Automatic Quality Enhancement of Radiographic Images by Fuzzy Logic

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Abstract— ***Although much progress has been made in X-ray imaging, conventional radiography is still used in many developing countries as well as less developed countries due to its lower cost and availability. These conventional approaches are however significantly influenced by multiple factors such as sensor and environmental noises, age of developer and fixing materials, exposure factors and the experience of the operator. The goal of this study is to apply a novel post processing technique to get digital image advantages with conventional radiographic images. Specifically, we propose a novel fuzzy system to create a standard gray scale level image. As a result, image details are clearer and can be better enhanced by morphological edge operations. This image enhancement can lead to faster and more accurate interpretation by medical professionals. A number of experiments on rats, rabbits, and birds confirm utility of the proposed approach.***

Index Terms— ***Computer-Assisted, Fuzzy Logic, Radiography, Image Enhancement.***

I. INTRODUCTION

X-Ray devices have contributed widely and extensively to medical field regarding diagnosis and treatment. While conventional radiography is gradually being replaced by modern digital imaging techniques [1], many of the clinics, particularly those in developing countries, still use traditional forms of film based (analog) radiography due to the higher cost of digital radiology systems.

It would be most desirable and cost effective if a system could benefit from the advantages of digital radiography by the use of existing conventional radiography equipment. Furthermore, such separation of hardware from post processing software can accelerate the development of new techniques and may lead to better radiography [2]. Images taken with conventional radiography are often influenced by environmental and sensor noises and thus generally has lower quality [3]. They are also affected by film quality; age of developer and fixer materials, and the operator. If exposure factors are not good when radiograph is taken and radiation is too high, the resulting image becomes darker than usual and it makes it difficult to interpret. If radiographic image is underexposed, the resulting image will be lighter than usual and again cannot be interpreted appropriately. To obtain maximum information from a radiographic image, its gray scale pixels must be coherent [1], [2] Contrast enhancing is a frame for maximizing concentration on important objects and it is more important for digital radiology [4]. Image interpretation can be difficult, due to tissue complexity in different animals, high noise rate, and bone and soft tissue overlapping [1]–[3]. The purpose of this study is to enhance image quality and to standardize image intensity in order to reduce the reading time and give accurate results to treating physician and researchers.

Using derivative method to improve radiographic images was used in 1994 by B S Shari [5]. In 1995, Bhanuprakash et al. removed background using “threshold” and by using median filter resolved noises of radiographic images. After that, they enhanced image contrast with histogram equalization [6]. In the same year, Gaborski et al. converted images to raw format using a phosphoric image scanner and detected edges using morphological edge detection. They used spatial segmentation algorithm to extract body parts and by utilizing unsharp mask they were able to achieve histogram enhancing and improved the final image quality [7]. In 2002 Lujun et al. showed how DICOM software enhanced gray scale radiographic images was not optimized, so with parameter automation, they tried to enhance gray levels. They proposed enhance contrast with scalable edge enhancement algorithm [8]. Whereas there is an optimized gray scale level for every radiographic image, in 2008 Luccheseand et al. identified the gray scale level and then enhanced the contrast [4]. In 2010, Tie-Rui et al. were improving image contrast by using gray level dynamic range, but sacrificing a small amount of radiographic image detail. They enhanced the edges by classic edge detections and tried different noise reduction filters such as Ideal low pass filter, butter worth low filter, the ideal high pass filter, butter worth high filter and holomorphic filter and then Otsu Threshold was used and bone edges were identified using Sobel edge detection [3]. Sobel edge detection uses Sobel masks. Smoothing and differentiation are provided by Sobel mask. Because of increasing noises after differentiation, smoothing efficacy is a better property for noise reduction [9].

Previous studies have been mostly focused on gray scale distribution in radiographic images and did not work on enhancing hardware gray scale methods. But in this paper, step wedge method is used for gray scale hardware enhancement. Step wedge is an aluminum strip with 15 steps with different thickness.

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These steps produce different light intensities with different degree of thickness.

The main idea in this paper is that since animal bodies are complex with different light intensity, a step wedge can be used as a base for image restoration. We can standardize, our radiographic gray scale using the step wedge. Then pixels are coherent and noise reduction is achieved by using median filter. After that, using morphology operation the image contrast is enhanced. With this technique we can reduce the need for reshooting of the images thus reducing the cost and speed while at the same time increasing the accuracy.

