New Approach to Information Extraction from X-ray Plates

High Quality Digitalization

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***Abstract*—This article aims at solving one of the most important issues of computer-based interpretation of medical images for diagnosis purposes – obtaining the maximum authentic image, which then can be processed by computer-assisted diagnosis methods. The article offers a new approach to the problem of the X-ray plate digitalization – namely increasing the quality and the quantity of information obtained from the X-ray plate by creating a model of the plate illumination while an X-ray image is being created. The implementation of the presented method is based on the theory of high dynamic range images. Increase and enhancement of human perception of X-ray plates and possibilities to diagnose more precisely many sicknesses are the final result of this work.**

Keywords-medical imaging; X-rays; HDR-images; image digitalization.

I. Introduction

In the era of computer-based medical applications, the requirements for the diagnostic process quality are directly related to the quality of the computer generated data/information used by physicians. This follows to the requirement for generation new approaches for data acquisition, data storage and data/information processing. On the medical images processing tools market this led to the development of many new solutions. For example, the desire for increasing the quality of generic images led to the fast progress in the hardware and software development of digital X-Ray machines, CT, MRI, ultra-sound apparatuses, and the possibility to control the image-taking process. The need to store these images without any loss of information and without any reduction of the quality leads to changing the standards for image processing as well as the standards for image archiving – the best example is the changing of the DICOM standard in the last 10 years.

One of the most important characteristics of the diagnosis process is the need to track patient's status over time. In the area of automated and semi-automated methods and systems for detection and diagnosis of diseases and changes in tissues, this required to define the concept of "equality" and "comparability" of medical images. Now, this term is used to define how the physicians' evaluation of the sameness of the two images coincides with the computer evaluation. This is a very serious problem, because tracking of a disease evolution is assessed depending on how the patient's organs and tissues have changed. This is based on images which were taken at different times, on different systems and under different conditions. Although some digital X-ray machine manufacturers have software for images obtained from various X-ray apparatus from their product list [12], this problem has not yet been solved when using images obtained by the apparatus of different manufacturers.

An additional factor, complicating the process of automated tracking of the disease, is the need to use X-ray images stored on plates and films. This requires the plates with X-ray images to be digitized with the quality and characteristics that allow computer-based comparison with images obtained by digital X-ray apparatus. From a technical point of view, this issue is much more complex than the problem of images portability between digital X-ray apparatus, due to the use of different physical phenomena in the process of obtaining digital images:

- The digital X-ray apparatus uses a digital sensor, which takes the X-ray photons and converts them into an optical picture depending on the sensor calibration – the process uses an additive type of lighting system because photo-photons, which are used for optical image generation, are generated by the emitting material, most commonly selenium. The resulting image is a medical image, which is displayed on a display and interpreted by radiologists. Therefore, in the same stream of X-ray photons radiologists can get different optical pictures depending on the sensor calibration and the sensor linearization [3][4]. This is used by radiologists for improving the quality of the final digital image.
- The digitization process of X-ray plates/films is an optical information conversion from an analog form (recorded on the plate) to a digital form to be displayed - this is a subtractive type of image generation, because the digital image is generated by measuring changes of luminosity when the light passes through the plate. This is a totally different class of problems, since the main limitation is the inability to obtain additional information to be used for the correction of deficiencies in the analog image. For example, it is necessary to use different type of methods and techniques for correcting

the nonlinearity and the constraints of a digitizing system.

Since the final image quality is the result of three different groups of characteristics – the quality of the recorded image on the plate, the way the X-ray plate is stored, and the quality of the digitalizing system – the development of new digitalizing methods and techniques requires the use of more diverse hardware and software tools. The classic solution in this case is the use of a very small size laser beam, which allows high accuracy of measurement of the luminosity change, low degree of influence of the diffuse lighting over the luminosity change, and the well-known apparatus architecture [8][9]. A major drawback of this approach is the fact that digitization cannot compensate for the change in the final image quality due to deterioration of the image quality with improper storage or because of an incorrect process of image creating on the plate [14][15][16].

