Medical image processing as an essential tool in the medical diagnostic process

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Abstract:

The necessity of applying mathematical processing of medical images for progress in the medical diagnostic process is substantiated.

A toolkit based on “conveyor 2D processing and real-time visualization” technology is proposed for working with medical images.

The results of "conveyor 2D processing of medical images" are presented in the form of graphic material.

The necessity of applying mathematical processing of medical images for progress in the medical diagnostic process. A toolkit based on "conveyor 2D processing and visualization of real time" technology for working with medical images is offered. The results of "conveyor 2D processing of medical images" are presented in the form of graphic material.

Keywords:

Processing and visualization of medical images, diagnostic DICOM station.

Index terms:

Processing and visualization of medical images, diagnostic DICOM workstation.

Introduction

The development of new technologies and digital equipment over the last decade has led to the emergence of a large number of new diagnostic and visualization methods.

Diagnostic physicians now have new opportunities to specifically influence the medical image visualization process for high-quality diagnostics.

Depending on the type of examination, doctors now need to independently determine the image processing algorithm, and to do this, they need to be provided with tools that allow them to perform such processing in the shortest possible time.

The power of modern personal computer processors and graphics visualization tools can meet virtually any medical image processing requirements, and a workstation with software and hardware for processing and visualizing medical DICOM images (example in Image 3) can serve as a tool for the diagnostic process.

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About the signal-to-noise ratio in medical images.

The concept of the signal-to-noise ratio came to medicine from the field of radio engineering. The transformation of the concept of "signal/noise" into the field of image visualization occurred with the advent of television systems ("snow" on the screen, "noisy" images, etc.). The nature of this noise remains in the field of electrical signal conversion, rather than in the field of image formation itself. There is a difference between the concept of "signal/noise" arising during signal conversion, which radio engineering and electronics have learned to cope with, and "signal/noise" arising during the initial formation of the image.

With the development of diagnostic medical equipment, the concept of "signal/noise" has migrated to the field of medical equipment characteristics, since a significant reduction in the "signal/noise" ratio when obtaining the initial image seriously complicates the diagnostic process.

Methods for obtaining medical radiological images are based on the passage of radiation through the patient's body, in which, simultaneously with absorption, there is also omnidirectional reflected radiation from the entire volume exposed to radiation - this is characteristic of all physical methods of obtaining primary radiological images.

The result is a "true" image overlaid with *an* "*induced (artificial) image*," which is parasitic noise that blurs the "true" image. This parasitic noise must be minimized.

About the resolution of diagnostic equipment

Recently, medical diagnostic equipment has achieved enormous resolution of primary medical image sources:

- in terms of the number of pixels - more than 32 million pixels (32 Mpix) per image frame, for example in mammography, with a volume of 64MB and more;
- up to 16,385 shades of gray (14 bits) per pixel, even up to 65,536 shades of gray (16 bits).

For dynamic processes characteristic of angiography, the trend towards increasing the resolution of each frame to 1024x1024 is accompanied by an increase in the shooting speed (up to 60 frames/second), which leads to a nonlinear increase in the volume of each angiographic series, which can reach 1GB (1 gigabyte), while the number of series (projections) can reach 10-15 or more. (Image 1, Image 2). The resolution of angiographic imaging is expected to increase to 2048x2048, which will cause another increase in the volume of angiographic studies.

A series of spiral computed tomography scans, with a standard frame resolution of 512x512 pixels, can have up to 3-4 thousand frames, which amounts to 1.5-2 GB (gigabytes) of information.

It should be noted that a twofold increase in image resolution leads to a fourfold decrease in the useful signal, with the same image acquisition parameters, and a fourfold deterioration in the signal-to-noise ratio in pixels.

The very high spatial resolution of medical images, for example, images obtained on the EOS scanner from Biospace Med, can reach a format of 16000x8000 (about 130 Mpix), which means that viewing the image at a scale of 1:1, or even 1:2 scale, is meaningless due to the prevalence of noise in the pixel over the image, and no mathematical processing methods can improve image quality at such spatial resolution.

Increasing the resolution of images leads to a significant deterioration in the signal-to-noise ratio in high-resolution images due to the physical properties of both the sensors and the radiation process. Improving the signal-to-noise ratio in a high-resolution image is only possible by applying special processing methods while simultaneously reducing the resolution, which is a compromise between increasing the image resolution and improving the signal-to-noise ratio.

