echocardiography
image processing
medical simulation

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USING COMPUTED TOMOGRAPHY IMAGES FOR A HEART MODELING

In this paper the quality and analysis of the computed tomography scan sets are presented in the context of creating a 3D/4D model of a heart for the ultrasonography simulator. Data was collected during regular patients examination, using various equipment and technique, therefore not every set has required quality. CT data can be fast characterized with histogram that can show if the brightness ranges of objects (heart structures) are selective. This makes CT data usable for simulation by applying a transform function on the CT images to produce ultrasonography-like images. The aim is to use a PACS system of Hospital, which is the source of data. Therefore a proper technique and system for analysis is needed.

1. DATA FOR CT2TEE SIMULATOR

CT2TEE simulator is a software that renders echocardiograms (both transthoractic and transesophageal) based on patient's real heart model [1]. The data is obtained from the computed tomography (CT) called "cardio-CT", which means its intensity is synchronized with ECG and includes the contrast agent usage to increase the visibility of blood vessels. This technique was described in [2] and [3].

CT data is collected in DICOM files, where each file contains an uncompressed 2D CT image of the body scan in vertical and horizontal axis as presented on the Figure 1. Spatial dimension of that image is either 512x512 or 256x256 and dynamic dimension is 12 bits per pixel, but aligned to 16 bits.

Set of files from one examination creates a three-dimensional block of data, which is evaluated by CT2TEE simulator. Blocks may represent different heart stage of the cycle, hence set of these blocks can be used to simulate animation of the heart activity. Otherwise one of these blocks can be selected for a static simulation. Figure 2 shows an example of the blocks set. The percentage values indicate the heart motion phase.

One CT examination produces large amount of data (from 2 up to 4GB) that should be evaluated in the context of the use in the CT2TEE simulator. This process should be automatic, as the CT data is kept only few days after the examination.

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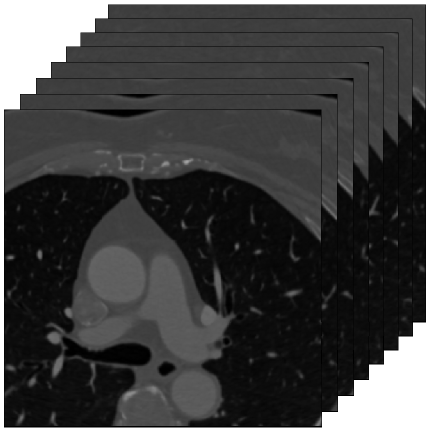

Fig. 1. An example of CT data block. 12bit values are rescaled to 8bit.

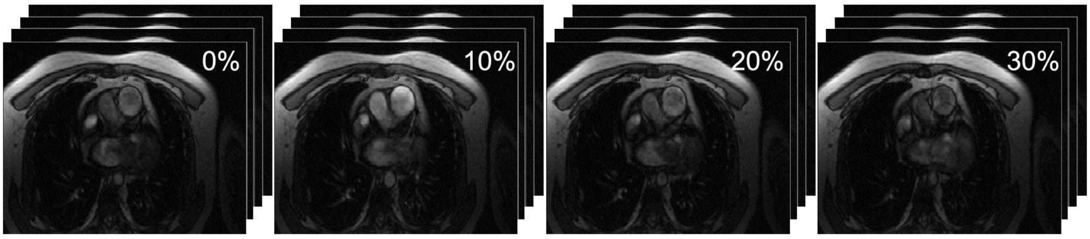

Fig. 2. Example of DICOM CT data set for different heart phase.

2. CT DATA TRANSFORMATION FOR ULTRASONOGRAPHY SIMULATION

CT data must be transformed in order to use for ultrasonography simulation (Figure 3). The reason is that computed tomography shows different than ultrasound-based imaging characteristics of the human body tissues, as this examination methods are based on different physical phenomenon. Human tissue response in the ultrasonography imaging has been already widely discussed [4-8].

What is more, each CT data set, or even a block, has its own features, as a result of different factors, for example: CT scanner features, amount and type of the contrast agent applied, X-Ray absorption characteristics of the tissue. This necessitates individual approach to each CT data set, which means that the transform function [9] should be selected so to ensure the best possible object separation (i.e. heart muscle from blood with contrast agent). Quality of the CT scans is very important in this process.