II. MATERIALS AND METHODS

At the first, image restoration was performed by using step wedge and fuzzy system. The step wedge consists of 15 × 0.25 mm step and was placed on radiographic cassette at the same level for each exposure. The radiograph was digitized by computer afterwards [10]. Several research groups described the X-ray film and step wedge calibration technique [11]-[14]. Afterwards noise reduction is performed using median filter. Finally, the image contrast is enhanced using morphological operation.

2.1. Image restoration

The goal of image restoration is to make a better images using previous knowledge. Restoration is a process that attempt s to reconstruct an image that has been degraded by using a prior knowledge of the depredation phenomenon [15]. Fig.1 shows proposed diagram of image enhancement system. In this system, the input is the scanned radiographic image. When proposed algorithm is done, image quality is enhanced and problems related to variation of light are reduced and edges are clearer. In this paper Sugeno Fuzzy System is used for Image restoration.

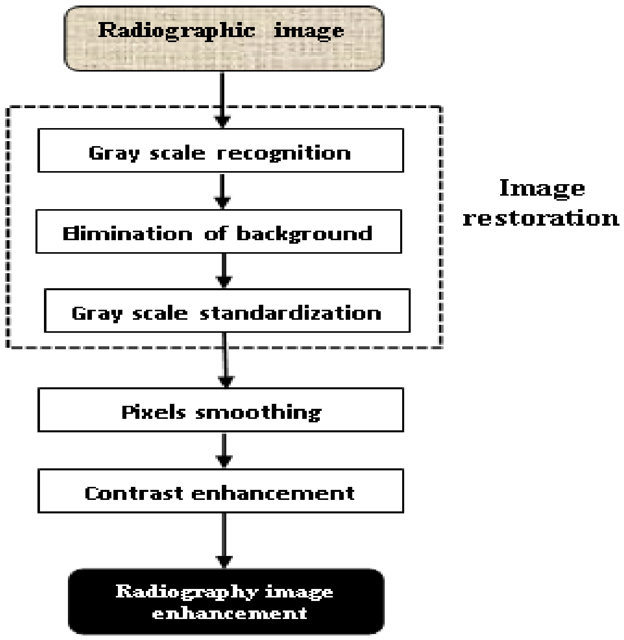

Fig. 1. Radiographic image enhancement diagram

2.1.1. Gray scale recognition

Step wedge is used for gray scale recognition. In radiographs, regions with darker pixels are places with high X-Ray passes and regions with lighter pixels are the places were X-ray penetration is low. Therefore soft tissue has more X-ray penetration and appears gray. Bone zones are lighter because less X-ray passes through.

Using the same principle we made an aluminum tape with different thickness. Less thickened portions due to higher X-ray passage appear darker while thicker areas are lighter for the opposite reason. Fig. 2 shows the step wedge.

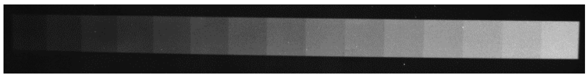

Fig. 2. Image taken of step wedge with X-Ray

Because of differences in gray scale level distribution in different animals, step wedge could produce a standard for gray scale distribution. In this study we use a connect component algorithm to find the step wedge. Then using an automatic algorithm (Geometric segmentation) we detect the different steps of the step wedge. To reduce the effect of variation artifacts we used Equation 1 in our calculations.

$$\left[\prod_{i=1}^{n} x_i\right]^{\frac{1}{n}} = \sqrt[n]{x_1 * x_2 * \dots * x_n} \qquad (1)$$

The geometric mean is a type of mean or average in mathematics that indicates the central tendency or typical value of a set of numbers using the product of their values. The geometric mean is defined as the nth root of the product of the numbers. $\{x_1, x_2, \dots, x_n\}$ are pixels intensity of each step.