It should also be borne in mind that the resolution of an image in pixels and the resolution of the same image in "line pairs per millimeter" (lp/mm) are completely different concepts that are related to each other through the physical size of the pixel, for example (theoretical values):

- the theoretical resolution of a mammographic image at 10 lp/mm corresponds to a pixel size of 50 microns, which on a 24x30 cm (10x12 inch) image results in a frame size of 4800x6000 pixels, and on an 18x24 cm (8x10 inches), the frame has a format of 3600x4800 pixels, and it is desirable to view 4 mammography frames simultaneously (Image 4)!

- For images obtained from a 432 x 432 cm (14 x 14 inch) Digital Flat Panel with a resolution of 2880 x 2880, the pixel size is 150 microns, and the theoretical resolution of the panel is approximately 3.3 lp/mm (Image 5).

On the need for mathematical processing

It is important to understand that the theoretical resolution of the image is unattainable due to the presence of *an* "*induced (artifact) image*," which is parasitic noise that blurs the "true" image.

The resulting (visible) resolution of the unprocessed source image is reduced by 20-40% due to the above reasons. At the same time, the "*induced (artifact)* image" can be partially, and sometimes significantly, eliminated through the sequential application of several mathematical image processing functions.

It should be noted that the processing technology depends both on the image itself and on the methods used to obtain it, so it is not possible to automatically set the processing functions and parameters. Instead, it is necessary to iteratively adjust the processing functions and parameters based on the displayed image in order to achieve the high-quality visualization required for the diagnostic process. The maximum resolution of the processing results depends primarily on the signal-to-noise ratio of the original images.

Similar tasks arise when creating a print image from one or more images, both when printing on medical DICOM printers and when printing on professional high-resolution printers.

For three-dimensional (3D) visualization, the vast majority of medical software developers have developed a huge set of tools for creating three-dimensional models of the objects under study.

However, even leading manufacturers of medical diagnostic equipment have not created high-quality tools for processing two-dimensional (2D) images, which forces doctors to guess rather than actually see the diagnosis in the image.

It is also necessary to distinguish between medical image processing for visual diagnosis and specialized calculations in specific areas of medicine. Calculation tools are usually available on modern devices and on some specialized DICOM workstations that are part of the PACS system.

About digital medical image processing technology.

Simply changing the brightness, contrast, and using a single filter (usually 8-bit), which are used in most so-called "DICOM Viewers" and even on most DICOM workstations, it is fundamentally impossible to solve the problem of high-quality visualization.

A fundamental publication on methods of mathematical image processing, including medical images, is the monograph by R. Gonzalez and R. Woods, Digital Image Processing. In the monograph, medical image processing is given one of the most important places, along with disciplines such as astronomy, physics, etc.

Mathematical image processing functions have been known for quite some time, but the issue lies in the creation *of medical technology—a sequence of individual mathematical image processing functions*—to obtain and visualize diagnostically significant images.

In our opinion, diagnostic physicians should be provided with the widest possible range of tools that will enable them to apply a sequence of several 16-bit 2D filters, several nonlinear 16-bit transformation functions, 16-bit image spectrum modification functions (histograms), special scaling functions, etc.

For maximum quality leveling of *the* "*induced* (*artifact*) *image*," it is necessary to build an *adaptive (customizable) sequential 16-bit processing pipeline from various mathematical functions* (methods) that implement the "2D Real-Time Processing and Visualization" technology.

As the authors' experience shows, the use of a sequence of mathematical processing functions allows the visible resolution of the primary image to be increased by 1.2-1.5 times (in lp/mm).

About the speed of medical image processing.

At the same time, it should be borne in mind that an increase in resolution leads to a nonlinear increase in the amount of computation required for high-quality, diagnostically significant visualization, so the issue of "real time" becomes crucial for ensuring the speed of the processing and visualization system in response to changes in the parameters of the processing functions.

The physician should feel that changes in processing parameters, within a minimum time interval, ideally zero, are reflected in changes in the image itself—this is the "real-time" mode.

Control of such tools must be at the physician's fingertips at all times for real-time work—minimizing menu navigation, which completely unjustifiably takes up working time, with all the consequences that follow.

