# Enhancement of CT images with Pseudo-HDR Method

**Desislava V. Georgieva, Vesselin E. Gueorguiev, Ivan E. Ivanov**

*Abstract* — **For decades the medical images have been an essential part of the diagnostic process of many diseases. In many cases the quality of diagnosis process depends on the quality of the medical images. An example is the diagnosis of cancer in its early stages, when the changes are very small and hard to spot. Therefore, the image quality improvement is an essential part of medical imaging techniques. This determines the importance of research to improve the quality of the medical images.**

**The paper presents a new version of our Pseudo-HDR Method for medical image enhancement: we examine ability to use our approach to quality enhancement of CT images. The presented results are the evaluation of method quality and the technology how to apply the method to CT image enhancement.**

*Index Terms* — **CT image, HDR imaging, quality image enhancement, X-ray image.**

## I. Introduction

The common technique of images interpretation as a part medical diagnostic process is the visual one. This makes the process depend on the observer [5]. It has been found that some physicians have systematic underestimation or overestimation of the information in the image: they reject some information as insignificant or overestimate the importance of structures in the image. Additional influence on the final image is exerted by overall readability of the image because the conclusions "no changes" or "no noticeable changes" are not the same thing. Some other factors for the proper medical image interpretation are time for investigation, environment, image lighting, type of media of the image, and the physiological/functional status of the physician [6][7]. All this leads to the need to improve the readability of images and to reduce the factors influencing the information extraction and perception.

Today image enhancement tools are a mandatory part of current generation medical imaging systems: the image enhancement is one of the preparatory steps and it is applied before starting the image analyses. Image enhancement refers to any technique that improves or modifies digital images, so the resulting image is better suited than the original for a particular application. During the image enhancement process one or more attributes of the image are modified. The set of modified attributes, the modification method, and the range of possible attributes values are specific to a given task. Moreover observer-specific factors such as the human visual system and the observer's experience will introduce a great deal of subjectivity into the choice of image enhancement methods. These problems are well addressed in the Arulmozhi, Perumal, Kannan, and Bharathi paper [5].

The human vision can be accommodated to a dynamic range of $10^{14}$:1 but the iris is simply not as flexible and the human perception of intensity changes is logarithmic (the Weber law). The human eye covers the dynamic range of about $10^{5}$:1 at one time and this is bigger than the top dynamic range of most real-world scenes. This is much more than the capabilities of modern devices for image creation and visualization: for comparison, computer displays have dynamic range of $10^{3}$:1 and digital cameras have dynamic range of $10^{4}$:1. A set of methods in photography/imaging, supposed to capture/create greater dynamic range between the darkest and lightest image areas than current standard digital imaging methods, is named High Dynamic Range Imaging [6][7]. Therefore, a non-HDR image device takes pictures at one exposure level with a limited contrast range. This leads to the loss of details in dark or bright image areas, depending on the camera exposure setting. HDR methods compensate detail loss by taking multiple pictures at different exposure levels and stitching them together to create an image which presents the greatest number of details in both dark and bright areas. Data stored in HDR-images typically corresponds to the physical values of luminance/radiance that can be observed in the real world and this presents a great difference from classical digital images: classical digital images represent intensities and colours that should appear on an output device (display, printer, plotter, etc.). Therefore, HDR image formats are called scene-referred while classical digital images are called device-referred.

In photography dynamic range is measured in EV (Exposure Values) differences between the darkest and brightest parts of the image that show detail: an increase of 1 EV is a doubling of the amount of light. Using EVs not very strict categories of images are [9]:

- High Dynamic Range (HDR) images: These have a dynamic range of about 14EV and these images (they use 32-bit float values without limitation for channels bits depth) are usually produced by merging multiple 12-14 bit images of different exposures (most often these are raw data files).
- Medium Dynamic Range (MDR) images: These have a dynamic range of [9 EV, 12 EV] and can originate from a file with 16-bit depth, or by merging 3 or more 8-bit images with different exposures.
- Low Dynamic Range (LDR) images: These have a dynamic range of lover than 8 EV. This means one 8-bit image.

