BIOMEDICAL IMAGE ANALYSIS OF HUMAN FEET WITH CHARCOT DISEASE

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Abstract

Processing of biomedical images is an actual topic nowadays, especially in investigation domain of application of image processing methods as it offers wide spectrum of ways a man could use. This paper is aimed to point out combination of these methods in order to gain statistically important information for further analysis. It applies combinations of parameters that significantly affects resulting segmented image, creating a mechanism that could process sets of images acquired by SPECT scanning technique, that are used for diagnosis of human feet diseases. Statistical analysis, based on characteristics determined from processed images, gives important information about differences among sets of samples. Whole algorithm is realized in programming environment Matlab, which provides many functions suitable for work with three-dimensional matrices.

1 Charcot disease

Charcot osteoarthropathy or so-called Charcot foot is a chronic and progressive disease of bone and joints caused by neuropathy and it is most often localized at the foot area. There are two main theories of the pathophysiology formation of neuropathic osteoarthropathy. Neurotraumatic theory (published by Leo Eloesser in 1917) assumed that the failure of sensory feedback and repetitive mechanical trauma causes progressive destruction of bones and joints. Second, neurovascular theory, emphasizes changes in vessels supplying caused by neuropathy - especially sympaticus disorder. It leads to vasodilatation (expansion of vessels) and hyperemia (greater blood flow) that promote bone resorption. The accuracy of both theories is supported by a number of clinical and laboratory observations.

Alongside with other diagnostic methods it is important to get as detailed image information as possible in order to localize affected areas. Computer tomography gives information about bones and joints, but this paper is focused on analysis of SPECT images.

2 SPECT imaging method

SPECT is an acronym derived from "Single Photon Emission Computed Tomography". It is a method of imaging used in nuclear medicine, which can show the spatial distribution of applied radioactive substance in the human body. This substance is often given intravenously to the patient right before image acquisition. In cooperation with the Institute of Clinical and Experimental Medicine in Prague were provided set of patients images with impaired feet acquired by SPECT imaging method. Here as a contrast medium (contrast agent) was used Tc99m methyl-diphosphonate. Any substance, that is normally present in the human body and has some function, may be given to a patient, only a certain atom in this compound is exchanged for radioactive atom. Radioactive atom is unstable over time, tends to convert to an atom bearing a lower energy and excess energy is radiated in the form of so-called gamma radiation. In case of Tc99m methyl-diphosphonate the half-life disintegration is determined to 6 hours.

The method is based on two-dimensional SPECT scintigraphy (from the perspective of the patient). However, it is enriched with computer system capable of many images captured from different angles to reconstruct a three-dimensional image. Unlike X-ray methods, which display body structure, the method focuses on the displaying of function of the organs resulting in recognition of areas, that increasingly accumulate the substance or vice versa areas those lag and are unable to absorb the substance. [1]

3 Foot recognition

Depending on software used in hospitals, images are sometimes saved in unordinary format, but many of those programs has an ability to convert those images into DICOM format, which saves many information about patient, image shooting information and other complementary details and separately image itself. As noted above, algorithm is realized in Matlab environment whose Image processing toolbox provides functions for manipulation with DICOM images.

Based on signal nature of the images and for processing purposes, we could split them into two main groups: healthy and massively affected by disease (hereinafter affected). The difference is obvious; the lighter area means the more affected area (see Figure 1).