2.1. OBJECT IDENTIFICATION PROBLEM

To use CT data in the ultrasonography simulations it must be possible to differentiate objects by their brightness on the image. Detection of the heart chambers in images from computed tomography was presented in [10], where various problems of automatic processing where also discussed. Another example of heart structure recognition and selection using image brightness was presented in [11].

Figure 4 presents an example of CT image and its histogram. It shows group of peaks and how they correlates with certain object, for example two peaks on the left represents lungs. In the simulation this part of data is removed (truncated to 0) as the ultrasound waves cannot propagate in this medium, because of the high difference of the acoustic impedance on the tissue-air border [12].

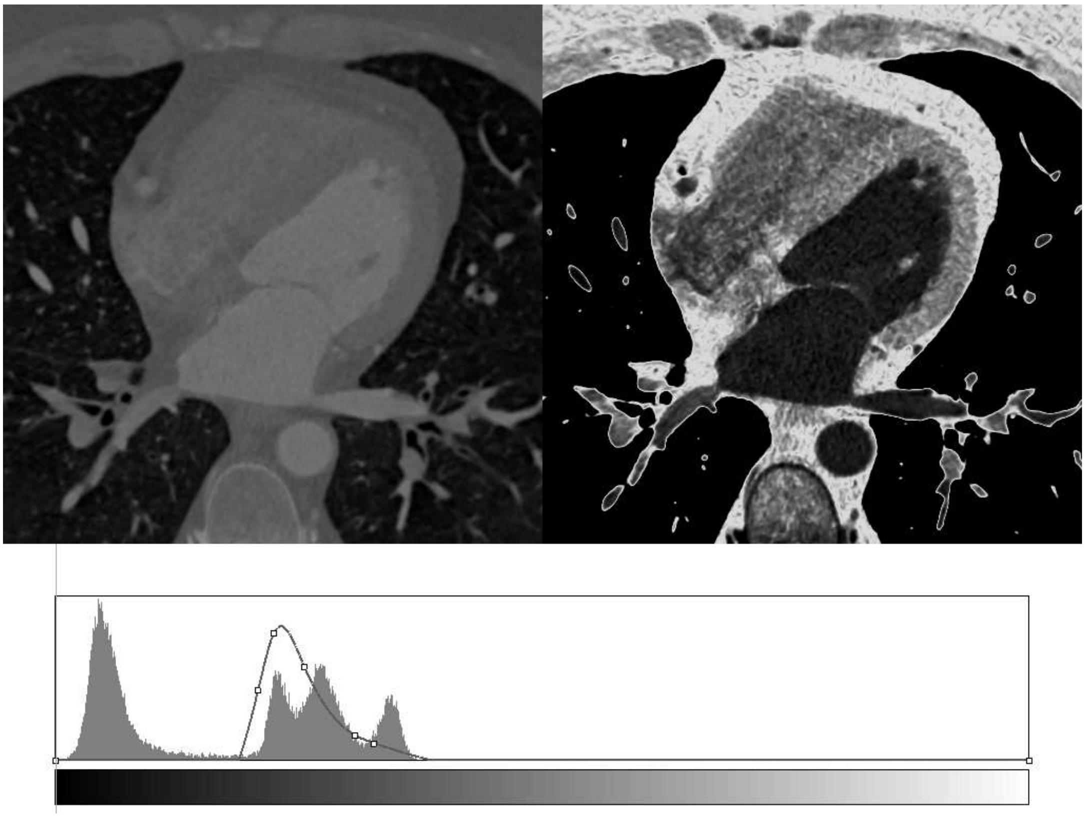

Fig. 3. An example of a transformation function of spline type, applied on a CT image (left) and the result (right).

