Advancing in Digitalized X-ray Images Post-processing

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***Abstract*—The aim of this paper is to present some results and comments about the process of increasing the quality of digitalized X-ray images. The presented results are obtained under several projects. The work is aiming at increasing the quality of computer-assisted methods for diagnosis, based on digital X-ray images. Some techniques and solutions for reducing and removing defects in images are discussed. As a conclusion, some new problems and requirements for these systems have been pointed out.**

Keywords-computer-assisted methods; digital X-ray image; adaptive filtering algorithms

I. INTRODUCTION

The development of medical imaging applications based on 2D medical images and their processing can be divided into two stages - before and after 2008. The first stage was focused on the development of medical imaging applications oriented to Computer-Aided Diagnosis systems (CAD systems) [1]. One of the major characteristics of this period is the big growth of CAD systems tools and modules market. The combination between the increasing of the interest of hospitals management in new CAD systems and technologies and the increased use of digital medical imaging devices and tools (X-ray, Magnetic-Resonance Imaging, Computer Tomography, etc.) led to annual growth per year expressed by two-digit number in percentage [2]. At the same time, the quality of medical results has been continuously improved and all this determined the growing demands for this class of application in medical and hospital practices.

Since the middle of 2008 this trend has been changed dramatically. Some of the reasons for this are the following:

- Who is the customer of medical imaging applications – patients or hospitals? Today the right answer is 'The hospitals are medical imaging applications customers. Patients are customers of hospital services.' But after 2008 hospitals have had limited funding for development of new systems and they divert the full financial burden to patients. Patients refuse to pay extra money for services they do not understand and they do not know they need. This resulted in the fact that hospitals decreased investments in new imaging-based diagnosis applications and this is the expected trend for the next several years.
- What types of applications are of interest - stand-alone applications or modules and tools for integration with existing Hospital Information Systems (HIS)? An analysis of the market shows that stand-alone applications have seriously been losing their market position. The market needs modules and tools that can be built-in as subsystems of the existing HIS. This has changed investments in research from more general to specific areas which results in products to be directly put on the market.

The additional effects can be divided into two trends and their impact on the new developments has continued to grow. Any of these trends affects the new research and applications directly and indirectly [3][4][5][6]:

- The first problem can best be defined by the conclusion: "Doctors expect from the new technologies only to increase their sensitivity and ability to understand information. They do not want automated diagnosis services and they do not want to be technicians. They want to be doctors."
- The rapid increase of Telemedical tools and devices and future trends in this area generated many questions of comparability of the CAD-application results based on images from different sources for one and the same patient. One of the telemedical approaches is based on distributed medical data obtaining, analysis and diagnosis. The results should be identical regardless of the source of the digital image (a digital X-ray or a digitalized old X–ray plate), and whether it is made in one or another hospital. For example in 10 years it is expected that there will be a new generation of machines and the image quality they will deliver will differ greatly from current quality.

This article is based on the results of an 8 year study and on a project in collaboration with the biggest Bulgarian hospital complex (the Medical University of Sofia). The main task of this collaborative work was to create a vision and architecture for a new generation HIS, taking into account the performance in Telemedicine, m-Health and p-Health approaches and applications and new devices for hospital and outpatient diagnostics. This has led to several interesting studies related to the investigation of techniques and solutions for increasing the quality of digital X-ray images which is the topic of this paper. The surveys on different techniques for digitalization of radiographic images [3,9] focus our studies on assessing the impact of various

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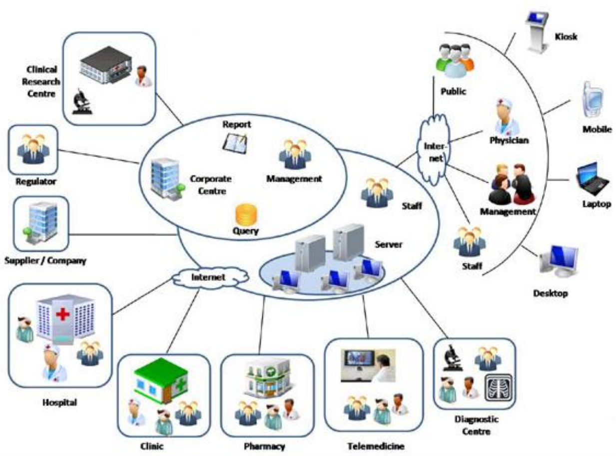
factors on the quality of digitalized X-rays. Three main groups of factor were identified: the process of creating X-ray plates, the condition of digitalized X-ray plates and the technology for digitalization. The results of these studies are presented below.