At first glance, this may seem to saturate the control interface, but this is compensated for by the ability to use processing functions that are not typical of standard imaging techniques, allowing the creation of diagnostically significant images, for example:

in dual-energy mammography or dual-energy lung imaging (Image 5), the use of subtraction technology elements allows soft or dense organ tissues to be leveled in the final image.

About medical imaging technology

The eye, as a physiological object, cannot distinguish more than 256 brightness gradations in the pixels of a gray image. In high-resolution images, everything depends on what range of values and what processing methods will be used to convert the final range of 256 brightness gradations (8bits) that can be correctly displayed by modern professional monitors.

Modern professional monitors operating in the full RGB color range have built-in calibration tools—12-bit (4096 steps) LUT (Look Up Table) conversion tables for each color separately.

A 12-bit LUT allows for a perfectly linear change in image brightness from the value of the visualized pixels, as perceived by the human eye.

Please note that the internal LUT tables of monochrome "medical" monitors are only 10-bit (i.e., 1024 steps). The use of monochrome "medical" monitors was due to the need to view darkened areas of the raw image, which was achieved by means of an additional DICOM LUT (10-bit) table of the monochrome monitor and a non-linear conversion function placed in the DICOM LUT.

In terms of technical characteristics, modern professional high-resolution color monitors surpass monochrome "medical" monitors, with the exception of the maximum brightness of the images obtained (it is twice as high for monochrome monitors). At the current stage of development, there is no need for excessive brightness. In the authors' experience, the brightness of professional monitors is set to 50% (with a contrast ratio of 75%), and thanks to mathematical image processing and visualization on the monitor across the entire visibility range—in 256 gradations of each color (or in 256 gradations of gray)—the visualization of even the most shaded areas does not present any difficulties.

CONCLUSIONS:

1. Medical image processing is not drawing something new on the image, as some believe, but is a mathematics-based technology for revealing hidden internal elements of the image that are practically invisible without processing.

2. Medical image processing does not distort the original data, but allows the detection of subtle organ structures in different types of examinations, specially visualized and enhanced for high-quality visual diagnosis.

3. Visualization of processed medical images is a mandatory first step, especially in complex pathologies, for reliable diagnosis.

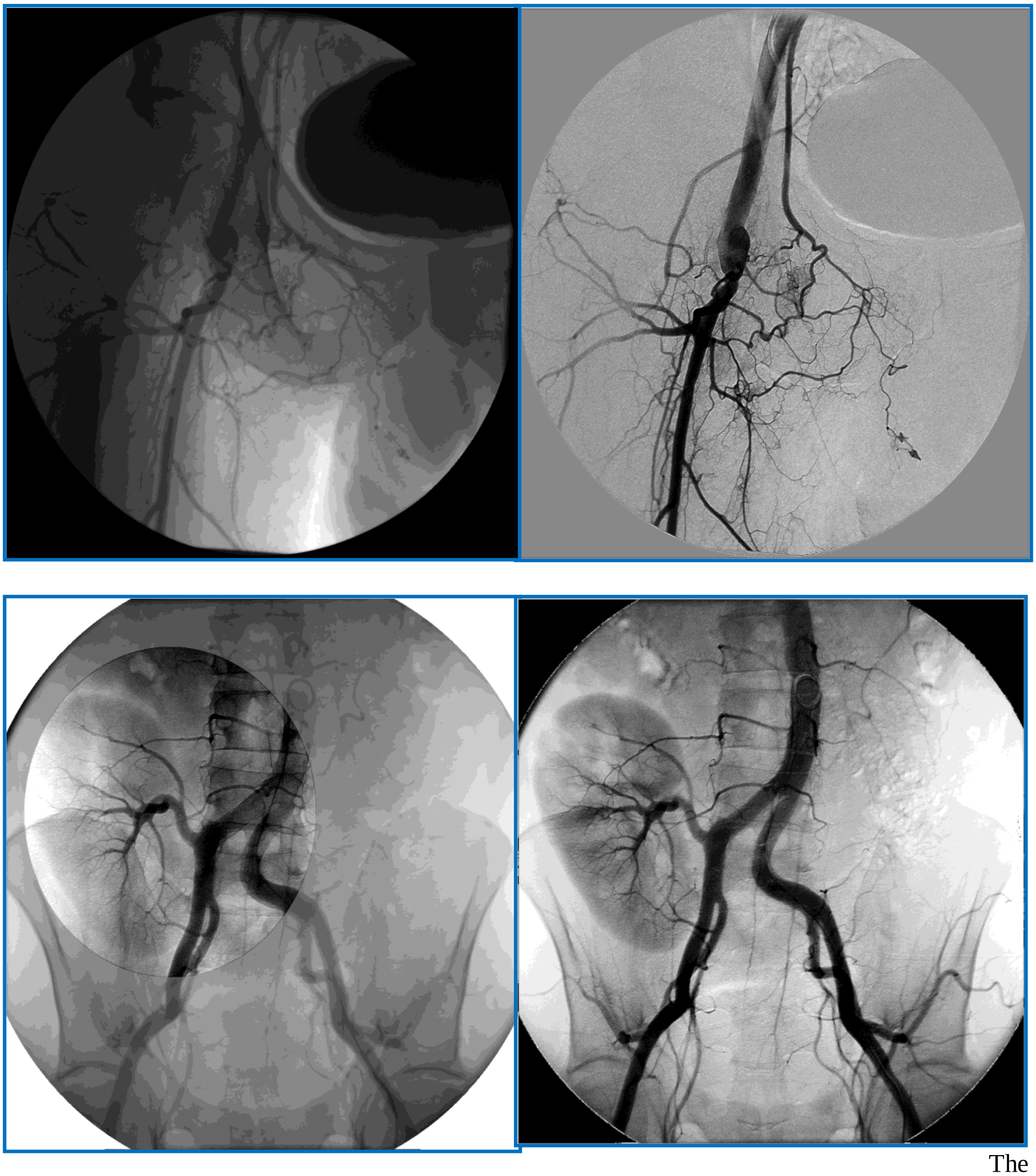
4. Medical image processing allows the use of professional "DICOM Ready" LCD monitors for high-quality visualization of the diagnostic process at a lower total cost of ownership (TCO).