2.1.2. Elimination of background

Because of different reason, artifacts can be produced in radiological images. In order to remove every part except original image a threshold is used to make a binary image based on steps in the end of step wedge. Then based on connected component, everything is removed except the original object. Fig. 3 shows final results:

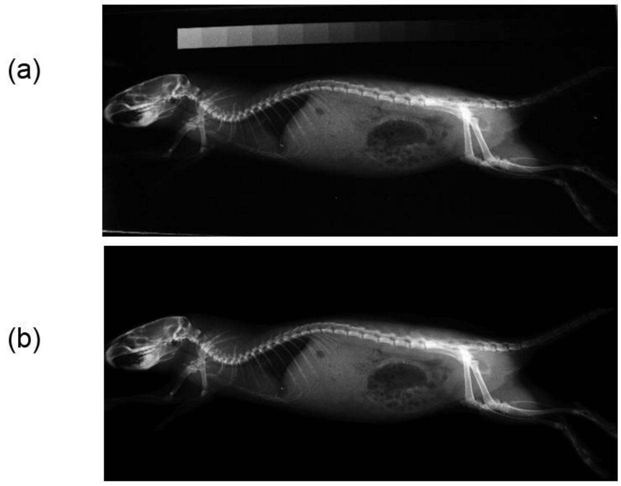

Fig. 3. Lateral overexposed radiographs of rat, a, shows original image, b, represents removing background using connected component of original image

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2.1.3. Gray scale standardization

We obtain a default standard based on step wedge in ideal situation and based on it, each input image obtain step wedge gray scale and consider it with fuzzy system. In this fuzzy system triangular input membership functions (MFS) was used, because of their simple formula and optimize calculation [16].There were 15 steps and one for air that is in the background, making 16 triangular MFS. Base on step wedge light intensity values in original image, input MFS are set. The peak of each MF is related to step light intensity of original image step wedge and the corners of each MF is related to the next step and the previous one. The left corner of the first step gets a zero and the right corner of the last step gets a value of 255. The intensity of brightness, that their values were less than the intensity of brightness of first step, was increased or decreased according to the intensity of the first step. The intensity of brightness, that their values were more than the last step, was increased or decreased intensities based on the last step, also. For example at the last step, the peak value was 154 and this value has been converted to 190 by fuzzy engine. This value is output MF for the last step. For values greater than 154 in original image, the increase of intensity of brightness is done based on the last step value. Input MFS concentrate in left part of Fig. 4 because of overexposed image. These ideal values are experimental and they can be different in different animals.

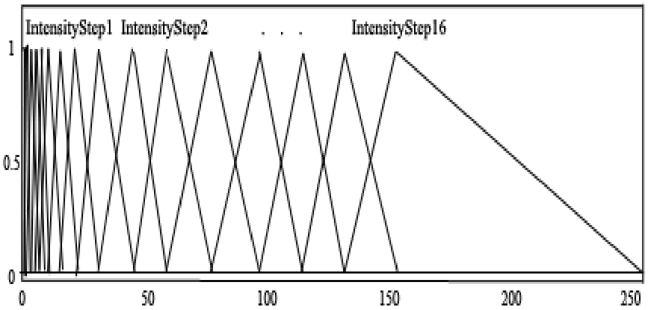

Fig. 4. Input membership functions

Output MFS in this system is linear zero degree with 16 values and is based on step illumination intensity in step wedge as defined in an ideal situation. Fuzzy system output is the ideal gray scale values of the step wedge. Fig. 5 shows more details of this system.

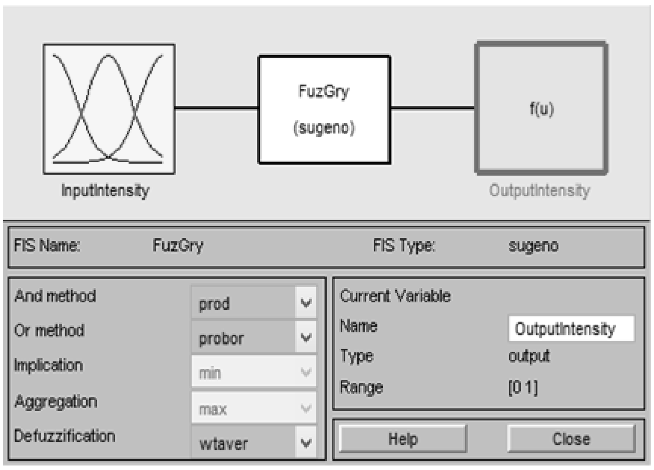

Fig. 5. Fuzzy engine for gray scale enhancement

The input values for our fuzzy system are intensity values in radiographic image. After fuzzy operation has been applied to all the pixels, the radiologic image changes to what has been illustrated in Fig. 6. Fuzzy engine has enhanced the quality of the image by changing gray scale values of the step wedge to ideal numbers. Table I demonstrates these Fuzzy rules.