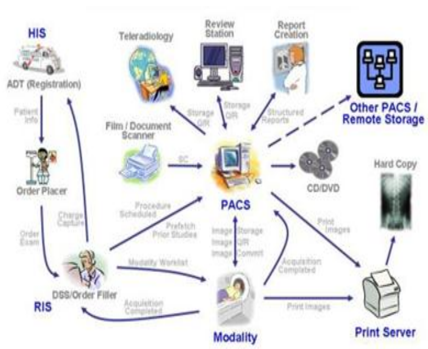
General and innovative structures of Hospital Information Systems are presented on Figure 1. Data sources for HIS and the data flows in these systems are presented on Figure 2.

a) HIS Classic view [10]

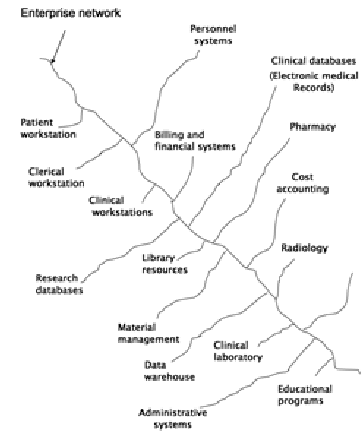


b) Modern HIS [11]

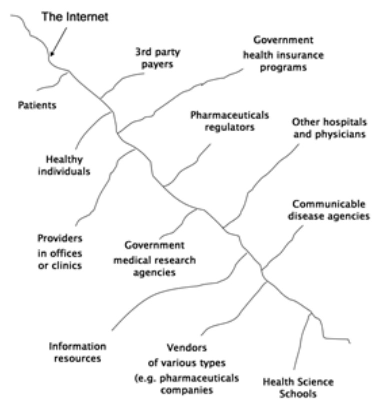
Figure 1. Classic and modern HIS structures and data flows



a) Classic data sources and handling [12]



b) HIS inside data network [13]



c) HIS outside data network [14]

Figure 2. Data sources and data flows in HIS

II. THE PROCESS OF DIGITAL X-RAY IMAGES CREATION AND THEIR QUALITY

The effect is expressed by looking at two sides:

- The need to have methods for normalizing/aligning digital images. The computer-based comparison methods need images of the same quality and characteristics. But different technologies create images with varying contrast, luminance and level of noise.
- Different X-ray machines (by producer and/or settings) produce a different level of illumination in patients with the same health condition. Very often this is accepted as an overexposure (large black areas) and underexposure (large white areas).

In case of underexposed image, shown on Figure 3, the main problem is the lack of information on the image. These types of images have a small dynamic range and unimodal histogram (Figure 3b): a pronounced peak is located at the top of the histogram and there are many small local peaks (the histogram isn't smooth). In this case the classical methods for image manipulation based on the histogram correction do not create credible images from a medical point of view: the resulting image is often characteristic of severe pathologies.

This requires methods which will be used to smooth the local peaks in the upper histogram. One useful solution to this problem is the implementation of adaptive filtering algorithms (Figure 3c).

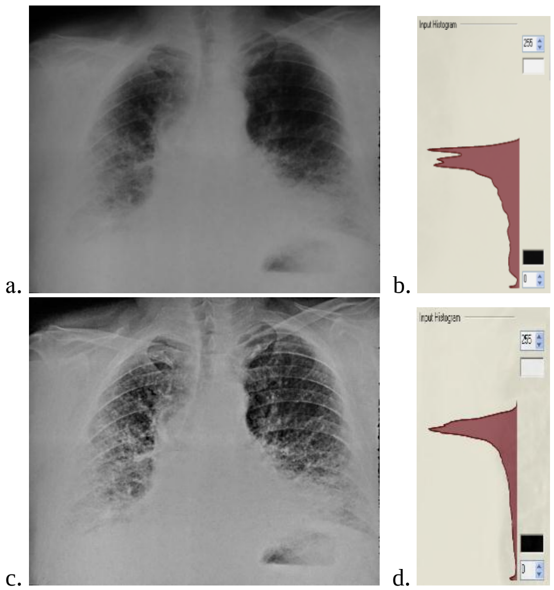


Figure 3. The underexposed X-ray image: a) a digitalized generic image and b) its histogram; c) the image after correction (without medical artifacts) and d) its histogram.