Human visual perception of images depends on small set of image's characteristics: brightness, contrast (local and global), sharpness, saturation, and dynamic. X-ray and CT images are grayscale images with bits depth up to 16 bits. Their visual perception depends on the three most common image characteristics: brightness, contrast (local and global) and sharpness. Saturation and image dynamic range are not directly relevant to these two types of medical images: they are grayscale (no saturation) and the dynamic range of the visualization systems (computer displays) is less than human vision dynamic range. Therefore, all quality enhancement methods change the intensity of pixels so as to provide optimal brightness, contrast and sharpness values. While brightness, contrast and sharpness may appear to be the simplest of image controls and may appear to be mutually exclusive controls, the reality is different: the changing any one of them can create quite complex effects in post-processed images.

This paper presents a new version of our image enhancement method for X-ray images. The new method uses same approach but we study the visual quality differences between X-rays and CT-images and adopt our technique how to use method. Medical image reliability analyzes are performed by specialists with appropriate medical qualifications.

## II. The Core Idea of Our Image Enhancement Method

The R&D medical image enhancement methods and techniques isn't a new research topic. Among the many types of image processing, image enhancement is one of the vital processes because it is one of the preparatory steps and it is applied before starting the image analyses. Essential image enhancement includes but is not limited to intensity and contrast manipulation, sharpening and filtering edges, noise reduction, and background removal. In this context, 'image enhancement' means any method or technique for image changing, so the resulting image is more suitable from user point-of-view. In paper "A Pseudo-HDR Method Implementation for Medical Images Enhancement - New post-processing method for X-ray chest image quality enhancement" [1] we present our classification of medical image enhancement methods (see Fig. 1). After 6-7 years the set of most often used methods have no a material changes.

General image enhancement methods use a wide variety of image processing operators [1], but only a part of them are used for the processing of medical images: the preservation of the medical image authenticity are the fundamental quality criteria. Our analyses show that medical systems most often use the following functional groups of operators.

- *Arithmetic/Logic* operators are different forms of unification/fusion of the pixels of the two images to obtain the resultant pixel.
- *Look-up-table (LUT)* operators change pixels' grayscale levels by functional transformation on a single pixel.
- The most common purpose of *geometric operators* is to remove the geometric distortions and shifting of the image, due to the image acquisition.
- *Image analysis* operators.
- *Digital filters*
- *Morphologic* operators are operators for analyzing pixels groups using mathematical morphology.
- *Attribute* operators are operators for detection of basic properties or characteristics: detect edges, lines or other specific structures are most often used operators.
- *Image transformation* operators are used to transform the image into another presentation in order to more easily process it for certain needs.
- *Synthesis* operators: most often these are noise generation methods.

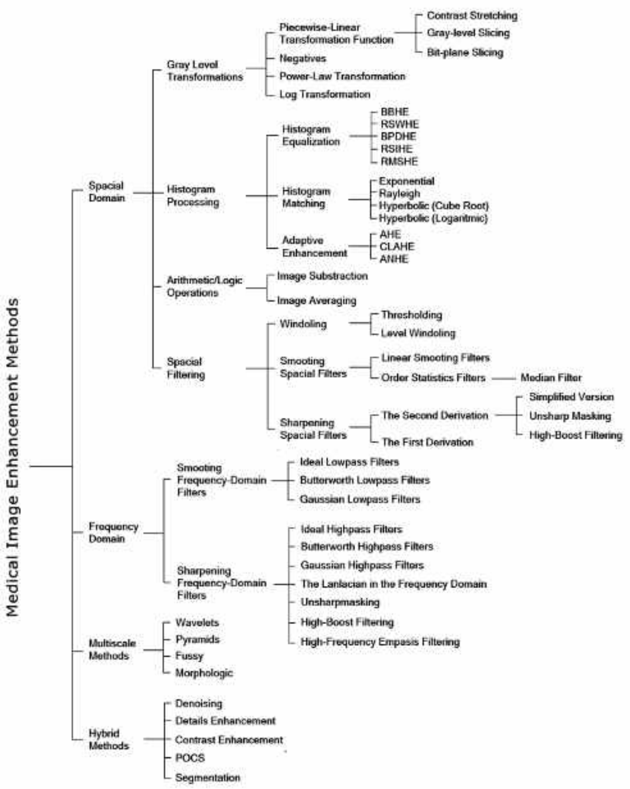


**Fig 1**. The classification of medical image enhancement methods (source [1])

The most common feature of the existing quality enhancement methods of medical images is the fact that they cannot substantially increase the dynamic range of the image: the improvement of the image contrast, sharpness, and brightness is achieved through redistribution of the values of the intensity of the image pixels. This limits the opportunities for selection of optimal values, because a limited amount of information about the luminosity/radiance power stored as pixel intensity is used. The main problem of this approach is the possibility of occurrence of medical artefacts because the resulting grayscale levels of pixels can be an indicator of pathological changes in tissues and organs! This reduces the quality and the plausibility of the resulting image, so the classical evaluation criteria (e.g., increasing the dynamic range and maximizing the contrast) of contrast enhancement are inapplicable.

