

IMAGE PROCESSING AND DATA ANALYSIS IN COMPUTED TOMOGRAPHY*

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Computed Tomography (CT) is a non-invasive technique to provide CT images of every part of the human body without superimposition of adjacent structures. Measurements with X-ray CT are subject to a variety of imperfections or image artifacts including: quantum noise, X-ray scattering by the patient, beam hardening and nonlinear partial volume effects. Image processing with Adobe Photoshop, ImageJ, Corel PHOTO-PAINT and Origin software has been used in order to achieve good quality images for quantitative analysis. Image enhancement technique allows the increasing of the signal-to-noise ratio and accentuates image features by modifying the colors or intensities of an image. It also includes linear and nonlinear filtering, deblurring and automatic contrast enhancement. Statistical functions enable to analyze the general characteristics of a neuroimage by displaying the image histogram or plotting the profile of intensity values. Data analysis of CT images can help distinguish between a neurological disease, a common disorder like Major Depression (MD) or Obsessive-Compulsive Disorder (OCD) and a normal brain.

1. INTRODUCTION

Computed Tomography (CT) is an imaging technique where digital geometry processing can be used to generate a 3D-image of brain's tissue and structures obtained from a large series of 2D X-ray images. X-ray scans furnish detailed images of an object such as dimensions, shape, internal defects and density for diagnostic and research purposes. Supposing that we have a very narrow pencil beam of monochromatic X rays which traverse an inhomogeneous medium and no scattered radiation reaching the detector, the transmitted intensity can be written [2, 3]:

$$I_{\phi}(x') = I_0(x') \exp\left(-\int_l \mu[x, y] dy'\right) \quad (1)$$

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where $I_0(x')$ is the unattenuated intensity, ϕ and x' define the position of the measurement, $\mu[x, y]$ is the two-dimensional distribution of the linear attenuation coefficient, l is the straight line joining the source and detector. The X-ray source and detector rotate with the $x'y'$ frame and the X-rays travel parallel to y' . Projection (Radon Transform) of the object $\lambda_\phi(x')$ is defined as [1, 6]:

$$\lambda_\phi(x') = -\ln \left[I_\phi(x') / I_0(x') \right] = \int_l \mu[x, y] dy' \quad (2)$$

The object is represented as a two-dimensional distribution of linear attenuation coefficient $\mu[x, y]$ (Fig. 1).

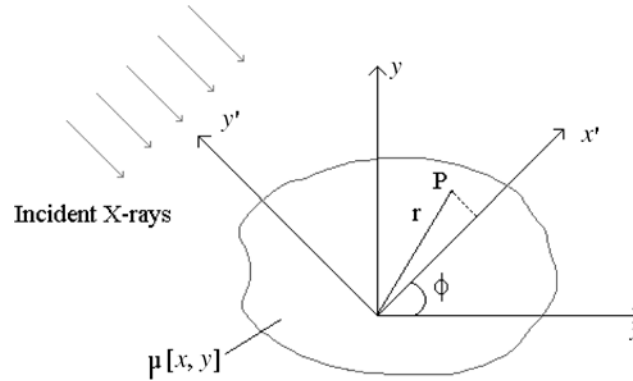


Fig. 1 – The $x'y'$ frame is rotated by angle ϕ with respect to the xy frame. The origin of both systems is positioned at the centre rotation of the scanning gantry and P is the general point in the object.

In CT scanners the X-ray attenuation according to equation (1) is measured along a variety of lines within a plane perpendicular to the long axis of the patient with the goal of reconstructing a map of the attenuation coefficients H for this plane [3]. The resulting attenuation coefficients, in Hounsfield units are usually expressed with reference to water:

$$H = \frac{\mu_{\text{tissue}} - \mu_{\text{water}}}{\mu_{\text{water}}} \times 1000 \quad (3)$$

Small differences in H can be amplified visually by increasing the contrast of the display.