Table I: Fuzzy inference rules list

If (InputIntensity is IntensityStep1) then (OutputIntensity is IdealIntensityStep1)
If (InputIntensity is IntensityStep2) then (OutputIntensity is IdealIntensityStep2)
If (InputIntensity is IntensityStep3) then (OutputIntensity is IdealIntensityStep3)
If (InputIntensity is IntensityStep4) then (OutputIntensity is IdealIntensityStep4)
If (InputIntensity is IntensityStep5) then (OutputIntensity is IdealIntensityStep5)
If (InputIntensity is IntensityStep6) then (OutputIntensity is IdealIntensityStep6)
If (InputIntensity is IntensityStep7) then (OutputIntensity is IdealIntensityStep7)
If (InputIntensity is IntensityStep8) then (OutputIntensity is IdealIntensityStep8)
If (InputIntensity is IntensityStep9) then (OutputIntensity is IdealIntensityStep9)
If (InputIntensity is IntensityStep10) then (OutputIntensity is IdealIntensityStep10)
If (InputIntensity is IntensityStep11) then (OutputIntensity is IdealIntensityStep11)
If (InputIntensity is IntensityStep12) then (OutputIntensity is IdealIntensityStep12)
If (InputIntensity is IntensityStep13) then (OutputIntensity is IdealIntensityStep13)
If (InputIntensity is IntensityStep14) then (OutputIntensity is IdealIntensityStep14)
If (InputIntensity is IntensityStep15) then (OutputIntensity is IdealIntensityStep15)
If (InputIntensity is IntensityStep16) then (OutputIntensity is IdealIntensityStep16)

In Table I, *InputIntensity* variable is the intensity of original image pixels and *IntensityStep1* variable shows intensity values of the first step in the original image. The *OutputIntensity* is output intensity base on *InputIntensity*. *IdealIntensityStep1* variable shows the ideal value that the first step must be had. Fig. 6 illustrates the effect of the fuzzy engine on the image.

Fig. 6. Image quality enhancement using fuzzy system

Using fuzzy system, gray scale distribution is normalized. And also, fuzzy engine makes a standard for gray scale radiologic image. Therefore, exposure factors, developing and fixing and film quality, and etc. have less influence on the final result.

2.2. Pixels smoothing

The major problem in radiology images is coherent pixels and noises that make soft tissue recognition much more complex. In this paper, radiology image pixels are combined using median filter. This makes soft tissue to be seen better. Fig. 7 is shows the median filter result on a radiographic image.

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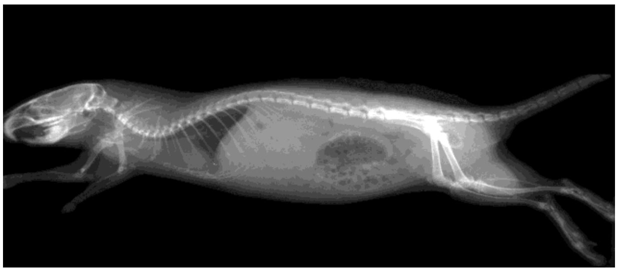

Fig. 7. The result of median filter on the radiographic image

2.3. Contrast enhancement

These operations make bone recognition easier. Opening morphology is used to enhance the contrast. Opening on gray scale images decreases the intensity of all bright areas. But it has negligible effect on the dark areas, and the background. The formula is as follows:

(2)

As shown in Equation 2, opening operation, is a result of combining erosion and dilation, which are part of part of basic morphological image processing. By subtracting Opening result from the original image, zones with higher intensity are extracted from original image and dark zone are made darker. Adding the opening result to the original image, increases the contrast.