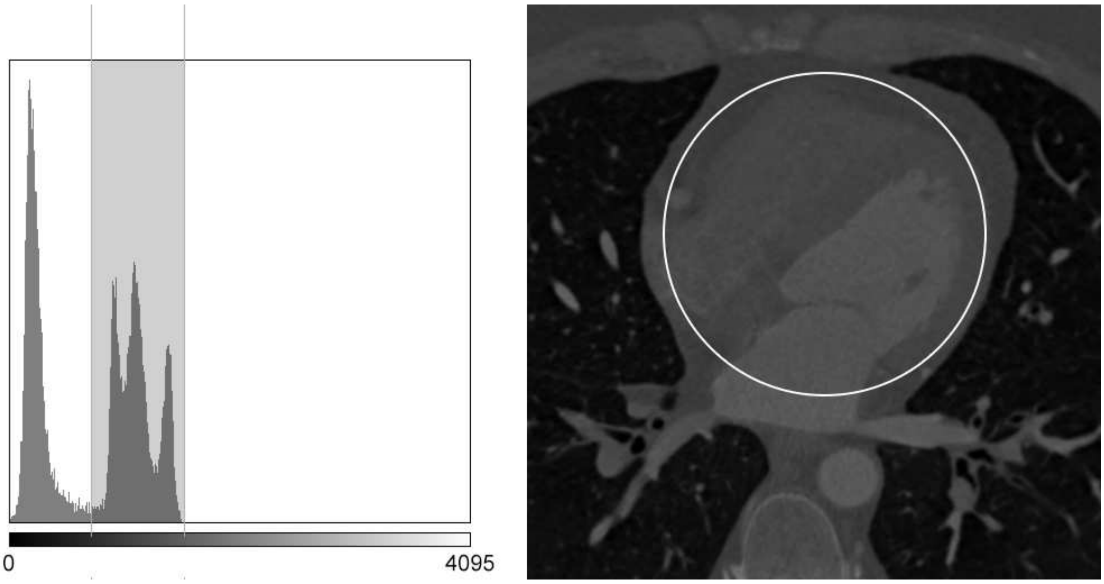

Fig. 4 The most important part of the CT image with the corresponding range on the histogram. Histogram is normalized and represents values from 0 to 4095 of 12bit DICOM image.

The most important part of the CT image is the range of tree peaks, usually between 800 and 1300 level of brightness, as presented on the Fig. 3. The first peak from the left, usually in the range of 800-1000, represents a heart muscle, the next one is correlated with contrasted blood. The last one is associated with saturated blood and bones (sternum and ribs). Quality and utility of the CT data might be defined as the selectivity of these histogram groups.

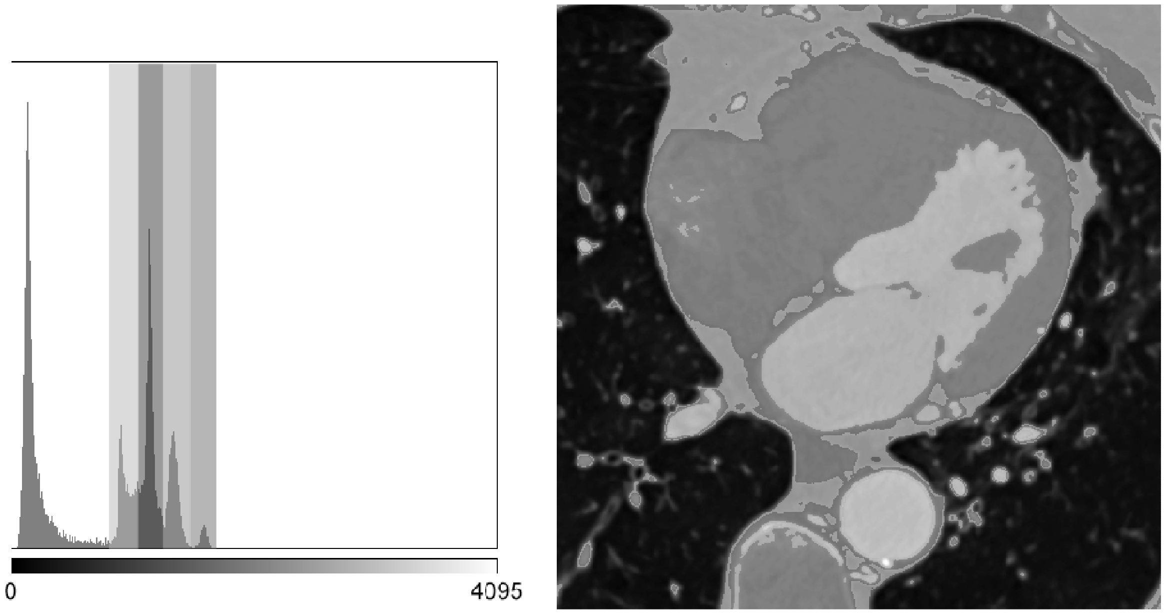

Fig. 5. Example of the correlation of objects on CT image with its histogram.