The present paper describes a new approach to the process of X-ray image digitalization from the plate, which allows for compensating the reduction of image quality due to deterioration in the characteristics of the plate. At the same time, this approach allows you to compensate the reduction in the final image quality, resulting from the overexposed/ underexposed X-ray image recording. Also, this approach allows to preserve all the necessary characteristics of the radiographic image such as resolution, dynamic range, contrast, sharpness, etc. This is achieved through an image pre-processing technique which resembles the characteristics of the X-ray-image-creating process by modern digital X-ray apparatuses.

This present paper is structured as follows:

- Section II background of the new digitalization method
- Section III describes the HDRI-based digitization method for X-ray plates
- Section IV includes the analyses of the results
- Section V is the paper conclusion.

II. BACKGROUND OF THE NEW DIGITALIZATION METHOD

X-ray imaging utilizes the ability of high frequency electromagnetic waves to pass through soft parts of the human body largely unimpeded. With classical X-ray apparatus, X-rays are usually generated in vacuum tubes by bombarding a metal target with high-speed electrons. The X-ray images are produced when the radiation passed through the body is absorbed by a photographic plate or digital X-ray sensor to produce a radiograph [17]. The resulting X-ray images show the parts of your body in different shades of black and white because different tissues absorb different amounts of radiation:

- Calcium in bones absorbs X-rays the most, so bones look white;
- Fat and other soft tissues absorb less and look gray;
- Air absorbs the least so lungs look black.

The quality of the digitalization process of such images will be measured with the difference between the information stored on the image and the one read from it.

From the perspective of optics an X-ray plate represents a type of material that fully corresponds to the laws of the physics of semi-transparent materials. This allows a much more flexible approach to be used for digitalization of the X-ray image plate in order to extract the fullest possible information for the optical picture recorded on the plate. One of the benefits of the computer system in this case, compared to the human vision system, is the fact, that the computer system does not have features like "visual weight" and "approximation of the color consistency”. At the same time, the computer system does not have different perception sensitivity for color and grayscale images, which is a well-known characteristic of human vision.

Analyses showed that the plate with a recorded X-ray image on it has the behaviour of a multilayer structure. This is due to several factors: the different photo-photons penetration into the material corresponding to their energy in the process of image creation; the different distribution of the light-sensitive elements (often silver) in the plate material; and the different penetration of chemical reagents when handling the plate after capture. Therefore, the change in the different plates when exposed to the same constant light is different. In terms of optics, this characteristic of the plate material causes the effects of the subsurface scattering – the effect strongly depends on the spectrum and the energy of the light flux passing through the plate. Thus, the resulting optical picture after passing the light through the plate is some kind of averaging of recorded illumination in the different levels of the plate. This means that if the plate is illuminated for a short period of time with light having constant spectrum and intensity, we cannot obtain all the information stored in the plate. This defines the main difference between X-ray scanner manufacturers using laser beam lighting - the choice of the beam spectrum and energy results in a different amount of loss of recorded information. These differences are particularly visible when scanning overexposed or underexposed X-rays. Another reason for the search of a new approach is the characteristic of human vision which allows manifold increase of its dynamic range. When a person has long been watching the same image or scene for a prolonged period of time he gradually starts perceiving its elements in a much different way from the initial perception.

This is due to the fact that the human dynamic range increases through the gradual light accumulation in the photoreceptors – mainly, this is a chemical process. In computer science the idea that comes closest to this one is the idea of creating and using the so-called HDR images.

Limitations in the dynamic range of photo-sensors require to look for new methods and approaches to solve this problem.

Different approaches were developed – from increasing the dynamic range of photo-sensors to methods based on the merging of information from photo-sensors with different photosensitivity.

Today a combined approach – photo-sensors with wider dynamic range and control of the sensitivity range is mostly used.

Thus, combining information obtained in different ranges it is possible to create an image with a much wider dynamic range. The most well-known and used method today is the High Dynamic Range Imaging (HDRI) [12].

HDRI, in photography and imaging, includes a set of techniques for obtaining and reproducing a greater dynamic range of luminosity (the difference between the brightest and darkest parts of the image) than when using standard photographic and imaging techniques [13]. Thus, HDR-images can present more accurate intensity levels of light for real scene. So, the HDR-image does not store pixels intensity values – it stores the information for the illumination in logarithmic form or as a real number without a fixed presentation of individual color channels [12]. Therefore, the use of HDR-images in the X-rays plate digitalization process allows the creation of a model corresponding to the illumination which has created the original image. In this way, by using lighting with different exposures, we can obtain information about the light flow which generated changes in the different levels of the plate. The only problem in this case is the number of exposure levels and the exposure value for these levels.

