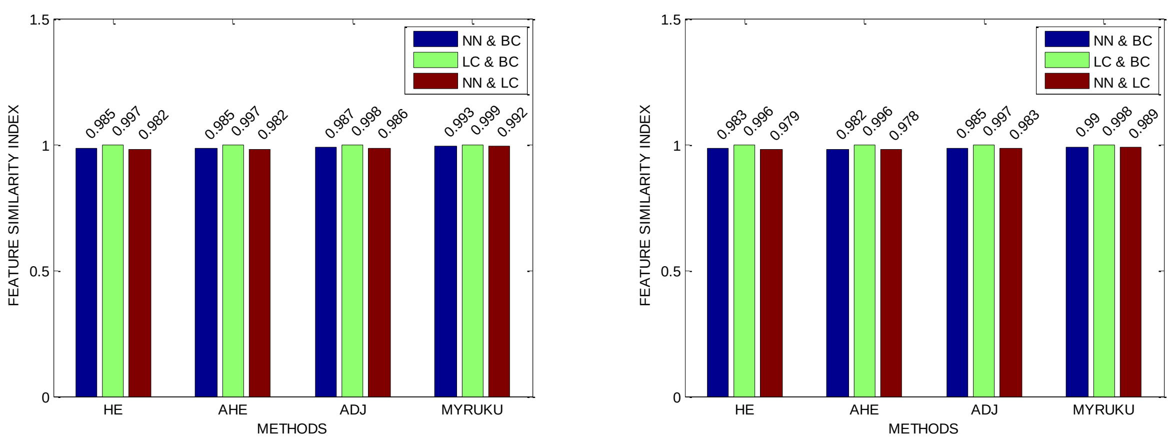

Figure 8. From left to right: The FSIM value for the enhanced and interpolated TIM1 and TIM2.

In Figure 6 the developed method demonstrated the smallest number of empty bins as well as the smallest MSE value with TIM1 (see LC and BC). Note that the best MSE value is equal to zero when two images are perfectly similar. The selective minimization of empty bins by the method developed has also led to achieving the highest feature similarity (FSIM) indices as shown in Figure 8. Note that the best FSIM value is equal to one when two images are perfectly similar. In Figure 9 and Figure 10 it can be seen that the HE, AHE, and ADJ changed too much the color of input TIM1 and TIM2 which should not be the case for visual diagnosis of image details. However, with the developed MYRUKU method there is a tendency of saturating quite many pixels (i.e. maximum lightness) especially in the brightest areas of TIM1 and TIM2 image.

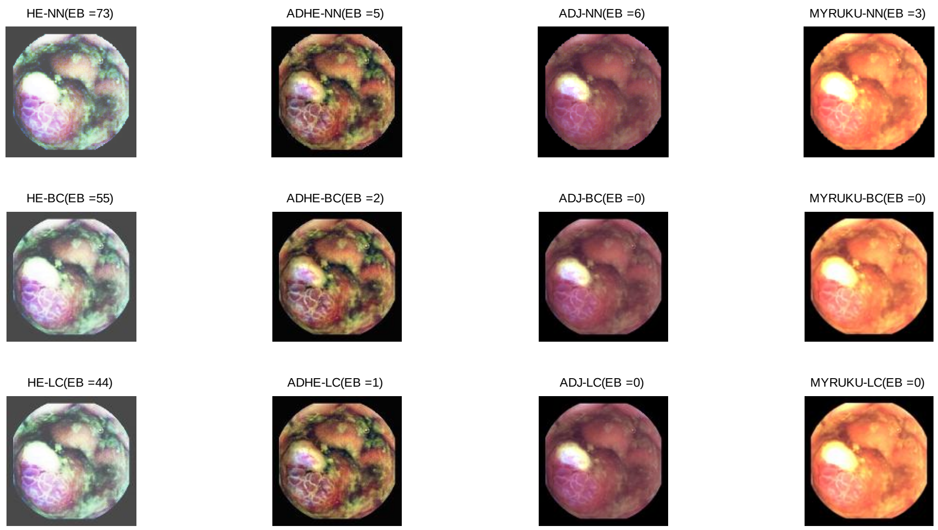

Figure 9. TIM1 enhanced and interpolated using the methods mentioned.

For too bright input images the developed method can lead to losing some details after enhancement which is understandably not good since no details should be lost. A study on the method that can take into account the 'maximum lightness' will be proposed in the next paper.

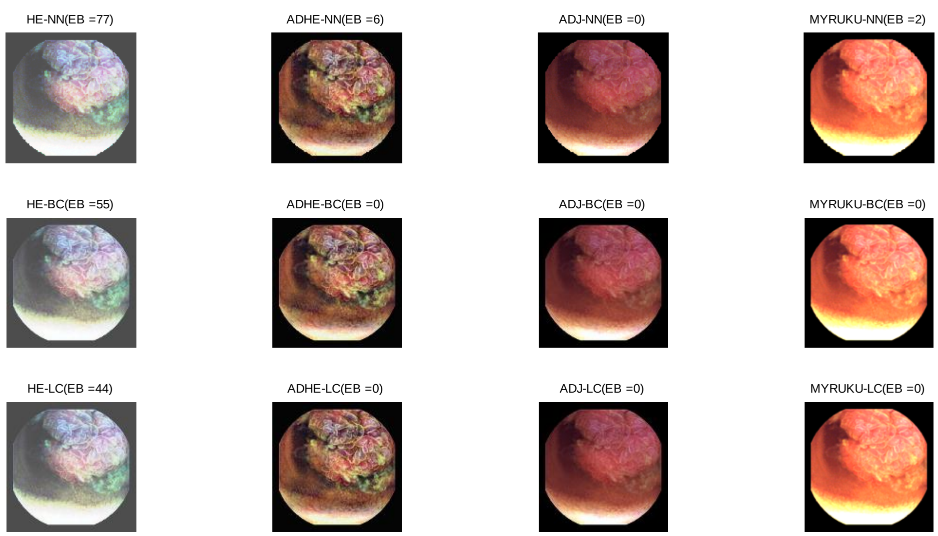

Figure 10. TIM2 enhanced and interpolated using the methods mentioned.

4. CONCLUSION

Discussions and results of a preliminary study of effects of empty bins on image upscaling in capsule endoscopy have been presented in this paper. A low contrast enhancement method based on the bilinear algorithm weighting scheme and pixels consecutiveness has been developed to distinguish between necessary empty bins and unnecessary empty bins in the effort to selectively minimize the number of empty bins before further processing. In general, the smaller the number of empty bins the better the visual quality provided that each gray level difference can be perceived by the observer, depending on the luminance levels of the display and illumination of the environment. However, it was demonstrated that yielding the smallest number of empty bins was not a guarantee of achieving the most acceptable representation of input image details. For example, with the TIM2 image, the ADJ produced a smaller number of empty bins than the developed method but changed considerably the original hue of TIM2. However, in all image cases, it could be seen that a preferable representation of the input TIM1 and TIM2 was provided by the developed method. Next efforts will be dedicated to developing new enhancement strategies that can avoid over-exposure of the brightest areas of the input image after interpolation.

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