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A New Technique to Improve the Quality of Medical Images

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Abstract - The purpose of this study is to assess the effect of different noise reduction filters on medical images. In particular Computed Tomography (CT) and Magnetic Resonance (MR) images are analyzed because they represent the most used diagnostic techniques in radiologist field. In a first step the statistical properties of noise that affects CT and MR images are investigated. Then a denoising technique was applied on CT and MRI applications to show the differences in the performance of the proposed method and to highlight in both cases the limits and the advantages.

Keywords: Computed tomography, Magnetic Resonance Imaging, image quality, denoising filters.

I. INTRODUCTION

Computed tomography (CT) is a radiographic inspection method that uses a computer to reconstruct the image of a cross sectional plane of an object. In most clinical conditions CT has been necessary added to conventional radiography. In fact, conventional radiographs depict a three dimensional object as a two dimensional image. Their main limitation is that overlying tissues are superimposed on the image. Computed tomography overcomes this problem by scanning thin slices of the body with a narrow x ray beam (produced by an x-ray tube) which rotates around the body of the stationary patient. The x-ray that passes through the patient is picked up a row of detectors. The tube and the detectors are positioned on opposite sides of a ring (gantry) that rotates around the patient [1]. The CT image is derived from a large number of systematic observations at different viewing angles, and an image is then reconstructed from the resulting projection data with the aid of a processor. Each image pixel has a computed tomography number (measured in Hounsfield units) [2] representing how much of the initial x-ray beam is absorbed by the tissues at each point in the body. This varies according to the density of the tissues. After the data for a cross sectional image is acquired the patient is advanced through the gantry into the nest stationary position and the next image is acquired.

Improvement in tube technology, computer and hardware performances has led to an evolution of CT scanners reducing the acquisition scan times and improving the resolution.

The last scanner technology is the *multislice CT* [3]. This system uses multiple rows of detectors. In this way, the throughput of the patient is considerably increased. However, multislice scanners generate an increased amount of data compared with the single slice scanner and practically the throughput of patients is limited by the time taken to reconstruct the acquired data.

Another common procedure to scan whole body giving 3D images is the Magnetic Resonance Imaging (MRI) which is based on magnetic properties of hydrogen content of tissues. The MRI scanner is a tube surrounded by a giant circular magnet. The patient is placed on a moveable bed that is inserted into the strong magnet which forces hydrogen atoms in the patient body to align in magnetic field direction [4]. Hence, at equilibrium, the net magnetization vector lies along the direction of the applied magnetic field. The nuclear magnetization is very weak and so it is difficult to measure it when is aligned with the strong static magnetic field. To overcome this problem, it is necessary to tip the moment away from the static field; this is accomplished by applying a second time-varying field (rotating radiofrequency field) that perturbs the magnetization equilibrium by tipping the magnetization in different directions. As the RF waves turn off the hydrogen atoms lose energy emitting their own RF signals. Different types of tissues generate different signals. The collected data are reconstructed into a two dimensional array.

MRI is a non-invasive examination because the patients are not exposed to radiation dose. One of the great advantages of MRI is the ability to change the contrast of the images. Small changes in the radio waves parameters and in the magnetic fields can completely change the contrast of the image. Different contrast settings will highlight different types of tissue. On the other hand, MRI scanning time is very long. It typically ranges from fifteen minutes to an hour. Then MRI cannot be done in patients who are claustrophobic. Moreover MRI produces low detailed images in bony structures examinations because bone is virtually void of water and therefore does not generate any image; then MRI is well suited for soft tissues. MRI is more expensive than CT.

II. IMAGE QUALITY

In CT exanimations the quality image is primarily linked to the radiation dose adsorbed by the patient. In particular a lower dose leads to increased image noise and results in unsharp images like abdominal or liver CT.

The relationship between image quality and dose in CT is relatively complex, involving the interplay of several factors, including noise, axial and longitudinal resolution, and slice width. Various figures of merit (FOM) have been developed to quantify image quality; the most used is the quality factor (Q) defined as follows [5]

$$Q = \sqrt{\frac{1}{R \cdot \sigma_n^2 \cdot CTDI}} \quad (1)$$

where R is the spatial resolution, and σ_n is the standard deviation of the image noise. Therefore, there is a tradeoff among image noise, dose and spatial resolution.

Many technical factors contribute to intensity dose in CT [6]. Following the major parameters and their implications for the diagnostic quality of the CT exams are explored.

- *Tube current* (mA) and *gantry rotation time.* These parameters are directly proportional to dose. The product of them (mAs) affects the number of photons emitted by x-ray beam and so it is responsible of radiation exposure. Moreover an increase in mAs produces the heating of the anode of x-ray tube.
- *Tube voltage peak* (kVp). It is proportional to the square root of dose. This parameter controls the velocity at which the electrons collide with the anode and directly effects the x-ray penetration. Moreover by using high values of kVp it is possible to reduce the difference in tissues densities and this can degrade the image contrast.