3. CT DATA ANALYSIS

In the next paragraphs the results of the CT data analysis is presented. The CT data was received from The John Paul II Hospital in Cracow as a part of cooperation with the AGH University of Science and Technology. The CT data is collected in sets of varying number of blocks and slices. Table 1 shows general characteristics of these data.

These data have not been gather with the intent of use in the ultrasonography simulation - it was a result of standard medical examinations. Selective sets were performed for assessment of coronary arteries. These sets may give the best results, because the intensity was not adjusted during examination and the spatial resolutions and contrast are high.

All the data have been anonymized before further processing.

Table 1. General characteristics of the CT data sets.

Name	Dimension [pixels]	No. blocks	No. slices	Data size [MB]	Equipment vendor
SET 2	512x512	1	324	161	Siemens
SET 3	512x512	1	351	176	Siemens
SET 11	512x512	8	262	1044	Siemens
SET 12a	256x256	10	261	326	Siemens
SET 12b	256x256	10	233	291	Siemens
SET 12c	256x256	10	218	272	Siemens
SET 15	512x512	20	210	2201	Siemens

3.1. QUALITY OF THE CT DATA SETS

As mentioned before, there are numerous and various factors that has significant influence on the CT image quality. One of them is the machine characteristic. First analysis of the CT data derived from the hospital showed that machine has implemented method of decreasing the X-ray intensity when a heart is in motion (some phases) to reduce patient radiation dose (CARE Dose technology). This solution creates streaks of noise on the CT images as can be seen on Figure 6. Noise is clearly visible at images of heart in motion phase as well on the related magnifications and their histograms, which show the destructive influence of noise. Therefore, only noise-free data blocks can be used for simulations without de-noising. Otherwise additional processing has to be made on the data.

One of the methods of de-noising was presented in [13]. For the ultrasonography simulation the median filter followed by the average blurring is satisfying and fast enough to be use in automatic CT data processing (Fig. 7).