In a third generation fan beam X-ray tomography machine a point source of X-rays and a detector array are rotated continuously around the patient. Data collection time for such scanners ranges from 1 to 20 seconds. A special computer program calculates the values of density and creates cross-sectional images of the brain. Modern CT scanner can acquire data in a continuous helical

or spiral fashion [5], shortening acquisition time and reducing artifacts such as: quantum noise, X-ray scattering by the patient, beam hardening and nonlinear partial volume effects [4]. Image imperfections can also be caused by insufficient calibration of detector sensitivity, inadequacies in the reconstruction algorithm, non-uniformity scanning motion, fluctuation in X-ray tube voltage, etc.

This paper carry-out our results concerning the X-ray CT image processing and data analysis by displaying Histograms, Profile Plots, Power Spectra using Fast Fourier Transformations (FFT) algorithm, 3D Color Surface Graphs and features of abnormal tissue growths.

2. CT INSTRUMENTATION AND COMPUTER SOFTWARE

Computed Tomography uses an X-ray tube, an elaborate radiation detection system and a computer that assembles the measurement data into a series of transversal slice of the subject's body. The X-ray CT images of the brain were performed by using a Siemens Sensation 4 VA47 C.

Image processing and data analysis were performed by using ImageJ, Adobe Photoshop 7.0, Corel PHOTO-PAINT 12.0 and OriginPro 7.5 software. ImageJ is a public domain Java image processing program suitable to measure distances and angles, to calculate area and pixel value statistics of user-defined selections and to provide density histograms and line profile plots. Adobe Photoshop 7.0 image processing software has been used in conjunction with Corel PHOTO-PAINT 12.0 programs to improve the CT images by adjusting and creating special effects. OriginPro 7.5 is a specialized program for data analysis providing FFT analysis, Profile Plots and 3D Color Maps Surface of CT images.

3. RESULTS AND DISCUSSIONS

3.1. IMAGE PROCESSING

Image processing techniques can help to differentiate the abnormal tissue growth (tumors) in question from other tissues, providing more detailed information on head injuries, stroke, brain disease and internal structures than do regular X-ray CT scans. By using suitable programs into the first stage we performed multiple processing on a typical tomographic image of a normal brain – S1 (Subject 1 – Fig. 2a) and two X-ray CT scans of an abnormal brain S 2.1 and S 2.2 which belong to the same subject S2 (Fig. 2c, e).

The Contrast Enhancement filter has been used to adjust the tone, color and contrast in the X-ray CT images. *The Threshold* setting changes pixel contrast, which can reduce or eliminate visible dust particles and other tiny marks. The radius setting enables you to control the number of pixels involved in the smoothing

effect that is applied. Threshold adjustment converts all colors to either black or white based on their brightness values (Fig. 2b, d, f). The *Histogram Equalization* filter was applied to redistribute the balance of shadows, midtones and highlights in the composite channel or in individual color channels. In order to highlight the edges in the X-ray CT image of normal brain we have been applied the *Variance* filter (radius 5) from ImageJ process menu. For clarity some regions are made transparent while the significant details can be easily seen.

Adobe Photoshop filters used in conjunction with Corel PHOTO-PAINT processing enable to apply automated effects to an image, allowing us to correct lighting and perspective fluctuations, increasing the focus of an image and adding depth to RGB X-ray CT image. *Psychedelic* effect was used to shift an entire RGB image from one color range to another. *Contour* filters detect and accentuate the edges of objects and selections in the X-ray CT image of the normal brain. By using the *Invert* filter after *Trace Contour* process we converted every color in the X-ray CT image to its exact opposite (Fig. 3).

Hue represents color, *saturation* indicates the color depth or richness and *lightness* shows the overall percentage of white in the X-ray CT images. *Brush Strokes* filter can be also use to emphasize the edges of the objects. The abnormal tissues are clearly visible after the CT image processing.