III. THE HDRI-BASED DIGITIZATION METHOD FOR X-RAY PLATES

Based on the research results of existing systems and technologies for X-ray plates digitization and using quality criteria for digital images from digital X-ray apparatus described in [1][5][6][7], the following primary requirements to develop a new method for digitization of chest X-ray images have been defined:

- The method should make it possible to obtain images with resolution at least 600 dpi (5 LP/mm).
- Digitized images should be grayscale images with at least 12 bits depth (4096 gray levels).
- The method should make it possible to obtain images with at least 120 dB dynamic range.
- The method should control the final image quality, similar to the pre-processing in digital X-ray apparatus.
- The method does not generate medical artifacts in digitization images.
- The method should allow compensating the reduction of image quality due to changes in the X-ray plate resulting from improper storage.
- The method should allow the digitization of all sizes of radiographic plates while maintaining the same quality.

The idea of the method is to create the illumination model (the HDR-image) which has led to the grayscale image stored on the X-ray plate. This idea is implemented by capturing the sequence of images with different exposures (these images are images with low dynamic range – LDR-images). Thus, the information about tissues and organs with different X-ray density would be obtained in great detail.

To achieve the above requirements a method for X-ray plates digitization based on a "photo-camera" type of scanner has been developed [10][14]. The main difference between those methods and the presented in the paper new one is in the way how the information in X-ray plates is extracted and in the quality of the digitalization X-ray images.

The method has the following main characteristics: digitalization of segments and bracketing over segmented image, remote calibration of the digital photo-sensor, stitching multiple images' segments and the HDR-image generation, pre- and post-processing of digital image.

The proposed new digitalization method uses the following steps to achieve its goal:

Step 1. Photo-sensor calibration to reach the biggest possible dynamic range according to plate's quality.
Step 2. Determining how many segments are needed to digitalize the processed X-ray plate.
Step 3. Segment by segment digitalization of the X-ray plate following pre-defined scanning path and using bracketing.
Step 4. Using segments stitching for simultaneous rendering of all the layers of the full image (captured with different exposures).
Step 5. HDR image generation.
Step 6. Image pre-processing and LDR-image generation.
Step 7. Post-processing and rendering of the final digitalized X-ray image.

The goal of the first stage of the method is a selection of photo-optical characteristics of the photo-sensor. This allows obtaining the largest possible amount of information about the luminance recorded on the plate.

These characteristics are sensitivity of the photo-sensor, optical zoom, focal length, shutter speed and white balance. To determine the optimal values of these parameters a procedure has been developed which is based on a comparison of the average exposure of the image and the exposure of the image in the brightest and darkest areas (the aim is to have difference between the brightest and darkest areas not bigger than 4.0-4.5 EV). The procedure is iterated till an appropriate value of the average exposure and exposure range of change between the darkest and brightest areas is found. The same settings of the sensor system are used for the processing of all segments [8][9][10]. This increases the final image quality because it reduces medical artefacts.

The second stage of the method requires to determine the number of segments (rows and columns) which the image should be broken down into. The selected algorithm includes the size of the X-ray plate, the required final image resolution, image size according to the selected values for the focal length and optical zoom, and the degree of overlap for the particular class of images (underexposed plates, overexposed plates, plates with loss of brightness, etc.). For chest X-ray plates, it was found that the best quality is obtained with an overlap between 35% and 45%, i.e., about 40%. Thus, for a plate size 43/40 cm a 5×4 matrix is used, while for 30/35 cm the matrix is 3×3.

The third stage is capturing plate segments using the bracketing procedure. In the initial versions of these photo-camera-based scanners, filming of the entire image was used, which determined the low resolution of the resulting image. The resolution of the resulting image is the CCD/CMOS sensor resolution. This limits the quality of the final image. The method uses technology based on digitalization of an X-ray plate as a set of ordered segments to meet the requirements for digitization of all sizes of X-ray plates and to achieve the necessary resolution of the final images (Figure 1).