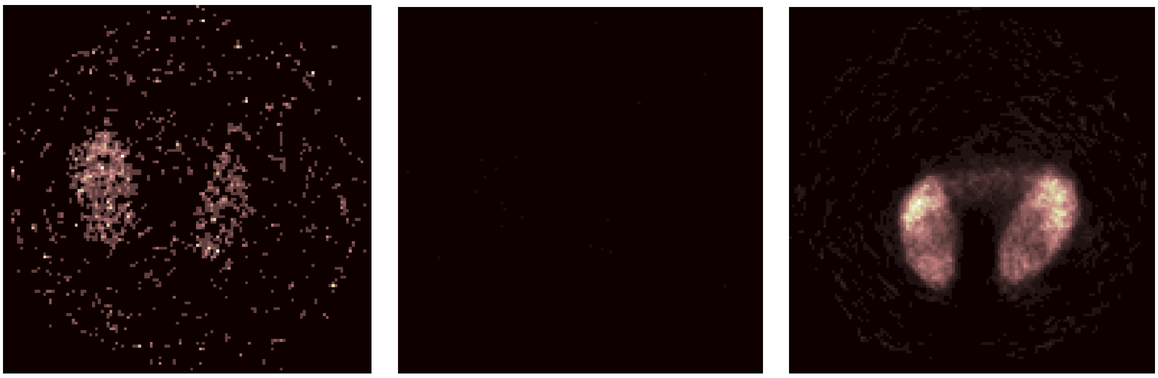

Image 1: healthy feet | Image 2: healthy feet | Image 3: affected feet

Figure 1: SPECT image comparison: (1) healthy with maximum pixel intensity set to 1709 (according to maximum of Image 3), (2) healthy with maximum pixel intensity set by itself (19), (3) affected with maximum pixel intensity set by itself (1709). Images level at z-axis = 35.

Research is focused mainly on basic image manipulation such as morphological operations (opening, closing), convolution by Gaussian 3D-kernel, median filtration or counting of nonzero neighborhood pixels combined with operations on binary matrices like filling holes and revoking small insignificant particles. The goal of this filtration is to obtain binary mask, especially based on optical observations, which could mark areas with feet. Due to fluctuating statistical nature of both image groups (healthy and affected) it is impossible to base such filtration on simple static threshold; images of affected feet has more frequent shot noise than in images of healthy feet.

Statistical distribution of image data (boxplot cannot be used for these reasons) shows, that 90% cumulative probability value of whole image is still equal to 0, which means that there are much more surroundings than useful data. Based on many observations, threshold was chosen as quantile of 95% cumulative probability value.

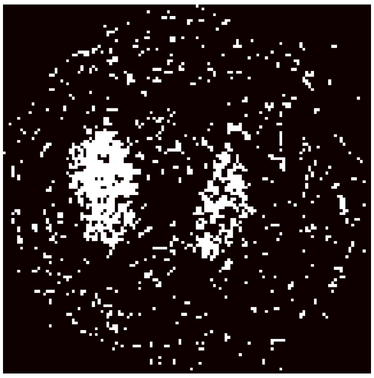
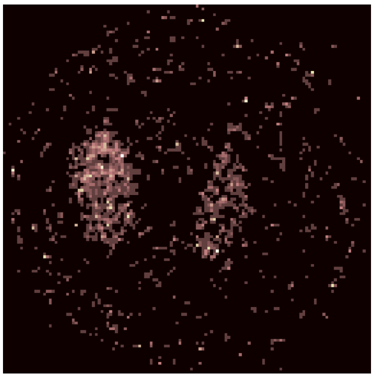

Image 4 Image 5


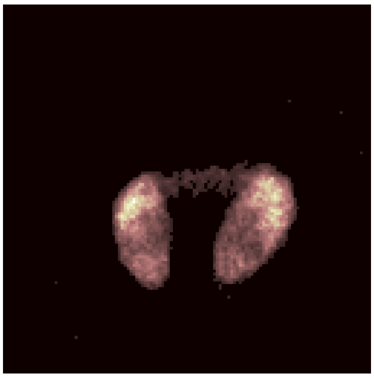

Image 6 Image 7

Figure 2: SPECT image comparison of masked images by thresholding by 95% quantile: (4) healthy feet mask, (5) healty feet masked, (6) affected feet, (7) affected feet masked. Images level at z-axis = 35.

Such masking is satisfactory and next mandatory adjustments follow. Median filtration by kernel of size 3px in each direction revokes small areas which are not feet. To be sure that there was no holes left in the big areas, algorithm fills them in three-dimensional meaning, the second one filling right after binary morphology closing made on mask.

