Title Analysis of Texture: Theory

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Medical imaging, especially the MRI, has significantly contributed to the recently observed change in the medical paradigm: from traditional to evidence-based medicine. Digital analysis of images can provide quantitative information about invisible organs and inaccessible tissues. It can help describe complex structure of tissues and characterize complicated mutual interactions between organs, both in time and space domains. This quantification can aid the medical diagnosis to make it more objective and accurate, for a better health care.

One of the approaches to quantitative image analysis is based on mathematical description of image texture. Although the notion of "texture" does not have any general mathematical definition, image regions of different appearance are easily perceived by humans. We can naturally distinguish images of rough and smooth surfaces, for example. As the texture can represent properties of "coarseness", "directionality", "granularity", "regularity", etc. (1), it originates in the physical structure of objects (e.g. tissues) that are visualized in images. Texture parameters can be defined to estimate the presence of certain intensity patterns in the image. It is known, for example, that there are two main symptoms of osteoporosis – reduced bone mass density (BMD) and changes in bone micro-architecture. Combination of BMD and texture parameter values provide better assessment of the fracture risk than that obtainable solely by BMD measurement (2). Hypothetically, an average number (or thickness) of bone trabeculae visualized in the image can be evaluated. Decreased value or increased dependence on direction (anisotropy) of such parameters could be an indicator of osteoporotic changes in the bone.

In the course of numerical analysis, images are segmented into disjoint regions, such that voxels belonging to a region share some similarity measure, which is not shared with the voxels in other regions. Regions that represent brain arteries in ToF images are brighter than regions of the neighboring tissue (3). The segmentation criterion can be based on image intensity in this example. By thresholding the image intensity, one can separate regions of blood arteries from the background tissue. On the other hand, in the case of texture analysis (TA), the image is segmented with the use of a measure of texture properties. Parameters (descriptors, features) that quantify texture are computed in a sliding window moved around the image. New images – texture feature maps – are produced in this process. Voxel intensity of each of these new images is proportional to the value of a corresponding texture descriptor computed inside a sliding window, located at the voxel coordinates. The maps are applied for image segmentation. Texture parameter values can be used to distinguish types of tissues that differ by their internal structure. For example, a possibly cancerous region, densely populated by thin blood vessels, can be discriminated from a normal, average-density vasculature. The map (image) of a texture parameter that reflects local blood vessel density in the image space will be brighter inside the neovascular regions. Interestingly,

texture feature maps can reveal borders between clinically valid image regions otherwise invisible to humans (4). Texture analysis describes a wide range of techniques that enable quantification of the gray-level patterns, pixel interrelationships and spectral relations in the image (5).

Numerical analysis of image texture has been a topic of active research since the sixties of the past century (6). Initial applications covered quantification of aerial images, but the methodology was soon extended to medical images. The main problem with clinical applications was in limited resolution, especially in MRI. A whole-body scanner at a matrix size of 256x256 pixels does not allow to resolve structural details smaller than 2 mm in size, e.g. individual cells in a liver and the image patterns they form. With the technological progress in MRI, especially the increasing value of static magnetic field, sub-millimeter resolution is now available with 1024x1024 images, at a sufficient signal-to-noise ratio. This contributes to increasing interest in clinical application of MRI texture analysis methods (7), (8), a "renaissance" of this methodology (9).

A review of the state of the art in image texture analysis is presented. The information processing steps in medical image analysis are characterized briefly with a block diagram. Examples are shown to illustrate image segmentation by intensity thresholding, as well as textured images that cannot be segmented this way. The concept of texture feature maps is introduced and its usefulness is demonstrated. General aspects of TA application in biomedicine are highlighted, for 1) tissue classification and monitoring, and 2) image segmentation. Consecutive steps of texture analysis are discussed (image acquisition, region of interest (ROI) selection, feature extraction, feature selection/reduction, texture classification). Feature extraction example by autoregressive model fitting is discussed in more detail to show texture descriptors can be interpreted in terms of the visualized object physical structure. Literature is referred to for texture feature definitions (5), (6), (10), software for ROI selection and feature calculation (8). The importance of image normalization inside ROIs is discussed (11).

In conclusion, texture analysis can provide numerical description of tissues for more objective and reliable medical diagnosis, for monitoring of disease progression and treatment response. The importance of TA is growing due to increased resolution and reduced noise in medical imagers, as well as increased capacity of computers used for image analysis. However, TA plays a supportive rather than comprehensive role in medical image interpretation, as it lacks the direct pathophysiological explanation in many cases. The potential pitfalls of the TA applications can be related to a lack of image homogeneity and limited number of voxels in regions of interest. Image inside ROIs should be standardized in terms of intensity mean and standard deviation. Physical and numerical texture phantoms are needed to validate new techniques of TA.

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