P.S. To highlight the essence of the problem and avoid overloading the article, the authors have deliberately omitted basic mathematical formulas and descriptions of medical image processing technologies (due to the excessive amount of information). A detailed description of the latter can be found in the literature listed below and on our organization's website.

Examples of image processing in radiological studies

Processing and visualization of medical DICOM images is performed on Michelangelo diagnostic DICOM stations, COURSE-AS1 LLC, Russian Federation.

Use of the **"Real-Time DSA"** module with various processing subfunctions.
Image 1. The format of each image frame is 1024x1024x10b at 30 frames/sec.

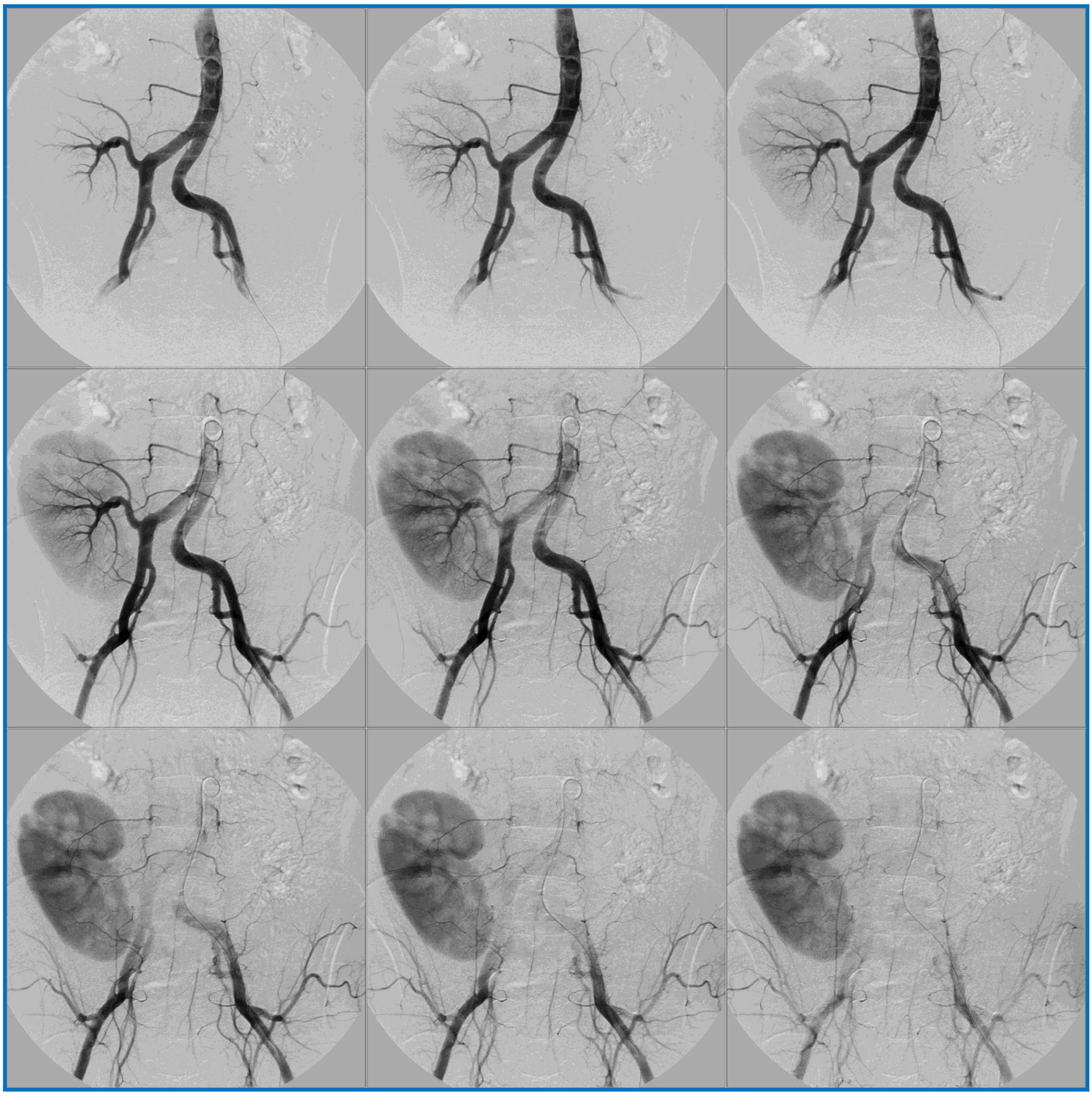


The original frames of the angiographic series are shown on the left.
The top right shows the clean "DSA mode" of the upper left frame of the series.
The bottom left shows the "Zone Processing" mode for the original frame.
The bottom right shows the integrated DSA mode with the original frame of the

series superimposed on it.

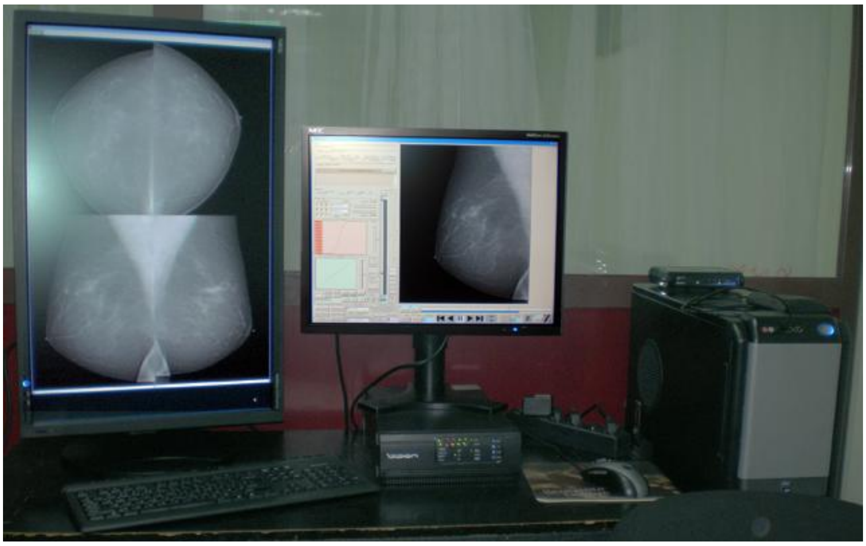
An example of multi-frame processing for **DSA** mode.

Image 2. Multi-frame DSA image format 3072x3072x10b.