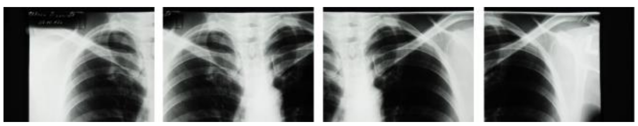

Figure 1. Digitalized X-ray - one row of image segments.

The method uses technology based on capturing of each segment by a bracketing procedure (our method uses 5 LDR-images with different exposures). To achieve the dynamic range value requirement all individual images are captured and stored with a 12-14 bits depth (when using images with 8-bits depth, the maximum value of the dynamic range does not exceed 60-65 dB); see Figure 2.

Figure 2. X-ray image bracketing with exposures 0 EV, -2 EV, +2 EV.

The fourth stage task is to generate an integral image from the segments - the image segments are stitched into one, and thus a total final image is obtained. The stitching procedure is done simultaneously for different exposure segments and this allows a physical and geometric homogeneity of the final images (one per selected exposure of image capturing) to be achieved. Of a particular importance for the quality of the processing at this stage are the settings of the photo-sensor and the capturing procedure of each plate segment. The reason for this is that lung X-rays have a great number of "looking similar" areas which frequently results in wrong stitching. To solve this problem a methodology for software stitching tool evaluation and selection was developed which can be used in the presented area of application (medical images) without generation of artifacts with diagnostic importance. The methodology includes 10 comparison parameters which allows to estimate the possibilities to work with sensor raw data, homogenization of luminosity between segments, working with different overlapping, simultaneous stitching of layers with different exposures, etc.

The next stage is the generation of a luminance model for the X-ray plate. To achieve this goal a 32-bits HDR-image using the Tone Mapping Algorithm is generated. The selected exposure values for individual LDR-images allow the required final image quality to be obtained for all radiographic densities. The result of this stage is an image which is analogous to the raw data obtained from the X-ray digital sensor.

Digital image pre-processing is the 6th stage – this stage has tasks similar to those addressed at the pre-processing stage of the digital X-ray apparatus, i.e. various operations are performed to correct the quality of the digitalized image. Most often these operations include the level of detail adjustment, local and global contrast changes, structures sharpness selection, eliminating the 'halo' effect, dynamic range adjustment (Figure 3). At the final stage of processing, the HDR-image is converted to the 16 bits per channel grayscale LDR-image. This is the final image after X-ray plate digitalization.

The last stage is the post-processing of the final image – as an additional stage in our method we propose the possibility to use methods for digital post-processing of the displayed final image. In this case the radiologist selects different values for brightness, contrast, level-of-details – this additionally improves the quality of the digitalized images. This stage is not obligatory and can be replaced by any product for medical images post-processing.

The main problem when using HDRI-based technology to produce high quality medical images is the choice of the exposure values for LDR- images that will be used to create the HDR-image. The classic technique requires using 3 LDR-images in which the base image is chosen so that there is an optimal presentation of the scene objects. The additional exposures are made at '+2 EV' and '–2 EV', which makes it possible to reach improved level of details and contrast in the brightest and darkest areas [11]: 1 EV corresponding to a standard power-of-2 exposure step. Experiments demonstrated that for the purposes of chest X-ray plate digitization the presented above set of exposure values is not applicable. The reason is that the X-ray image does not have great homogeneity of the pixels color and intensity distribution in the entire range, because there are various well-defined radiographic densities, which lead to strictly defined grey levels. Therefore, the method is oriented to take 5 LDR- images with the following exposures: '0 EV', '+1.67 EV', '+2 EV', '–1.5 EV', '–2 EV'. In this way the quality of the HDR-image is a function of the correct photo-sensor calibration to create a base image (the image with 0 EV) – the goal of Stage 1.