Current technological developments for radiation dose management include automatic tube current modulation (ATCM), improved x-ray beam utilization.

Many CT protocols for adjustments in scan settings have been empiric [7], [8]. The core question is really how set up the CT parameters to reduce intensity dose and still provide acceptable diagnostic quality. This is obviously a complex issue and involves a great many variables, including also factors linked with the patient, such as characteristics of the lesion or disorder, size of patient, intrinsic contrast of the region examined.

In MRI exanimations the quality image is primarily linked to the time required to complete the acquisition of data (*acquisition time* or *scan time*). It is been proved that Signal Noise Ratio (SNR) improves as the root square of the acquisition time [9].

$$SNR \propto B_o \frac{voxel\ volume}{noise\ volume} \cdot \sqrt{T_{acq}} \quad (2)$$

where T_{acq} is total time required to carry out an acquisition, B_0 is the static magnetic field, *noise volume* is thermal noise is used to generated in the receiver coil (that is used to receive the RF pulse) by the body itself and *voxel volume* is the sample volume seen by the coil.

The acquisition time depends on different factors such as time between the application of a RF pulse and its successive, (called *repetition time*), the number of sampled RF echoes analyzed, the number of images averaged and son on.

The optimization of MRI parameters to improve the image quality is a very complex issue

III. NOISE IMAGE

CT and MRI images are intrinsically noisy, and this poses significant challenges for image interpretation and then for correct diagnostic. Modeling noise is a common problem in most image processing application as evident in the extensive literature.

CT noise affects the visibility of low-contrast objects. By using well engineered CT scanners it is reasonable to neglect the electronic noise caused by electronic devices [10] Then in CT image the primarily contributor to the total noise is due to the quantum noise, which represents the random variation in the attenuation coefficients of the individual tissue voxels [11]. In fact, it is possible that two voxels of the same tissue produce different CT values. A possible approach to reduce the noise is the use of large voxels which absorb a lot of photons assuring a more accurate measurement of the attenuation coefficients. But the use of large voxels increases blurring and limits the visibility of fine details. A lot of studies have proved the *Gaussianity* of the pixel image generated by TC scanner [12], [13], [14]. This result permits us to establish the stochastic image model and to conduct a statistical image analysis of CT image.

In MRI examinations the dominant noise source is the thermal noise from human body and receiver circuit in data acquisition. The image intensity in magnetic resonance magnitudes images in the presence of noise is shown to be governed by *Rician distribution* [15], [16]. Unlike additive Gaussian noise, Rician noise is signal dependent and consequently separating signal from noise is a difficult task. Rician noise is especially problematic in high resolution low signal-to noise ration regimes where it not only causes random fluctuations, but also introduces a signal dependent bias to the data that reduces image contrast.

IV. DENOISING FILTER AND EXPERIMENTAL RESULTS

In many image processing applications a suitable denoising phase is often required before any relevant information could be extracted from analyzed images. This is particularly necessary when few images are available for the analysis.

These techniques work as filters which reduce random noise and enhance structures. In this way, it is possible to get high quality images without to increase the radiation dose and the acquisition time in CT and MRI respectively.

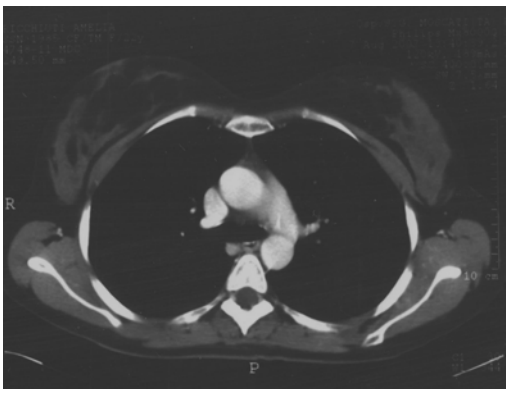
In this work some image filters to reduce the noise contribution are proposed.

With regard to CT analysis, 20 high dose chest CT images supplied from the Radiologist staff of "G. Moscati" Taranto Hospital have been examined. In particular, our attention was pointed to chest examinations due to the high frequency with radiologists investigate chest pathology, and the good availability of this type of images. In fact in the abdomen, CT is generally better than medical imaging analysis such as MR for the hollow viscera. Moreover, lung is the only organ whose vessels can be traced without using contrast media and this simplifies the image elaboration.