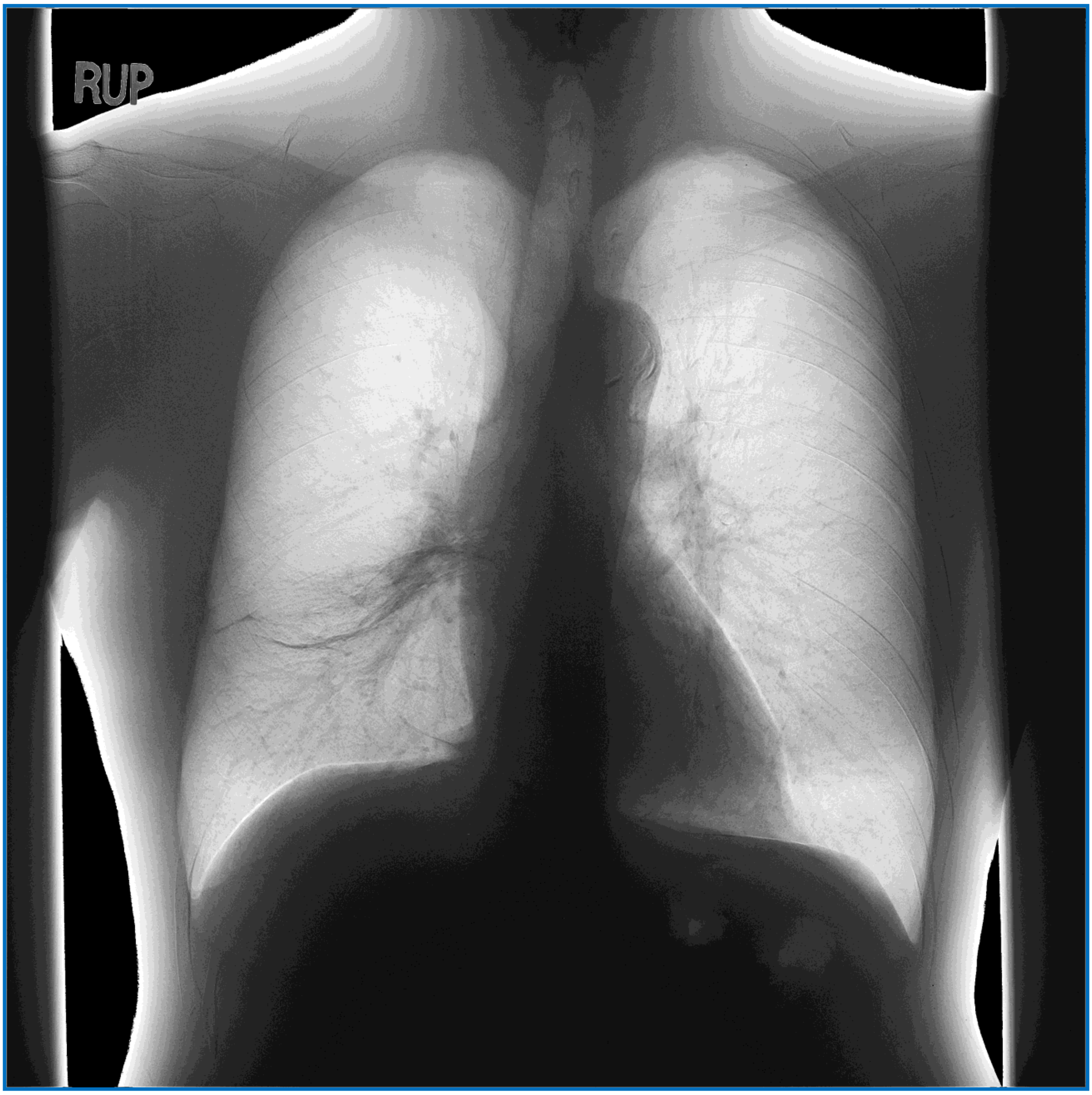
2-x monitor DICOM Processing and Visualization Station "Michelangelo".

Image 3. Visualization on a 30-inch 4-Mpix monitor with a resolution of 1600x2560.