IV. Analysis of the Results

The experiments with the proposed method for digitization of chest X-ray plates, validated by physicians with over 20 years' experience from hospitals at the Medical

University of Sofia, have led to the following conclusions on the applicability of the method:

- The possibility to control the number of segments used to capture the plate, makes it possible to receive the digitized image with a resolution better than the grain of the plate. This allows the correction of the digitalized image which does not generate medical artifacts. The only problem is the increased digitalization time when the final image resolution is increased.
- The creation of the illumination model (the HDR-image) allows one, much more correctly, to choose the values for the different characteristics of the final image (dynamic range, contrast, sharpness, level of details, etc.). This significantly improves the final image quality compared to other digitization techniques.
- Classic X-ray plate scanners use constant exposure for the image capturing. In the case of images with a pronounced bimodal histogram this creates significant image readability problems. The proposed digitization method makes possible to avoid the appearance of this type of image histogram, due to the ability to manage the process of transformation from an HDR-image to the final LDR-image.
- In medical images with a small dynamic range, after digitalization, the image histogram has a narrow stretch and a very large peak in it. This creates serious problems for quality enhancement methods, which very often lead to the intrusion of medical artifacts. Examples of such images are underexposed images: they have small dynamic range and large peak in white area. The proposed digitalization method makes it possible to create images with a unimodal histogram with a normal (Gaussian) distribution of intensities.
- In overexposed X-ray images most often the histogram has a bimodal nature. The approach used in the proposed digitalization method allows to create an image with a unimodal (or similar in nature) histogram because the created illumination model (the HDR-image) makes it possible to minimize the peaks in the dark area (the user has control over the mapping process between the HDR-image and the final LDR-image). This significantly improves the image quality and the possibility for using automated methods of digital image processing.

Some results of the presented digitalization method are shown in Figure 4 and Figure 5.

V. CONCLUSION

The proposed X-ray plates digitalization method is highly adaptable depending on the condition and quality of the X-ray plate, and some specific needs. The possibilities to manage sensor settings and the presence of a pre-processing stage substantially improve the quality of digitalized images. Comparability of results for different types and different sizes of X-ray plates show that when a correct adjustment of the digitalization system is set the captured images have higher quality, or at least similar to that captured by classical X-ray scanners. In several cases, the presented method has allowed to diagnose or exclude the occurrence of diseases that until now could not unambiguously be interpreted only using the original X-rays.

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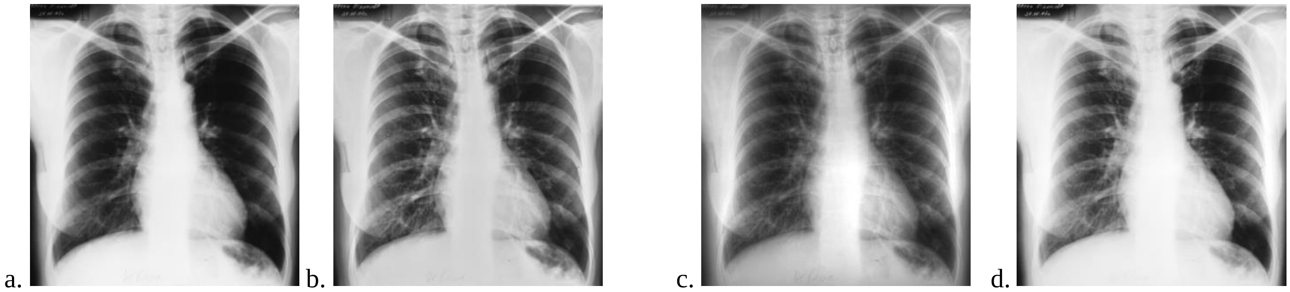

Figure 3. Images after different pre-processing operations: (a) the basic image; (b), (c), (d) corrected images.