In 2012 year, we have been finishing a first stage of a project with Medical University of Sofia: the goal of the project is a development a new set of methods for high quality digitalization of X-ray, CT, and MRI films and plates. Why somebody needs a plate digitalization if the new generation X-ray, CT, and MRI apparatus are digital machines? In practice physicians need to compare current and past patient's status very often, but patients have no "digital archive": if the disease requires tracking patient's status, patient receives plate (or plates) with medical images when leaving the hospital. The result of our activities is a new high quality method for digitalization of plates/films [2][3][4].

In 2013 year, we have been starting a second stage of the project: the goal of the project is a development a new method for image quality enhancement. Why you need a new quality enhancement method if we have a new high quality digitalization method? In practice patients use different apparatus for digitalization and many times the digital image quality is not quite good.

The first version of our new method has been creating to enhancement a quality of digital Xrays [1]: we use a different approach to solve the issue of the optimal intensity distribution over image pixels. The core idea is to simulate conditions of medical image generation: this is achieved by creating a creation a model of a luminosity distribution. We select a HDR imaging as a core technology because HDR-image represents the description of the luminosity/radiance in the nature scene. After a HDR-image is created the method allows determining the optimal mapping from a HDR-image to a LDR-image: the goal of this activity is similar to the goal of the digital X-ray apparatus setup procedure before the actual patient shooting.

To achieve the correct results, it is necessary to create a correct luminosity model. The quality of the HRDI-based model is determined by the selection of "right" set of LDR-images: these images are created with different exposure value. In photography this is achieved through capturing a new image with a selected exposure. This isn't applicable for our method because we have no a real shooting. We have a single digital image and we can use this image to obtain an image that is accurate enough to simulate shooting result with different exposure values. Therefore, it was necessary to establish a procedure that simulates changes in the image when shooting with different exposure.

We performed a large amount of experiments with real images and they showed the following pattern: increasing/decreasing the exposure value changes shooting image characteristics sharpness, contrast, and brightness. The pixel-level this manifests itself only as a change of intensity of image pixels because digital Xrays are a grayscale images with up to 14 bits depth. Our tests and analyses of digital editing tools and applications have been showing that a few different techniques can be used for simulation a pixel-level intensity changing [1]:

- using the brightness and the contrast control;
- using the gamma-correction;
- using the brightness and the contrast control followed by a gamma-correction;
- using the gamma-correction followed by a brightness and contrast correction.

There is also another possibility, the so-called "direct exposure changing" or "exposure control". Our test showed that this function is very specific for every editing tool and we stopped to use it.

## III. Our new version of Pseudo-HDR Method

The digital X-ray apparatus and the CT (computer tomography) use different approaches for digital image creation [8]:

- A X-ray apparatus uses radiation to produce images of the body: the apparatus sends electromagnetic waves (radiation) through the body and they reflecting the patient's internal structures on the exposed film.
- A CT scan creates cross-section images of human body: it combines series of X-rays taken from different angles and final image provides more detailed information than classical X-ray images do.

The visual difference between the two types of images is also very well visible (Fig. 2):

- CT images are more contrast and more sharpness.
- CT images have well defined contour edges between internal structures.
- CT images have well visible small details.

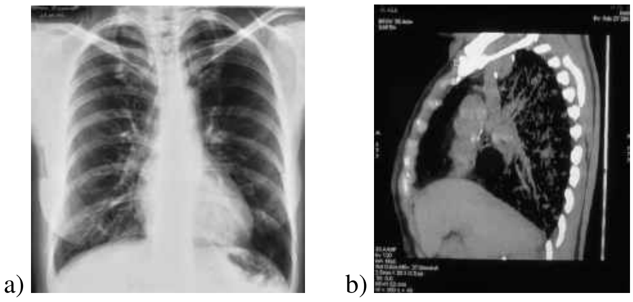

**Fig 2**. The visual differences between (a) X-ray image and (b) CT image.

These differences have to be carried out repeated tests to simulate the intensity of image pixels. Figure 3 shows the representative images for the three main classes of images used for research (the separation is based on the visual characteristics of the images).