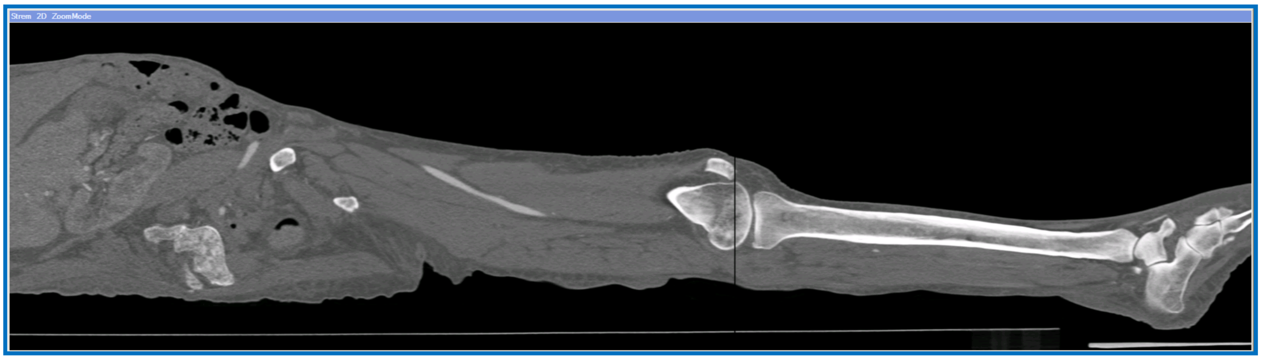


Fragment of multi-frame processing of 4 images simultaneously.
Image 4. Multi-frame image format 7640x9176x12b.

Light image processing, Dual_kV mode, Flat Panel Detector (Direct Conversion).
Image 5. Format 2880x2880x14b, image size 432x432 mm (pixel = 150 mkm).

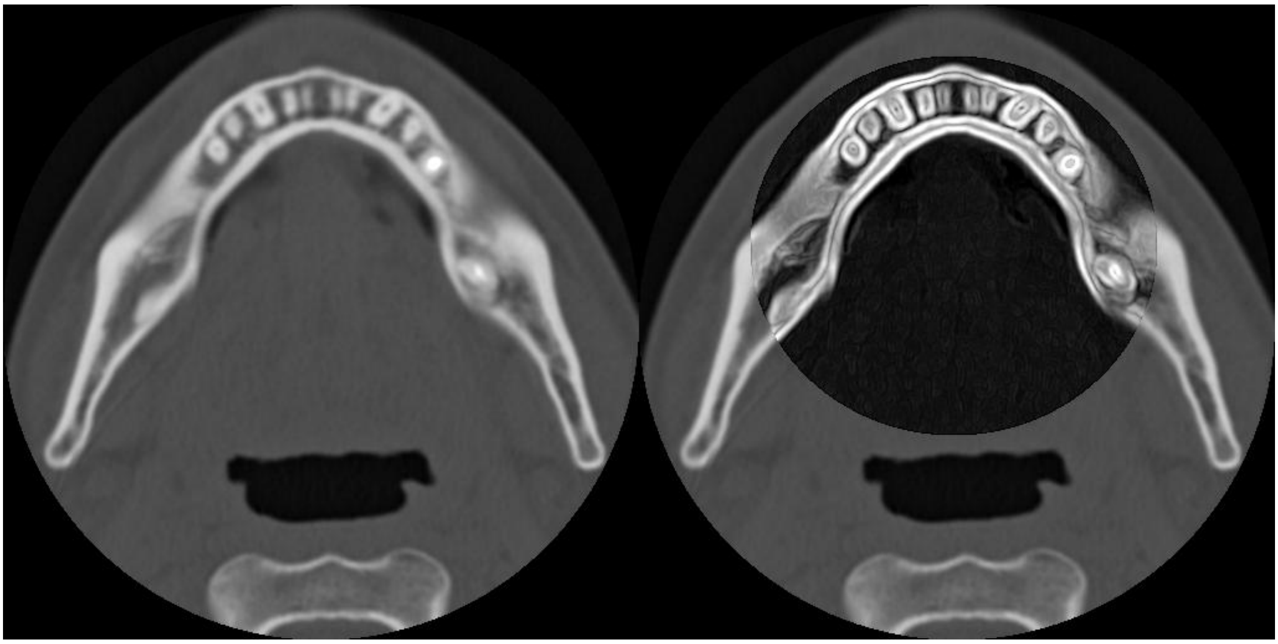


Example of orthogonal reconstruction of a CT series with image processing.
Image 6. Image frame format 512x1950x12b.



Example of processing in the area of interest against the background of the original image
Image 7. Image frame format 1024x1024x10b.

Image 8. CT image and processing in the "area of interest" of bone tissue in dentistry.



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