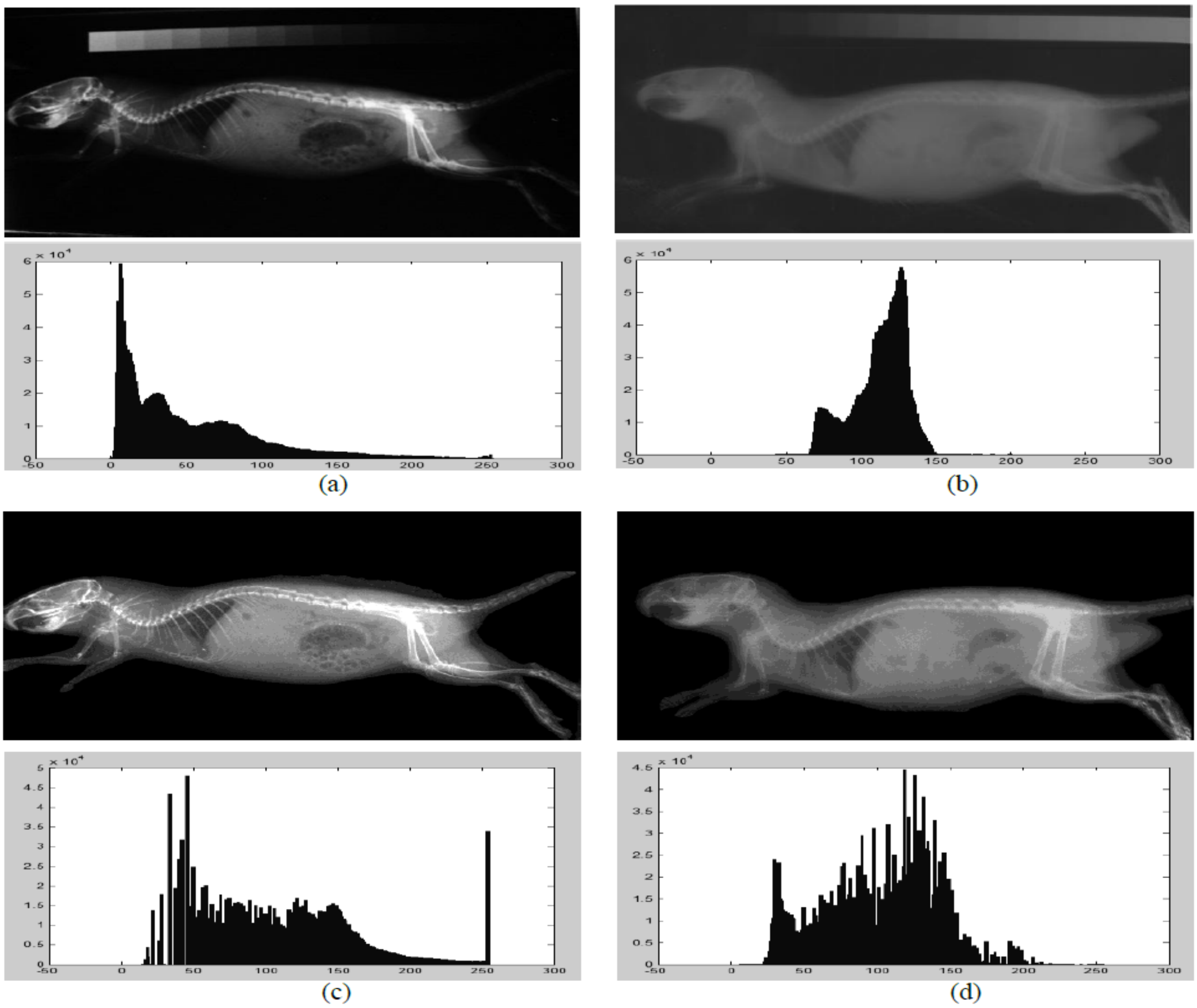

Figure 8. Changing in gray scale image after image enhancing operations {a} Radiographic image of rat that shows overexposure problem, {C} the image after application of the proposed system (b} Radiographic image of rat that is underexposed, d, the image after application of the proposed system

$$I1 \circ SE = (I1 \ominus SE) \oplus SE \qquad I2 = I1 + (I1 - (I1 \circ SE))$$

(3)

Here I1 is the original image. SE is a disk with a radius of 10. Fig. 8 shows that proposed method could solve common problems in obtaining radiographs. This method reduces reshooting cost, and by using image restoration and contrast enhancement, decreases reading time and improves accuracy. In Fig. 9 we discuss the system operation on rabbit and pigeon radiographs.