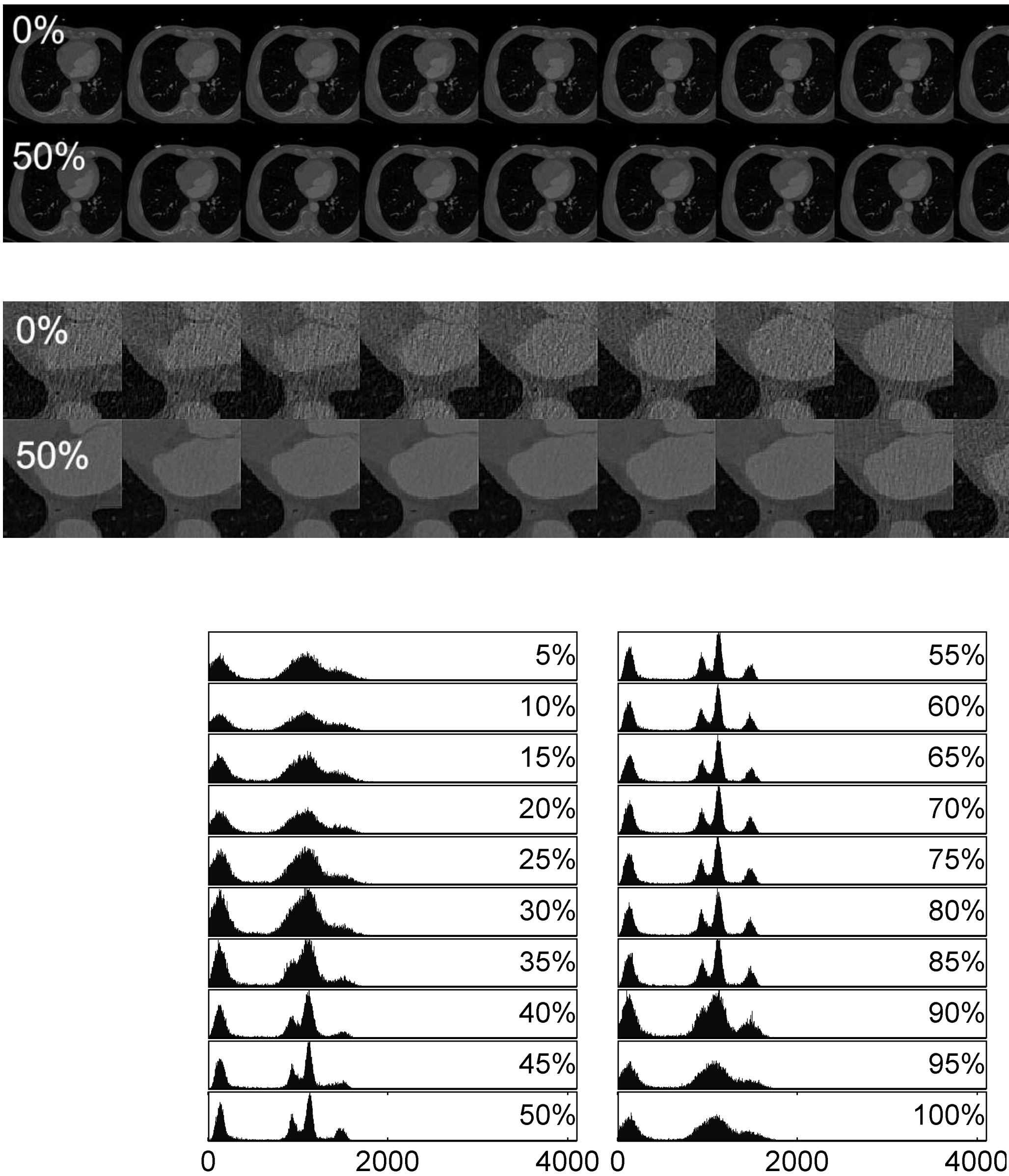

Fig. 6. CT data frames from Set 15 that represent one slice of the heart activity animation (above) with corresponding noise level magnifications (middle) and histograms.

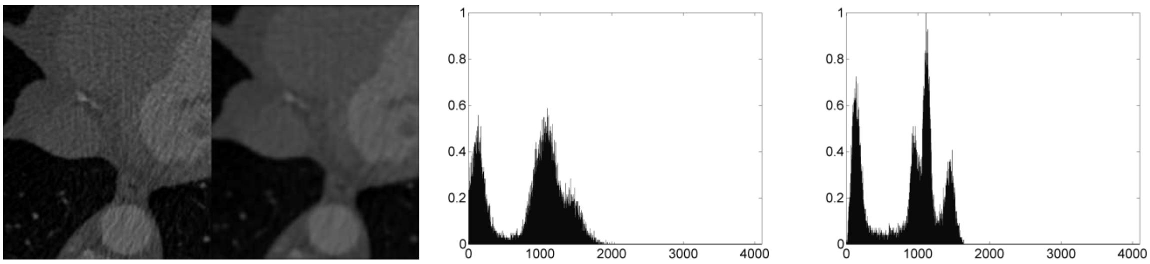

Fig. 7 Example of de-noising filter application on low-dose CT image (0% heart stage) with corresponding histograms.

Another important feature of the CT images is their dimension. Data sets of 512x512 size (in pixels) might provide more details, but on the other hand, large data set may be difficult to use in ultrasonography simulation, because of the limited memory resources.

3.2. DATA BLOCK ANALYSIS

Data block where analyzed in the context of usability in the simulator. Analysis was focused on the histogram characteristics.

Block from Set 3 can be described as a good data set for the simulator (Figure 8). The histogram of a single image yields three main peaks correlated to the heart muscle, same the block histogram. The variance of each slice (in the range from about 1.7e5 up to about 2.7e5) gives information about the domain resolution of the set, which can be considered as good. What is more, the images are 512x512 pixel size and the majority of their space is covered with the heart muscle.