3.2. DATA ANALYZE AND INTERPRETATIONS

By using ImageJ software we have been performed Histograms, Profile Plots and Particle Analysis for X-ray CT scans of S2 abnormal brain.

Histogram illustrates the number of pixels distributed on X-ray CT image (y-axis) for each level (gray value) from darkest (0) to brightest (256). The total pixel count was also calculated and displayed, as well as the mean, modal, minimum and maximum gray value by using ImageJ program (Fig. 5a, b). Count indicates the total number of pixels corresponding to the intensity level. Mean (65.836 for S2.1 and 69.226 for S2.2) shows the average intensity value. It is the sum of the gray values of all the pixels in our selection divided by the number of pixels. With RGB (24-bit) X-ray CT images, the mean was calculated by converting each pixel to gray scale by using the formula: $\text{gray} = 0.299 \text{ red} + 0.587 \text{ green} + 0.114 \text{ blue}$. Std Dev (Standard Deviation) with the values 74.494 and 77.933 for S2.1 and S2.2 respectively, indicates how widely intensity values vary. Min (0) and Max (255) represents the minimum and maximum gray values within the X-ray CT images. The Mode (Modal gray value: 2 and 10 attributed to S2.1 and S2.2 respectively) was computed as the midpoint of the histogram interval with the highest peak.

Particles Analyze command counts and measures objects in binary or threshold images. Once the image has been segmented we can obtain various information regarding particle size and numbers. By using ImageJ software we

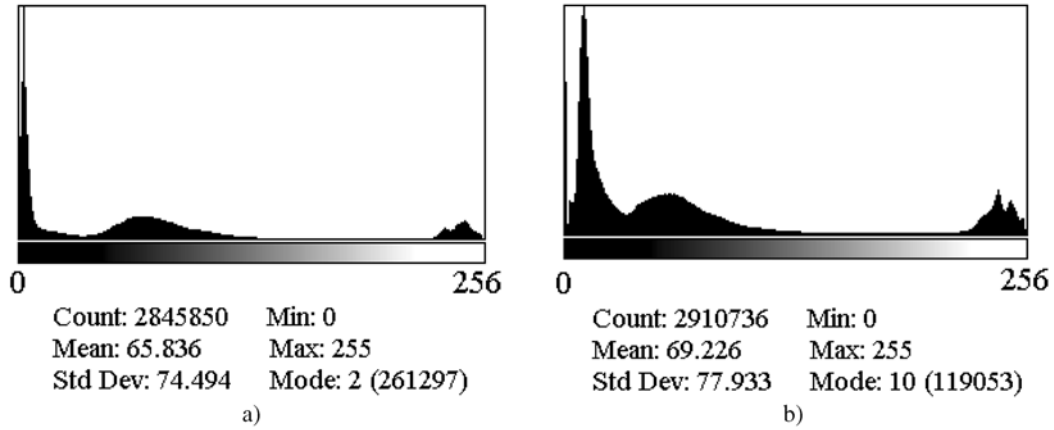


Fig. 5 – *ImageJ* histograms of X-ray CT abnormal brain scans. (a) Histogram of S2.1 X-ray CT scan
 (b) Histogram of S2.1 X-ray CT scan.

can also perform a set of measurement on a selected object (the brain tumor showed in Fig. 2e). The Integrated Density represents the sum of the values of the pixels in the selection, being equivalent to the product of Area and Mean gray value. Median (97) exhibits the middle value of the pixels in the selected brain tumor. The Feret's diameter (Caliper length = 1.724 cm) is the longest distance between any two points along the selection boundary. The measurement results are presented in calibrated units (Table 1).

Table 1

The measurement results of a brain tumor

Area [cm ²]	2.079	Min/Max gray value	8/248	Skewness	0.420
Std Dev	59.245	Mean gray value	105.029	Kurtosis	-0.765
Circularity	0.997	Modal gray value	64	Perimeter [cm]	5.118
Integrated Density	218.341	Median	97	Feret's diameter [cm]	1.724

A fundamental task in many statistical analyses is to characterize the location and variability of data set. *Skewness* is a parameter that describes the asymmetry of a PDF (Probability Density Function) while *Kurtosis* is a parameter that depicts the shape (the degree of peakedness – broad or narrow) of a PDF.