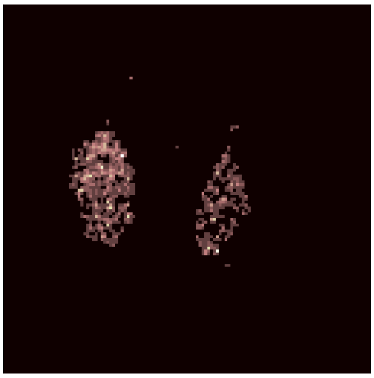
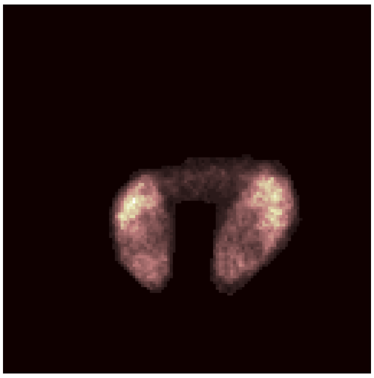

Image 8 Image 9

Figure 3: SPECT image comparison of filtered images by complete mask: (8) healthy feet, (9) affected feet. Images level at z-axis = 35.

4 Statistical analysis

Set of characteristics for each image is passed to two-sided Student's t-test. Images are acquired in two phases, the second one 24 hours after the first acquisition. Thus their characteristics must be tested separately; first day the radiation is greater, e.g. first could be mistakenly understood as affected feet because of the higher values. Next necessity is to mark each foot by its diagnosis, especially whether the foot was amputated (thus the area not to be tested), and test those diagnoses towards each other.

Each foot has its determined characteristics:

- kurtosis, skewness and standard deviation calculated from image values (and their logarithms too) higher than 95% quantile
- kurtosis, skewness and standard deviation calculated from image values (and their logarithms too) masked by binary mask
- maximum value, arithmetic mean and median calculated from image values masked by binary mask
- count of local maxima in binary masked image (ρ = 10px), their mean value, median, standard deviation (and its logarithms)

Kurtosis is described as the degree of peakedness of a distribution, defined as a normalized form of the fourth central moment μ_4 of a distribution:

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3 \qquad (1)$$

where μ_i denotes the i-th central moment (and in particular, μ_2 is the variance). A distribution with a high peak ($\gamma_2 > 0$) is called leptokurtic, a flat-topped curve ($\gamma_2 < 0$) is called platykurtic, and the normal distribution ($\gamma_2 = 0$) is called mesokurtic.

Skewness is described as a measure of the degree of asymmetry of a distribution:

$$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}} \qquad (2)$$

If the left tail of the distribution is more pronounced than the right tail, then $\gamma_1 < 0$, otherwise $\gamma_1 > 0$. If the two tails are equal, then $\gamma_1 = 0$.

5 Results

Table of complete results could be seen in attached spreadsheet (*results.xlsx*). The goal of this paper is to distinguish healthy feet from affected (especially those with Charcot disease). According to results of rejected H_0 hypotheses on signification level $\alpha = 0.05$, based on use of combination of more than one characteristic, we could safely identify both groups of images.

In addition, there are results of testing among disease groups. Unfortunately, there wasn't found any characteristics that could differentiate between two concrete diseases.

6 Conclusion

Statistical analysis is made on 126 samples of human feet belonging to 52 patients. To prove robustness of those characteristics it is intended to test more samples. Sometimes it is hard for doctors to diagnose patients correctly, thus given data may not be proper. Extent of methods that could be used and parameters that could be set is great, thus it is important to choose the robust ones and focus on optimization of their parameters.

Further research will be focused on filtering of artifacts seen on Image 9. Between both feet is some kind of cluster probably made by high values of radiation that is gained during SPECT scanning. Next point of research would be use of nonlinear filters [3] and use of neural networks for data classification.

References

[1] SPECT. Webdio, s.r.o. (on-line). [Quoted Jan 25th 2011]. Available on the Internet: » http://vysetreni.vitalion.cz/spect/ «

[2] *Wolfram MathWorld* (on-line). [Quoted Oct 28th 2012]. Available on the Internet: » http://mathworld.wolfram.com/ «

[3] MITRA, Sanjit K., SICURANZA Giovanni L. Nonlinear image processing. London (GB): *Academic Press, 2001*. 455 s. ISBN: 0-12-500451-6.

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