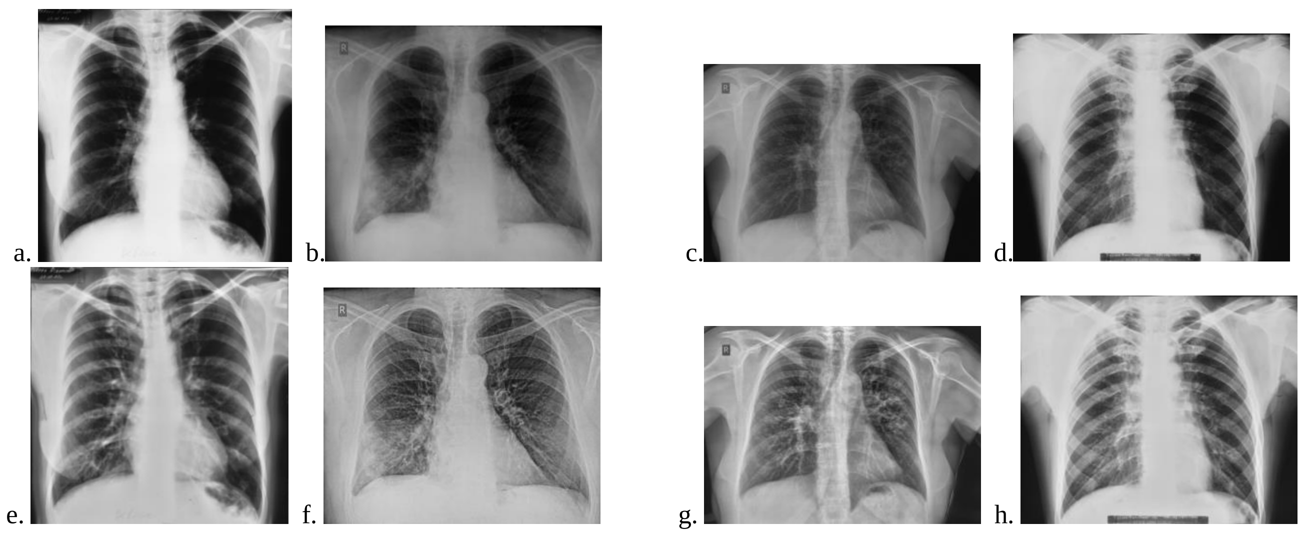

Figure 4. Comparison between classical digitalization method and presented HDR-based digitalization: (a)(b)(c)(d) digitalization by classical method; (e)(f)(g)(h) digitalization by the presented HDR-method.

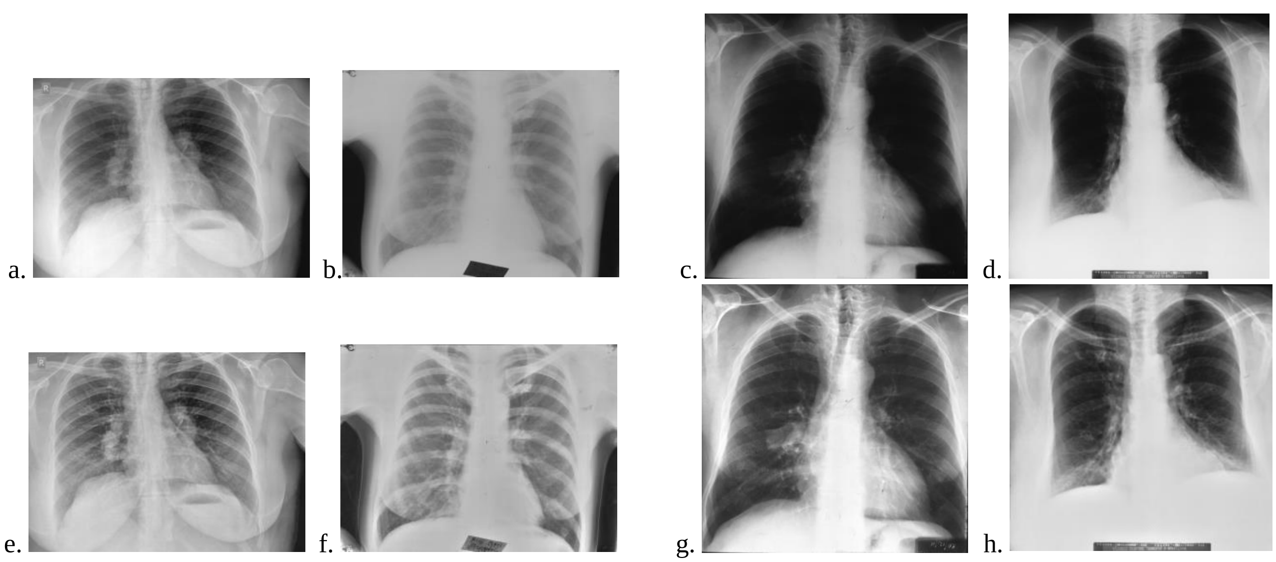

Figure 5. Comparison between classical digitalization method and presented HDR-based digitalization: (a)(b)(c)(d) digitalization by classical method; (e)(f)(g)(h) digitalization by the presented HDR-method.