For univariate data: X_1, X_2, \dots, X_n , the formula for skewness is given by:

$$skew = \frac{\sum_{i=1}^n (X_i - \bar{X})^3}{(n-1)s^3} \quad (4)$$

and the kurtosis is defines as:

$$kurt = \frac{\sum_{i=1}^n (X_i - \bar{X})^4}{(n-1)s^4} \quad (5)$$

$$kurt\left(\sum_{i=1}^n X_i\right) = \frac{1}{n^2} \sum_{i=1}^n kurt(X_i) \quad (6)$$

where \bar{X} is the sample mean, s is the standard deviation and n is the number of data points. The skewness for a normal distribution is zero and the kurtosis for a standard normal distribution is three. This statistical measure was used to describe the distribution of observed data around the mean. Positive values for the Skewness (0.420) show data are skewed right. Negative Kurtosis (-0.765) indicates a “flat distribution”.

Profile Plot displays a two-dimensional graph of the intensities of pixels along a line (x -axis or y -axis) within the X-ray images (Fig. 6a, b). For plotting

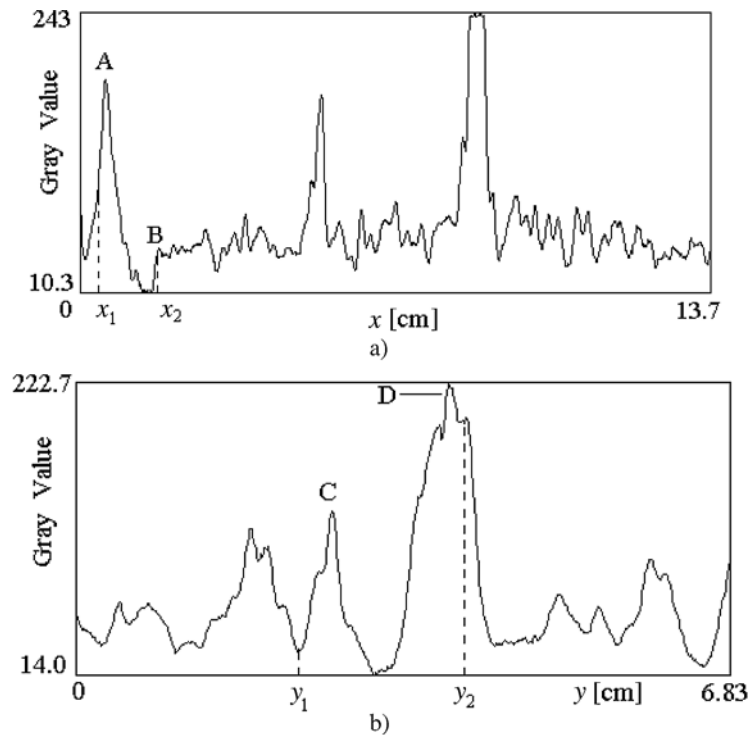


Fig. 6 – *ImageJ* Profile Plots of S2.2 – X-ray CT abnormal brain scan: a) on x -axis: $x_1 = 0.4$ cm, $x_2 = 1.67$ cm, b) on y -axis: $y_1 = 2.33$ cm, $y_2 = 4$ cm.

the S2 X-ray CT of abnormal brain we have been used the Fig. 2e. High peaks (A, C and D) which depict calcified tissue and boundary valleys with lowest gray values showing the lack of tissue in Profile Plots on x -axis and y -axis describe the tumor location in the range 0.4–1.67 cm and 2.33–4 cm respectively.

The FFT computes the Fourier Transform displaying the angle or the signal power as a function of frequency (Fig. 7a, b).