In case of overexposure the problems in X-ray images are different because the dynamic range is much larger and the histogram has a bimodal nature (Figure 4). The results of overexposure are the soft tissue (grayscale levels near black) and areas with low pass X-rays having grayscale tones near white (e.g. thicker bones). In this case the corrections are made at transitions to a unimodal histogram by minimization of the peak in the dark area.

The experiments lead to the conclusion that many of the X-ray plates with the described types of defects can be properly digitalized and can be used for medical purposes. Before the implementation of this processing in many cases the diagnosis made on the basis of defect X-ray plates was impossible or unreliable which led to additional X-ray taking, i.e. increased radiation load of patients.

III. The Condition of X-ray Plates as a Factor of Digitalized Images Quality

The defects in the digitalized X-ray images resulting from changes and defects in the X-ray plates are the next group of problems. The main reasons for these changes are improper storage of plates (usually exposure to direct sunlight) or the effect of aging. As a result, the plates whiten and / or become stained.

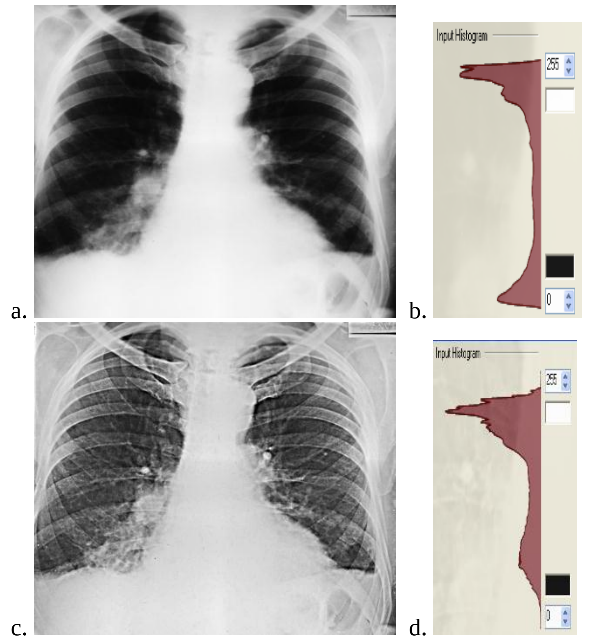


Figure 4. The overexposed X-ray image: a) a digitalized generic image and b) its histogram; c) the image after correction (without medical artifacts) and d) its histogram.

When defects in digitalized images occur the results of physical damages on the surface (scratches, breaking of plates, etc.) a lack of adjustment was demonstrated during the experiments. The reason for this is the lack of information which will allow determining whether the affected place was the fault lesion. Very often the initial form of lesions affect areas of around 2-3 pixels in size and the condition and characteristics of adjacent image areas do not allow to determine the nature of the image in the damaged area.

The changes to the image, which will occur when there is whitening as a result from constant exposure to external light, lead to the following limitations in the digitalized image:

- Reduction of the dynamic range of the image.
- Reduction of the image contrast: uneven whitening of dark and light areas.

It should be noted that these changes can have either global or local nature (according to the exposed area of the plate).

When the change affects the entire image, the actions taken to correct the defects can greatly improve the digitalized image. Examples of these corrections are shown in Figure 3 and Figure 4. In some cases, the order of the application of treatments is essential for the final result.

The quality of the X-ray plate material and the way plates were stored lead to staining, i.e., they are no longer grayscale (Figure 5). For physicians it is not a serious problem to use these modified X-ray plates because of the peculiarity of the human visual system, known as 'approximate color consistence' [3]. Unlike humans, computers do not have this ability. Therefore, after digitalization the added colors often distort the information in terms of computer applications.

Doctors also began to notice the color: approximate color consistence in this case does not work. This makes it mandatory to switch from color to grayscale when the images will be used for the purposes of clinical diagnosis.