Block from data sets 12a, 12b and 13c also present desirable characteristics (Figure 9). The single image histogram is good and three peaks can be found on the block histogram as well. The variance graph also proves that the blocks quality is more than satisfying. However, this data set has lower resolution (256x256), which has negative impact on the image quality, but might also be considered as advantage, because its smaller size makes this data set more portable.

The last block described in this paper is from set 15 (Figure 10). It has very poor usability in ultrasonography simulation, as only one peak related to the heart muscle can be found on histograms. As described before, streak noise has to be removed with de-noising processing to make this set useful. Another disqualifying feature of this set is the black area where no tissue can be found.

Other data sets, not described in this paper, shows similar characteristics, and will be used to create automatic decision algorithm.

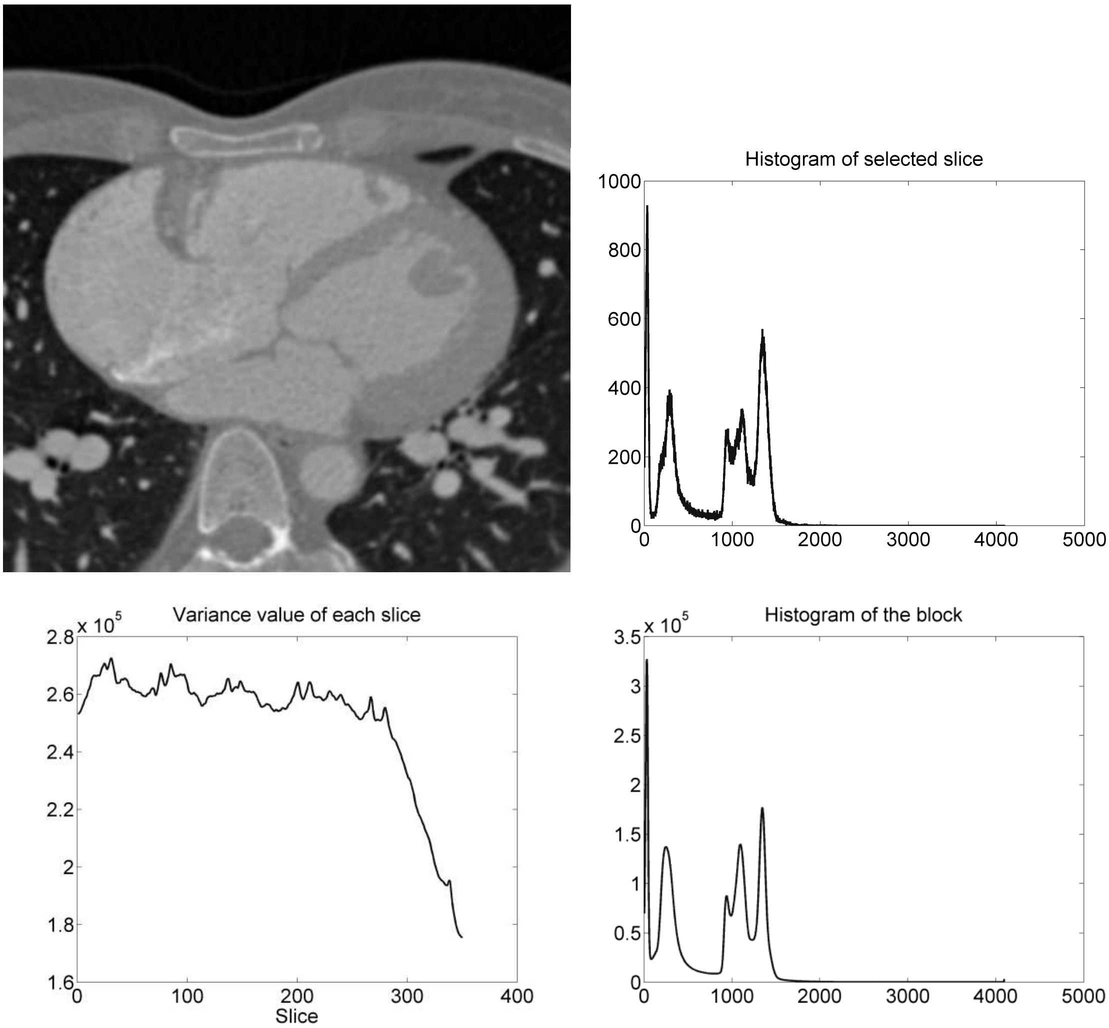

Fig. 8 Set 3 characteristics.