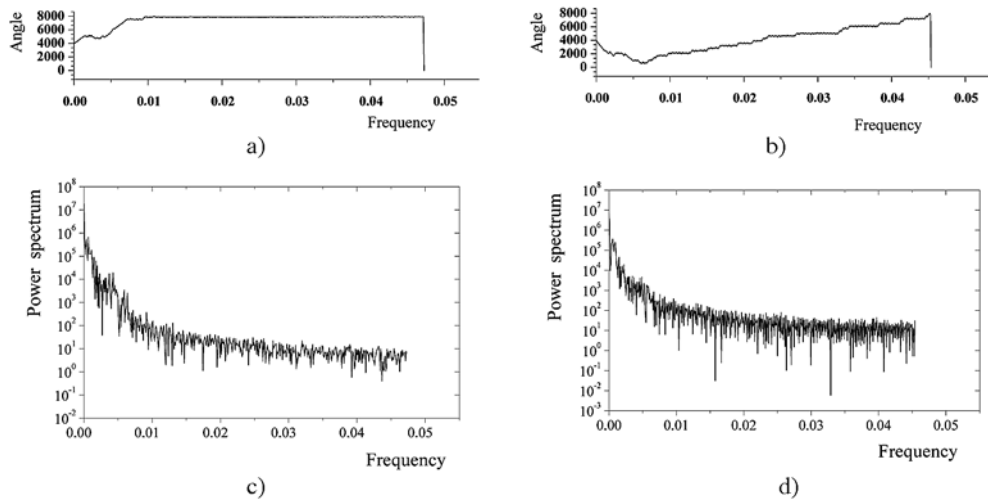


Fig. 7 – *OriginPro* FFT analyze of S2.2-X-ray CT abnormal brain scan plotted on x -axis (a,c) and plotted on y -axis (b,d).

Origin Pro 7.5 software converts each pixel to an RGB value giving the corresponding matrix cell an index number to a gray scale palette, based on the RGB value of the pixel. By using this software we have been created Profile Plots, Profile Contour Plots and 3D Color Surface Maps of CT images.

Contour Plot is useful for delineating organ boundaries in images. The X-ray CT image of the abnormal brain can also be plotted using a graph template that includes X and Y projections. While the X-ray CT scan show a tumor located in the middle temporal gyrus, the Contour Plot (Fig. 8a, b) reveals additional data about other brain tissue damages in both hemispheres.

3D Color Surface Map displays a three-dimensional graph of the intensities of pixels in a gray scale or pseudo color image (Fig. 9a, b).

CONCLUSIONS

Image enhancement technique allows the increasing of the signal-to-noise ratio and accentuates image features by modifying the colors or intensities of X-ray CT brain image. The X-rays penetrate the tissues differently depending on

the type of tissue. The solid tissue, such as bone, appears white and the air appears black. Image processing of X-ray CT scans displayed the characteristic pattern of a normal and abnormal brain showing calcified and lack tissues or asymmetric perfusion in both hemispheres correlated with the neurological disease. Image analysis with OriginPro 7.5 and ImageJ programs revealed Histograms, Profile Plots, Power Spectra, measurements on a brain tumor with a Feret's Diameter of 1.724 cm and 3D Color Surface Graphs.