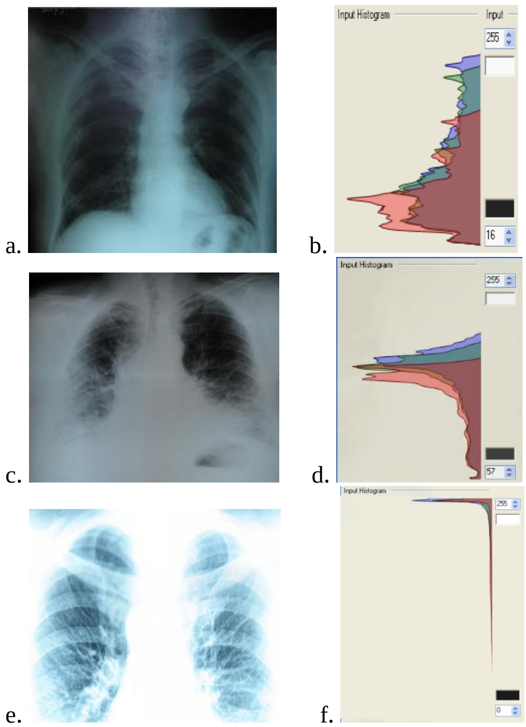


Figure 5. The staining of X-ray plates as a result of improper storage: a), c) and e) generic image; b), d) and f) the histograms of digitalized images (histograms of R, G, and B channels are added).

To minimize the occurrence of artifacts, i.e. to obtain credible medical images, it is necessary to solve the following two major problems: the algorithm used to convert from a color to a grayscale image and the moment of conversion (before or after defect image correction). The studies have shown that the use of grayscale digitalizing devices (scanners or other) is not a solution because today color scanning systems are used. These systems have embedded algorithms for converting the scanned color image to a grayscale one. Unfortunately, assessing the quality of conversion is based on the requirements for printing images and not for medical imaging.

The process of choosing the moment of transformation is essential for the improvements of image characteristics, because the results are not identical. This is due to the fact that these are not commutative operations, i.e. the removal of the color component and processes for quality improvement (correction of the histogram, dynamic range and contrast) give different outcomes in each different order of execution.

In Figure 6, the difference between processing the image before and after conversion from color to grayscale image is shown.

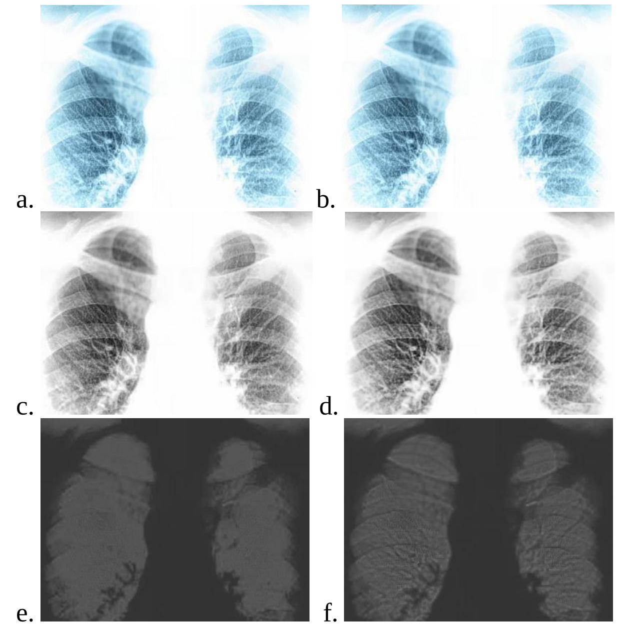
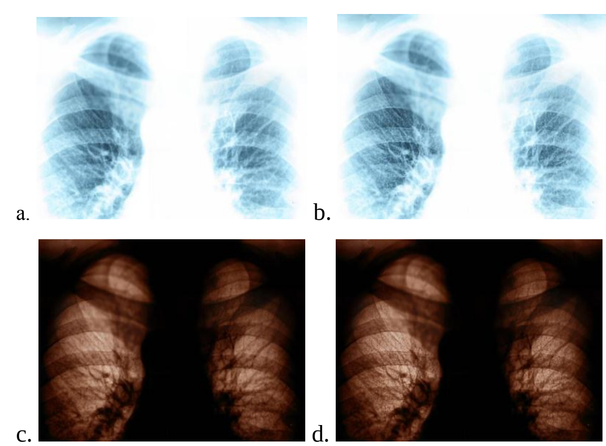


Figure 6. The difference between processing the image before and after conversion from a color to a grayscale image (‘a’ and ‘c’– refocusing; ‘b’ and ‘d’ – local contrast correction): a, b) the correction is on the color image; c, d) the correction is on the grayscale image; e) the difference between ‘a’ and ‘c’ (‘a’ is converted to grayscale); f) the difference between ‘b’ and ‘d’ (‘b’ is converted to grayscale).