**Fig 3**. Examples of CT image types.

The technology for determining the values for contrast involves the following steps (Fig. 4):

Step 1: An identification of optimal exposure parameters of for high quality single shooting – this image is our "base image" and we named it "0 EV image"

Step 2: A high quality digitalization of real CT images with different exposures - from -3 EV to +3 EV by a 0.5 EV step based on the "0 EV image".

Step 3: A creation of image with a simulated exposure value – this is accomplished by changing the parameters of the "0 EV image" to reach the visual characteristics of the image with predefined exposure.

Step 4: An evaluation of simulation quality - the difference between the real image and the simulated image is evaluated. If necessary, we return to step 3 to change the simulation parameters

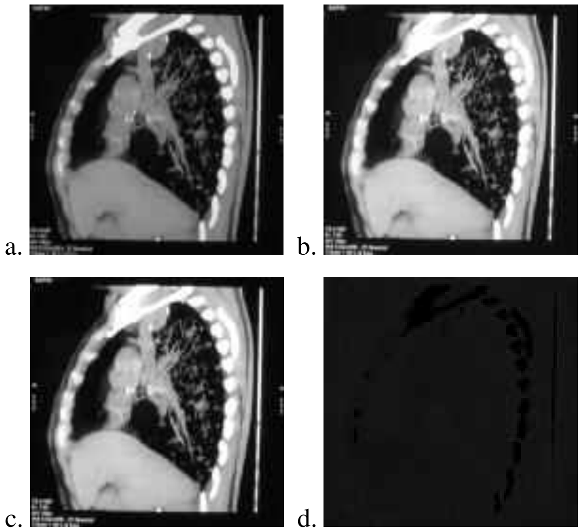

**Fig 4**. Visual presentation of a test process: a) the "0EV image"; b) the captured image (+1.0 EV); c) the simulated image (Table 1 values); d) the difference between (b) and (c) - the histogram is stretched 4 times.

More than 500 images were examined to determine the optimal simulation values. The final values are shown in the tables below as follows:

- simulation by brightness and contrast followed by gamma-correction – Table 3;
- simulation by brightness and contrast – Table 2;
- simulation by gamma-correction followed by brightness and contrast – Table 3.
- simulation by gamma-correction – Table 4;

TABLE I. VALUES EXPOSURE SIMULATION: BRIGHTNESS AND CONTRAST FOLLOWED BY GAMMA-CORRECTION

| | Exposure (EV steps) | | | | | |
|---|---|---|---|---|---|---|
| | *-3.0* | *-2.5* | *-2.0* | *-0.5* | *-1.0* | *-0.5* |
| brightness | *-85* | *-65* | *-57* | *-48* | *-33* | *-85* |
| contrast | *-55* | *-43* | *-37* | *-33* | *-25* | *-55* |
| gamma-correction | *1.04* | *1.04* | *1.03* | *1.02* | *1.02* | *1.04* |
| | Exposure (EV steps) | | | | | |
| | *+0.5* | *+1.0* | *+1.5* | *+2.0* | *+2.5* | *+3.0* |
| brightness | *-15* | *21* | *35* | *49* | *65* | *74* |
| contrast | *-6* | *16* | *29* | *37* | *45* | *53* |
| gamma-correction | *1.01* | *0.99* | *0.99* | *0.98* | *0.98* | *0.98* |

TABLE II. EXPOSURE SIMULATION: BRIGHTNESS AND CONTRAST

| | Exposure (EV steps) | | | | | |
|---|---|---|---|---|---|---|
| | *-3.0* | *-2.5* | *-2.0* | *-0.5* | *-1.0* | *-0.5* |
| Brightness | *-85* | *-65* | *-57* | *-48* | *-33* | *-15* |
| Contrast | *-55* | *-43* | *-37* | *-33* | *-25* | *-6* |
| | Exposure (EV steps) | | | | | |
| | *+0.5* | *+1.0* | *+1.5* | *+2.0* | *+2.5* | *+3.0* |
| Brightness | *21* | *35* | *49* | *65* | *74* | *83* |
| Contrast | *16* | *29* | *37* | *45* | *53* | *58* |