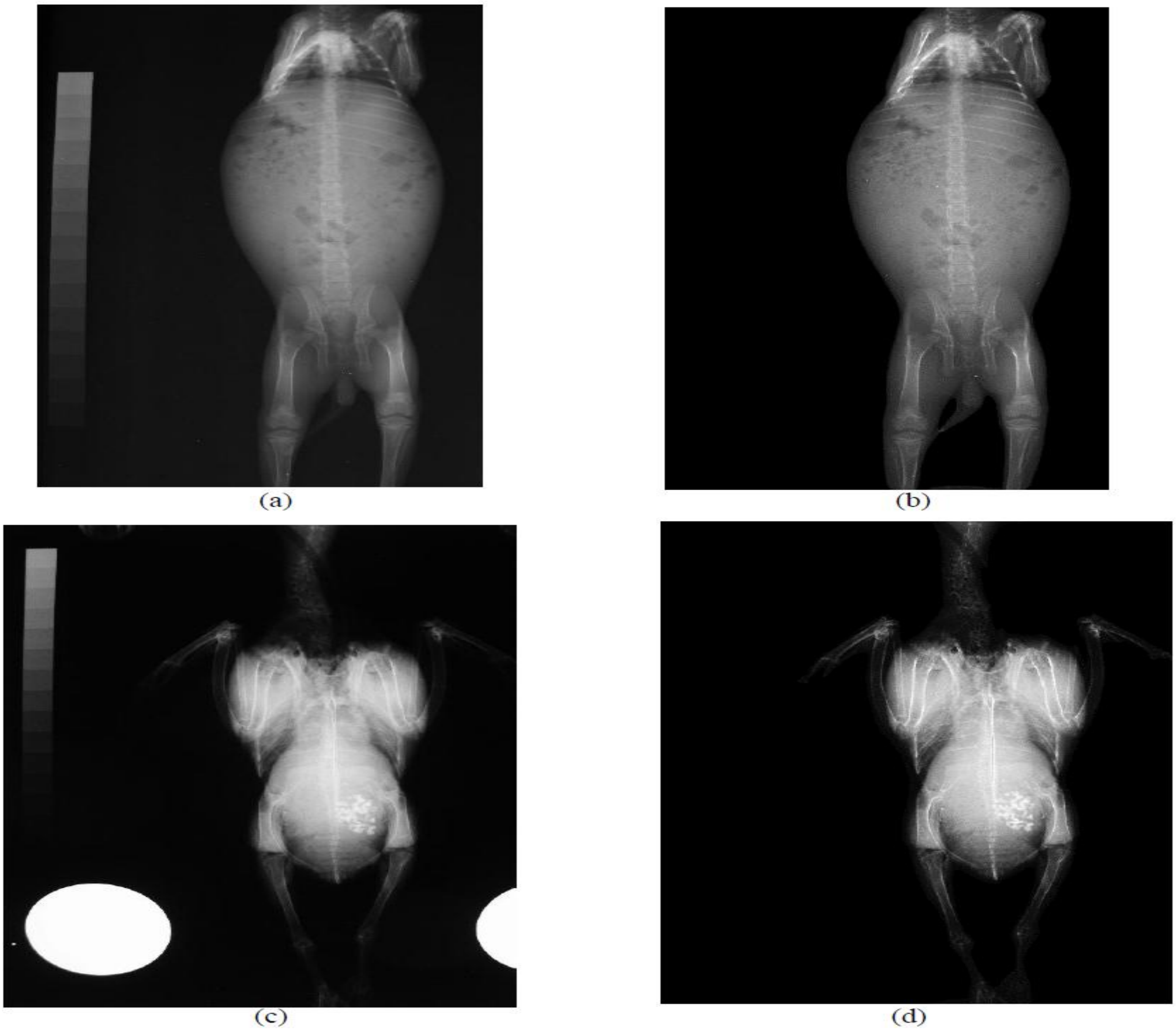

Figure 9. a, this represents plain radiograph of rabbit and c, shows plain radiograph of pigeon. The Image b and d represent the improved images by the proposed system

In our rabbit enhanced radiograph, gray scale has improved on soft tissues around the stifle joint and as a result more details are apparent. Also, the edge enhancement of following bones, femur, tibia, fibula, transverse process and body of the lumbar vertebrae, were improved. In the improved radiographic image of pigeon, cortex and edge of following bones, humerus, radius, ulna, metacarpal and digit, hind limbs, femur, tibiotarsus, metarsus, digits and Sternum, are significantly sharper while the viscera of the coelom shows more details.