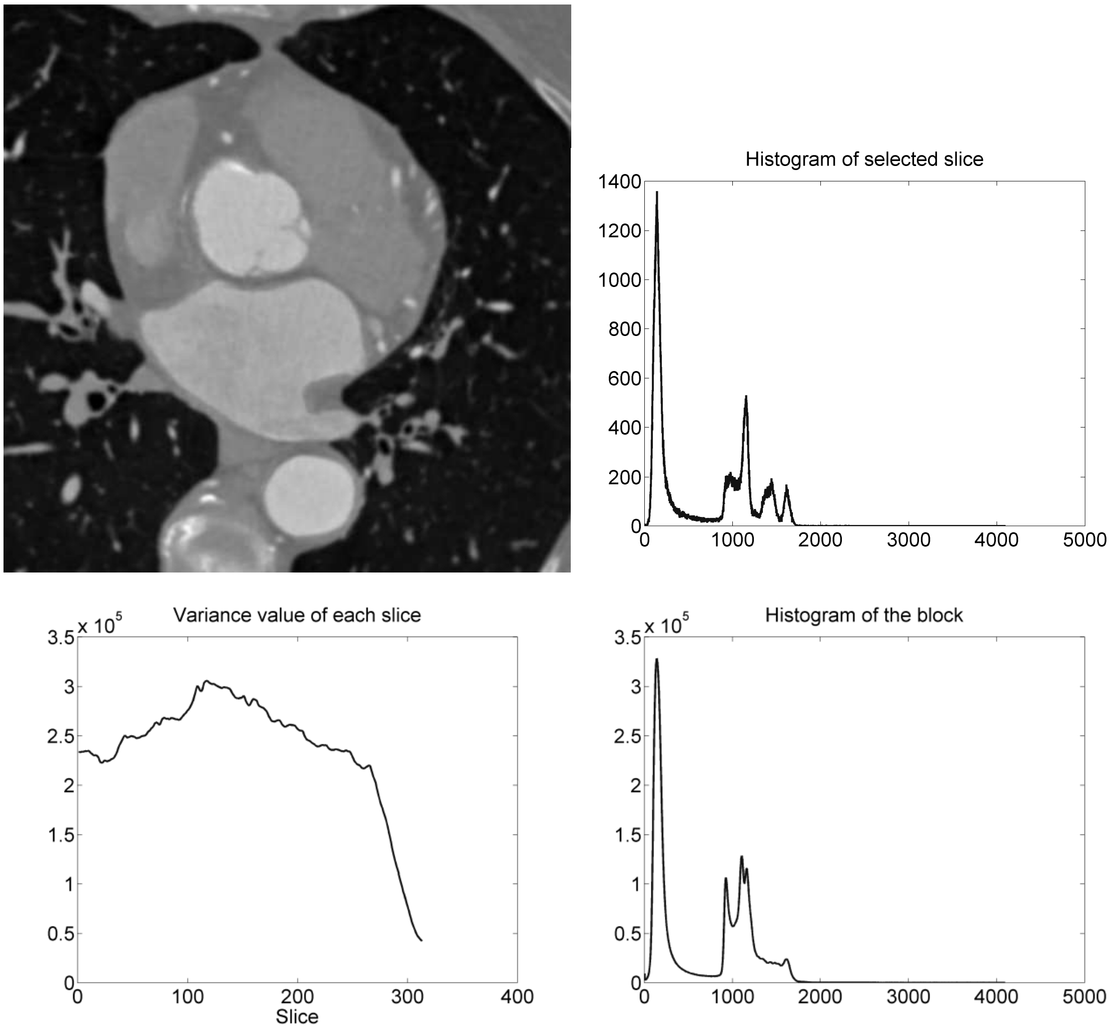

Fig. 9. Set 12 characteristics.