TABLE III. EXPOSURE SIMULATION: GAMMA-CORRECTION CONTROL FOLLOWED BY BRIGHTNESS AND CONTRAST CORRECTION

| | Exposure (EV steps) | | | | | |
|---|---|---|---|---|---|---|
| | *-3.0* | *-2.5* | *-2.0* | *-0.5* | *-1.0* | *-0.5* |
| gamma-correction | 2.82 | 1.97 | 1.89 | 1.44 | 1.35 | 1.24 |
| brightness | -64 | -45 | -33 | -30 | -16 | -5 |
| contrast | -65 | -46 | -37 | -28 | -20 | -10 |
| | Exposure (EV steps) | | | | | |
| | *+0.5* | *+1.0* | *+1.5* | *+2.0* | *+2.5* | *+3.0* |
| gamma-correction | 0.78 | 0.64 | 0.57 | 0.49 | 0.41 | 0.36 |
| brightness | 5 | 7 | 8 | 8 | 6 | 4 |
| contrast | 14 | 24 | 31 | 39 | 43 | 46 |

TABLE IV. EXPOSURE SIMULATION: GAMMA-CORRECTION VALUES

| | Exposure (EV steps) | | | | | |
|---|---|---|---|---|---|---|
| | *-3.0* | *-2.5* | *-2.0* | *-0.5* | *-1.0* | *-0.5* |
| gamma-correction | *2.82* | *1.97* | *1.89* | *1.44* | *1.35* | *1.24* |
| | Exposure (EV steps) | | | | | |
| | *+0.5* | *+1.0* | *+1.5* | *+2.0* | *+2.5* | *+3.0* |
| gamma-correction | *0.78* | *0.64* | *0.57* | *0.49* | *0.41* | *0.36* |

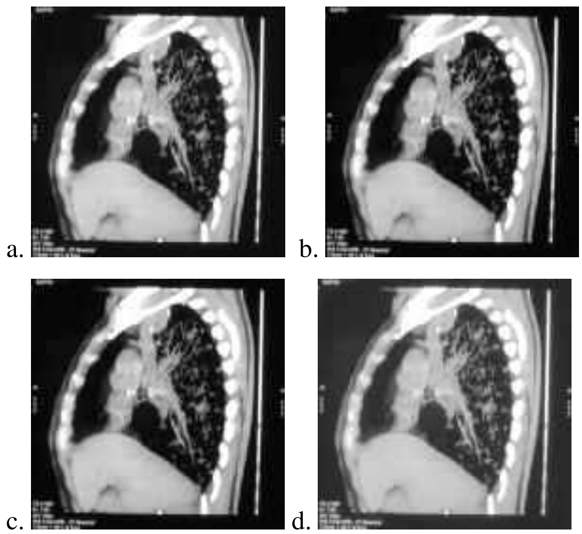

**Fig 5**. Exposure value simulation comparison: a) the original CT-image (+1.0 EV exposure); b) Table 1 based values; c) Table 2 based values; d) Table 3 based values.

The evaluation of the simulation results shows that most suitable image exposure simulation is the simulation "Brightness and Contrast followed by Gamma-correction": Fig. 5 shows simulation comparison; Fig. 6 shows the difference between original image and simulated image..

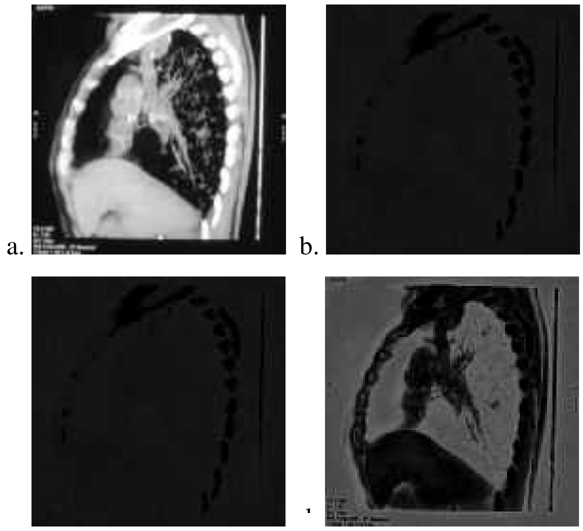

**Fig 6**. The differences between original image and simulated image (histograms are stretched 4 times) Exposure value simulation comparison: a) the original CT-image; b) Table 1 values; c) Table 2 values; d) Table 3 values.