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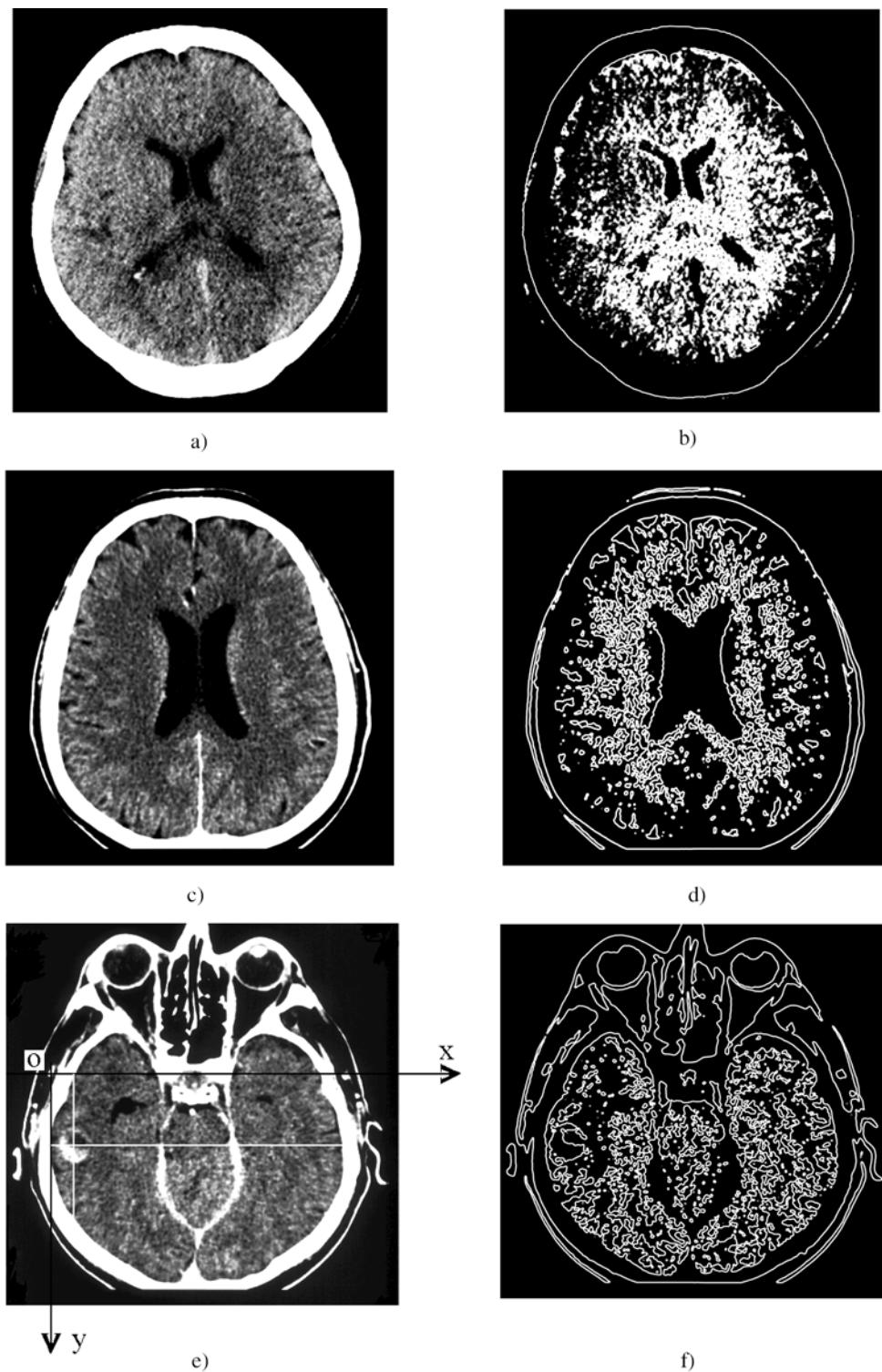


Fig. 2 – RGB-X-ray CT scan of (a) S1-normal brain (1971×2171 pixels), (c) S2.1.-SP-33.3 abnormal brain (1730×1645 pixels), (e) S2.2.-SP-73.3 abnormal brain where the subject's eyes, nose and ear lobes are clearly visible (1744×1669 pixels) and 8-bit images performed after ImageJ triple processing: Enhance Contrast (Saturated Pixels 5%, Equalize Histogram), Binary (Threshold) followed by Variance filter (Radius 5 pixels) on X-ray CT scan of (b) S1 normal brain, (d) S2.1 abnormal brain and (f) S2.2 abnormal brain.