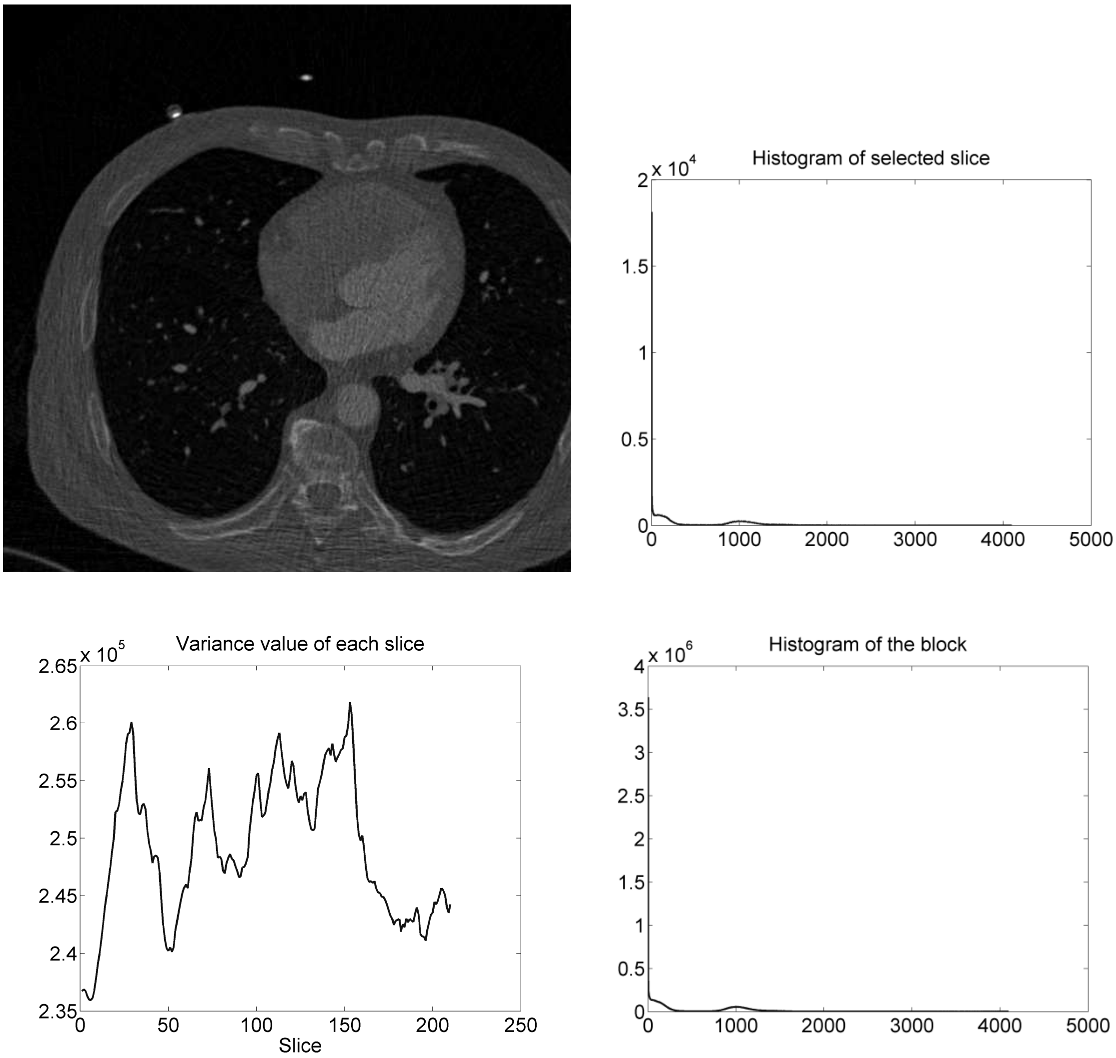

Fig. 10. Set 15 characteristics.

4. SUMMARY

In this paper the quality and analysis of the real CT data sets were presented. The analysis focuses on the selectivity of the heart structures by using the histogram of the individual images as well as the whole sets. The best results was achieved for the CT scans that came from the CT coronary angiography, because it does not include the intensity change during the examination and produces high spatial resolution images.

The histograms analysis is essential during the decision process of CT scan sets usability, as described in this paper. What is more, automatic decision process, part of the future work, will also rely on the histogram analysis. Furthermore, future work involves creating a complex Internet-based solution for eTraining using simulators [14].

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