## IV. THE ANALYSIS OF RESULTS

### *A. Method Implementation Results*

The first step to implementing our method is the determination of the number of LDR-images used to create the HDR-image. There are several different options for the number of LDR-images and their exposure values but most common are 3 LDR-images with symmetrical values. We start with symmetrical sets: [0 EV, -2 EV, +2 EV], [0 EV, -2.5 EV, +2.5 EV], [0 EV, -3 EV, +3 EV], [0 EV, -1.5 EV, +1.5 EV]. The second group of tests are sets of asymmetrical exposure values: [0 EV, -2 EV, +2.5 EV], [0 EV, -2.5 EV, +2 EV], [0 EV, -3 EV, +2 EV], [0 EV, -2.5 EV, +1.5 EV], [0 EV, -1.5 EV, +2.5 EV], [0 EV, -1.5 EV, +3 EV], [0 EV, -3 EV, +1.5 EV].

The quality analysis of the resulting images showed that the use of a set of 3 LDR-images is not useful. So the next group experiments were based on sets of 5 images.

The first group of tests were aimed at determining the effect of symmetrical and asymmetrical exposure values of LDR-images.

The second group of tests were designed to determine whether the exposure values should be modified with approximately the same step or can be big differences between the adjacent values.

The third group of tests aimed at determining the range of exposure values: we test ranges [-4EV,+4EV], [-3.5EV, +3.5EV], [-3EV,+3EV], [-2EV,+2EV], [-1.5EV,+1.5EV].

Evaluation of the results shows that:

- The best results are obtained when using the set [-2.5EV, -1.5EV, 0 EV, +1.5EV, +2.5EV] – Fig. 7.
- Use the values in the range (-1.5 EV, +1.5) has no practical significance.
- The sets of asymmetrical exposure values do not lead to the improvement of the image quality enhancement compared to the sets of symmetrical exposure values (Fig. 8).
- The exposure values should be modified with approximately the same step. This reduces the likelihood of the occurrence of medical artifacts. At the same time, the mapping process of the HDR-image to the LDR-image becomes easier.

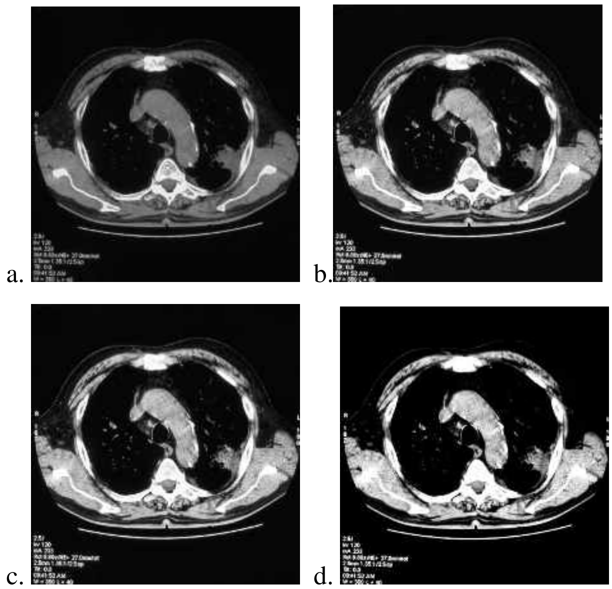

**Fig 7**. Visual presentation of a test process (symmetrical exposure values): a) the original CT-image;
b) the set [-2.0,-1.5,0.0,+1.5,+2.0];
c) the set [-2.5,-1.5,0.0,+1.5,+2.5];
d) the set [-3.0,-2.0,0.0,+2.0,+3.0];.