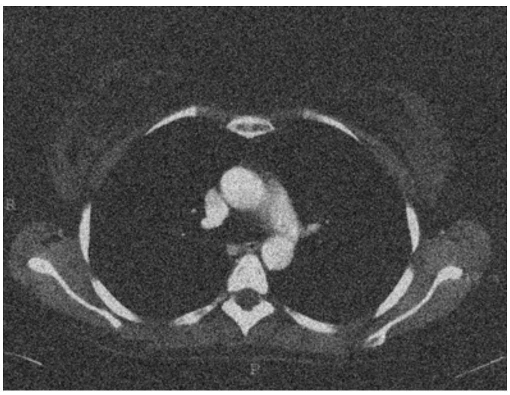
All images (512x512 pixels) were in DICOM (Digital Imaging and Communications in Medicine) format which represents the standard in the radiology and cardiology imaging industry for data exchange and image-related information. This standard groups information into data sets including important characteristics such as image size and format, acquisition parameters, equipment description, and patient information [17].

Each image was corrupted by additive zero mean white Gaussian noise to simulate a low dose CT image. To this aim, we have simulated the reduction in the tube current level by adopting an amount of noise in agreement with the results of previous studies about simulation of dose reduction in CT examinations [18], [19]. Figures 1 show an example of original chest CT image and its noisy version obtained by adding Gaussian noise.

To evaluate the effect of the noise addition on the original images the relative root mean square error (e_{RMS}) was calculated as follows:



(a)



(b)

Figures1. (a) Chest CT image obtained with high dose of radiation; (b) Noisy image obtanied by adding Gaussion noise

$$e_{RMS} = \sqrt{\frac{\sum_{i=1}^{R}\sum_{j=1}^{C}(I_{i,j} - I_{Oi,j})^2}{\sum_{i=1}^{R}\sum_{j=1}^{C}(I_{Oi,j})^2}} \quad (3)$$

where I_o is the original high dose image, I is the original image corrupted by Gaussian noise R and C are the row and column number, respectively.

Experimental results have showed that this parameter is on average about 13%.

With regard to MRI analysis, 20 high quality images supplied from the Radiologist staff of "G. Moscati" Taranto Hospital have been examined. In particular our attention was pointed to brain examinations which represent a bottleneck in the MRI clinical diagnostic, because of the very long acquisition time. In this case the images were corrupted with Rice. The magnitude of MRI images is formed by calculating the magnitude, pixel by pixel, from the real and the imaginary images. The probability distribution of pixel image is given by [15] .

$$p_M(M) = \frac{M}{\sigma^2} \cdot e^{-\frac{M^2 + A^2}{2\cdot\sigma^2}} \cdot I_0\left(\frac{A \cdot M}{\sigma^2}\right) \quad (4)$$

where A and M is the image pixel intensity in absence and in presence of noise respectively, I_0 is the modified zeroth order Bessel function of the first kind and σ is the standard deviation of the Gaussian noise in the real and imaginary image (which we assume to be equal).

To carry out a correct comparison between the filtering effect on the two diagnostic examinations, we have started from the same e_{RMS} for both CT and MRI images. Then σ is been chosen to produces relative root mean square error of about 13%.

Using some algebra, it is possible to show that absolute mean square error is given by:

$$E_{RMS}{}^2 = \frac{1}{R \cdot C}\sum_{i=1}^{R}\sum_{j=1}^{C}(I_{i,j} - I_{Oi,j})^2 = \frac{1}{R \cdot C}\sum_{i=1}^{R}\sum_{j=1}^{C}(M_{i,j} - A_{Oi,j})^2 = \sigma_r^2 + bias^2$$
$$bias = A - \mu_r \quad (5)$$

Where σ_r and μ_r are the standard deviation and the mean of the Rice distribution. These parameters can be estimated in the background (where A=0). In this case it is possible to use the following relationships:

$$\sigma_r = \sqrt{2 - \frac{\pi}{2}} \cdot \sigma; \qquad \mu_r = \sqrt{\frac{\pi}{2}} \cdot \sigma \quad (6)$$

By combining (5) and (6) it is possible to calculate the values of σ that allows a relative root mean square error equal to 13%.

Then, a Rice noise is added on the MRI images by using (4). Figures 2 show an example of original

(a)

(b)

Figures2. (a) Brain high quality MRI image obtained (b) Noisy image corrupted with Rice noise.

brain MRI image and its noisy version obtained by adding Rice noise.

To reduce the noise effect different low-pass filters have been largely used in medical image analysis, but they have the disadvantage to introduce blurring edges. In fact, all smoothing filters, while smooth out the noise, also remove high frequency edge features by degrading the localization as well as the contrast. Therefore it is necessary to balance the trade off among noise suppression, image deblurring and the edge detection.

To this aim non-linear anisotropic diffusion denoising filter [20] has been applied. Several simulations have been carried out to test the filter performance on noisy TC and MRI images.

In a fist step the effects of variation of the different parameters of anisotropic filtering (number of iterations, the function used to calculate the diffusion coefficients, size of mask used to calculate the edge directions) have been investigated.

An initial analysis of the simulation and experimental results highlights that the TC images are more sensitive to variation of diffusion coefficients function whereas the MRI images are more sensitive to mask size.

As preliminary result it is been identified a parameters configuration that allows the reducing in the relative mean square error to about 8%.

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