The purpose of processing the digitalized image is improving its quality without the occurrence of medical artifacts. Processing of underexposed images (very white) proved that the negative treatments give an easier way to implement changes (it is easier to select the degree of change). The reason for this is the problem with the visual weight of objects in the image and the perception of the degree of correction. The experiments and tests have shown that for the grayscale image, the differences between whether correction is on the normal image or on the negative image are very small and most often do not generate medical artifacts. In colored images it is not the same - even less staining leads to very big image differences (Figure 7).



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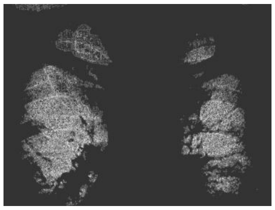

Figure 7. For a color image, the difference between whether the correction is on the normal image or on the negative image is significant: a) generic image; b) corrected image; d) negative of generic image; e) corrected negative image (correction is the same as ‘b’); f) the difference between corrections in normal and negative mode.

Over the years some, research of color-to-grayscale converting methods based on a survey by Čadík has been conducted [4]. The metrics proposed by the authors were not acceptable because they are oriented to image processing for the needs of B/W printing. For medical needs, the quality of the conversion must be determined by the occurrence of medical artifacts or loss of important information needed for the diagnosing of diseases. At this point, we use a heuristic criterion based on the degree of difference between the application of the basic treatment method on a normal and negative image.

- The negative image (Figure 8d) is created from a generic (color) image (Figure 8a).
- The generic and the negative images are converted to grayscale images using the chosen algorithm (Figure 8b, 8e).
- Testing correction is applied to grayscale images (Figure 8c, 8f).
- The corrected negative image is inverted back a normal image (Figure 8g).
- The quality is measured by the difference between the corrected images in a normal form and a negative form (Figure 8h).

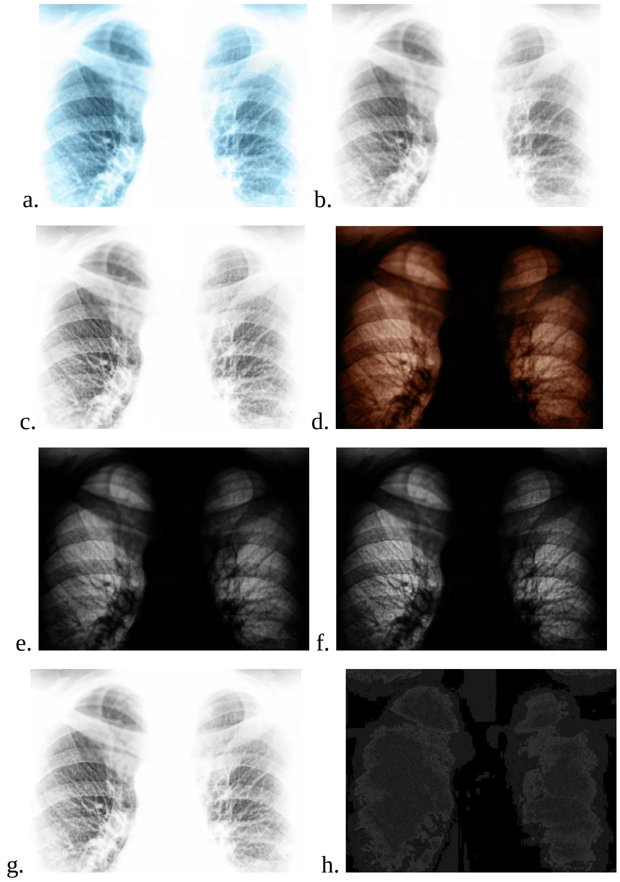

Figure 8. Consecutive activities to evaluate the quality of color-to-grayscale converting methods for medical purposes: a) generic (color) image; b) grayscale image from ‘a’; c) corrected image ‘b’; d) negative image of ‘a’; e) grayscale image from ‘d’; f) corrected image ‘e’; g) inverted image ‘f’; h) difference between ‘g’ and ‘c’ (image histogram is stretched).