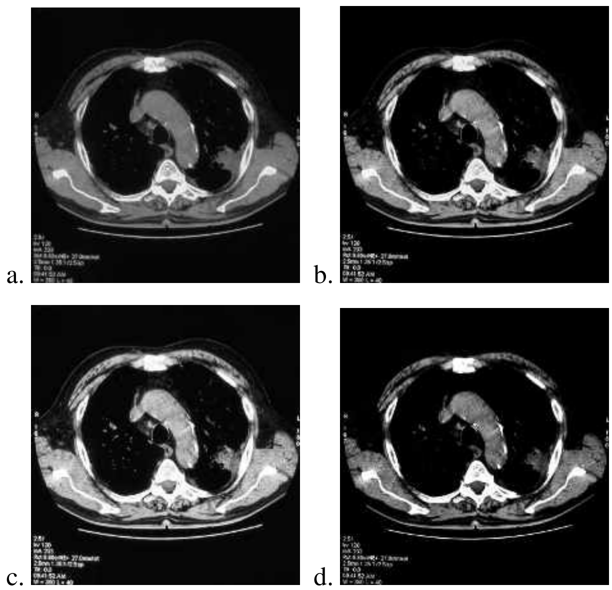

**Fig 8**. Visual presentation of a test process (asymmetrical exposure values): a) the original CT-image;
b) the set [-2.5,-1.5,0.0,+1.5,+2.0];
c) the set [-2.5,-1.5,0.0,+1.5,+2.5];
d) the set [-2.0,-1.5,0.0,+1.5,+2.5];.

### *B. CT-oriented vs. Xray-oriented Method Versions*

The analysis of the test results showed some significant differences between two method versions:

- The “Contrast” value gradient is much higher.

- Exposure-based image changes can be simulated much more accurately. This allows to expand the range of simulated exposure to [-4 EV, + 4 EV] if the dynamic range of final image should be extended.
- The “Gamma-correction” value gradient is much smaller: The increase in the value very quickly leads to the occurrence of medical artifacts in the image.
- The use of the “Gamma-correction” and the “Gamma-correction followed by Brightness and Contrast correction” techniques leads to very rapid deterioration of simulation results for exposures outside the range [-1.5EV, +1.5EV]. The differences between exposure simulation techniques aren’t so dramatic in the X-ray oriented method version.
- The new version must use 5 LDR-images to create the HDR-image, while the old version could be used even 3 LDR- images.
- The noise level substantially alter only when exposures out of range [-2.7 EV, +2.7 EV]. This substantially increases the ability to enhance the contrast of the final image without leads to occurrence of medical artefacts.
- The exposure values of the LDR-images are much more evenly distributed than in the X-ray version.
- The use of asymmetrical values for exposure of LDR-images in a +EV and in a –EV directions does not lead to a significant change in quality.
- CT-oriented version has faster and easier mapping process of the HDR-image to the LDR-image.

## Conclusion

Image quality enhancement is very important because it increases readability and usability of the medical images because internal details and structure become more easily identifiable and more visible. The presented method for pseudo HRD enhancements of medical images enables increasing quality of understanding and information gathering. The comparison of the results of the proposed method with other techniques showed that this method can help to obtain a major improvement in quality without the occurrence of medical artefacts. The presented method was used for analyses of CT images of heads for endocrinology diseases in Medical University Sofia.

The next step is extending the Pseudo-HDR Method to MRI images.

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**mag. arch. Desislava Velcheva Georgieva. PhD,**. is an assistant-professor in the Informatics Department, New Bulgarian University – Sofia. Her research interests include: computer graphics, 3D realistic visualization, computer animation, computer aided medical imaging, computer-based medical system, She has been participated in many research projects and she is an author of many science papers and publications

**mag. eng. Vesselin Evgueniev Gueorguiev, PhD**, is an assistant-professor in the Faculty of Computer Systems and Control, Technical University of Sofia, Bulgaria and a lecturer in New Bulgarian University of Sofia, Bulgaria. He starts his academy activities in 1992 as a PhD student in TU-Sofia. His research interests include: embedded and mobile systems; program generators; validation and verification of software projects, systems and applications; computer graphics and animation; stereoscopic visualization; medical informatics. He has more than 80 papers and he has been participated in many research projects.

**mag. eng. Ivan Evg. Ivanov, PhD,** is an associate-professor in the Faculty of Automatics, Technical University of Sofia, Bulgaria. He starts his academy activities in 1982 as an assistant-professor in TU-Sofia. His research interests include: embedded and mobile systems; program generators; validation and verification of software projects, systems and applications; medical systems and apparatus. He has been participated in many science and R&D projects. He has more than 90 papers and many R&D projects.