III. RESULTS

The study was done in laboratory animal housing of Veterinary Medicine of Ferdowsi University of Mashhad. In this study 86 radiographic images of rats were evaluated. The radiographs were taken using an X-ray apparatus (Soyee SY-HF-110) on Kodak high resolution mammography films with exposure factor (58 kVp, 0.8 mAs). Focal film distance (100 cm) and position of step wedge are constant in all radiographs. Field of view was set at the minimum size that covers the whole body of rats.

Then intensity variation rate of the step wedge is evaluated by mean absolute error rate. In each phase, step wedge intensity sampling is done using the Equation 1. Then mean absolute error rate is compared to steps with ideal values and the difference is evaluated. Equation 4 shows mean absolute error.

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} \left| \mathrm{IdealIntensityStep}_i - \mathrm{IntesityStep}_i \right|}{n} \quad (4)$$

In Equation 4 the variable n shows the number of step wedge steps. *IdealIntensityStep* is the amount of intensity in ideally step wedge and *IntensityStep* is of the step wedge in the original image. Fig. 10 shows the difference in step intensity in each radiographic image with ideal values.

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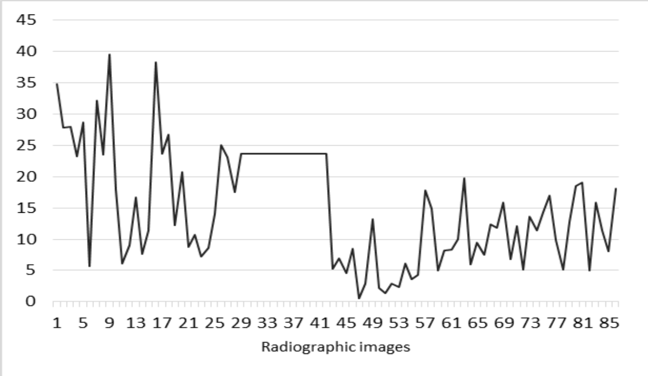

Fig. 10. Mean absolute error rate of step wedge intensity in radiographic image

After image restoration step wedge intensity is standardized using fuzzy system. Then sampling by Equation 1 is performed on images that their gray scale has been standardized. Fig. 11 is shows mean absolute error in these radiographs.

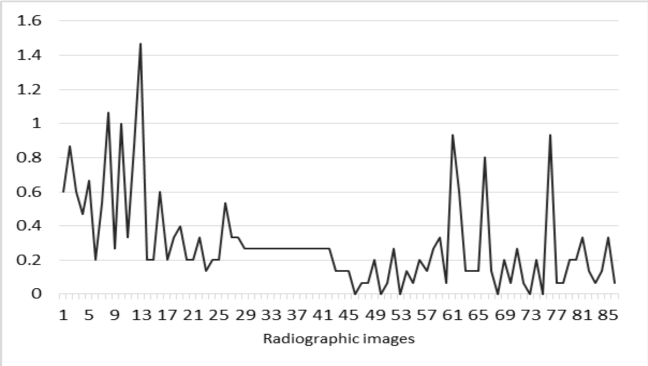

Fig. 11. Mean absolute error rate of step wedge intensity in radiographic image that gray scale standardization operation is done on them

As seen in Table II, our proposed system has reduced intensity variation in radiographic images. Mean intensity error is conventional radiographic images is 15.063 that our proposed system has improve the rate to 0.297.

Table II. Gray scale standardization effect on error rate

	Average error	Minimum error	Maximum error
Without gray scale standardization	15.062	0.533	39.533
After gray scale standardization	0.297	0	1.467

IV. CONCLUSIONS

In this paper we introduce a new system that can achieve digital radiographic image advantages using a low cost light conventional radiographic image. The proposed method reduces problems like underexposure and overexposure. This system is useful for clinics and laboratories that are using conventional radiology. In this paper we propose a novel fuzzy system of image restoration, and test it with 86 radiographic images. The system is able to perform accurate image restoration. Enhancing contrast and morphological method suggested in this paper improves bone visualization and quality. Gray scale fuzzy system proposed in this paper provides a baseline for more research in other areas and provides a standard brightness intensity in environments with high variation in their brightness intensity.

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