IV. Some Comments on the Technology for Digitalization as a Factor for the Quality of the Digitalized Images

The influence of the technology for digitalization generally demonstrates its impact as follows:

- The possibility to digitalize plates greater than the device dimensions and the type of organization of this process
- The existing systems for digitization as color systems
- The characteristics of the lighting systems of the digitalization device.

The lighting system in the scanners is very interesting and has a significant impact on image quality: it can either create defects, or helps to eliminate existing defects. The results received after the experiments leads to the following conclusions:

- The use of a lighting source with variable intensity allows extracting more information compared to the ones with constant intensity. This can be observed better in underexposure images or images with strong staining in the cyan spectrum.
- To take additional advantage of the control of the lighting source intensity it is necessary to develop an algorithm which to determine the optimal intensity. Currently our research does not make possible the development of an automatic procedure for optimal intensity selection: we use manual control and analysis of the resulting images (looking for overexposure areas).
- The use of sources with a different spectrum and the subsequent 'fusion' of the resulting images allows to obtain much more information than the classical lighting spectrum. Here the fusion procedure follows the procedure of images conversion to grayscale.
- The scanners are systems with constant exposure time and parameters. Using a scanner with controllable exposure duration enables the creation of High Dynamic Range Images (HDRI). After

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conversion to Low Dynamic Range Image (LDRI) this allows to obtain a reliable medical image with much more information in comparison to images obtained after a standard digitization procedure (Figure 9). This method produces good results for plates with different quality but its advantages are most pronounced for overexposed images.

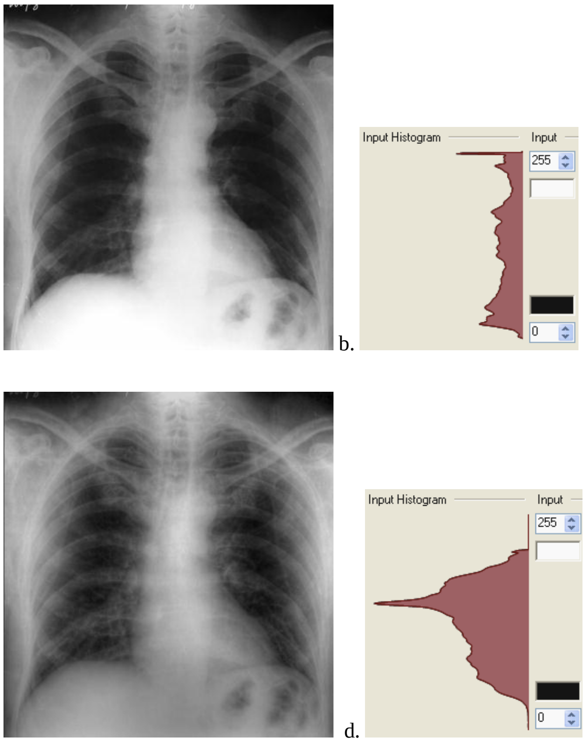

Figure 9. HDRI scanning vs. LDRI scanning: a) generic image (classical scanning procedure); b) its histogram; c) resulting image after HDRI scanning procedure; d) its histogram.

V. CONCLUSION

The need to archive digitalized images obtained during a period of 30-35 years and their use in HIS requires new implementation approaches. According to this, the generation and saving of the native (generic) images, is one of the basic problems to be solved. The need for comparability of the results adds a new level of complexity to this process because it affects the quality concept. When analysis is done by humans (in this case medical doctors) the images quality and comparability is very important but the final result is determined by the doctors' qualification. When the analysis is to be done by computer processing, it requires other approaches. The combination of these contradictory requirements and the fact that doctors refuse to become computer specialists brings new challenges to the well-known area of data handling and representation. One such example is the X-ray images generation, digitalization, handling and processing. This presupposes the development of automated procedures for the preparation of digital radiographic images to be used in the medical system. New types or modifications of the existing adaptive filtering algorithms are also to be developed.

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