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Scintigraphic image enhancement by digital filtering*

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We describe in this paper a digital method of image enhancement that compensates the modulation transfer function (MTF) of a scintigraphic system.

1. Introduction

The scintigraphic image enhancement processing is based, in general, on the application of digital filters. They are easily applied because a gammacamera is generally connected on line to a computer in which the data are stored, and the image is given in an intermediate stage as a numerical matrix.

Some revisions on different digital filters are described by several authors [1, 2]. In this paper, we study the effects on the image of a simple digital filter matched to the inverse of the modulation transfer function and applied on the Fourier transform of the image. This type of filter has been chosen for its independence from the object and its possible application to a general case.

The modulation transfer function varies with the object-collimator distance and with the thickness of the tissue placed between the object and the collimator. Firstly, we have studied the effect on the image of a filter designed to compesate the MTF of the system working in the conditions in which the image was obtained. Next, we have studied the effect on images for which the filter is not exactly adapted in order to know whether a reduced number of filters could improve the image quality under different image formation conditions.

2. Method

The scintigraphic system modulation transfer function (MTF) has been obtained from the experimental data of the line spread function (LSF). The LSF was measured from the image of a linear source consisting of a plastic capillary tube of 0.35 mm of diameter filled with sodium pertechnetate eluted from a Technetium 99 m generator, as described by several authors [3].

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The MTF is obtained as the modulus of the normalized Fourier transform of the LSF. It has been computed for different object-collimator distances and different thicknesses of tissue simulated by polystyrene plates of density 1.04 g/cm^3 placed between the source and the collimator.

The image filtering technique can be described as follows: The image of an object is given as a numerical matrix and obtained directly from the scintigraphic system. The Fourier transform of this matrix is computed. This spectrum of the image is multiplied by the filter consisting of a numerical matrix with circular symmetry computed from the MTF, obtaining the filtered image as the inverse Fourier transform of the product matrix.

Here the scintigraphic images are obtained with an Ohio-Nuclear Sigma 400 gammacamera with a lead collimator (14S17010) of parallel holes suitable for photons of enrgy lower than 200 keV. The gammacamera is connected to an HP 2100 A computer of 32 kbytes of central memory provided with a Data Scintigraphic System 5407 A.

In order to be able to judge the filtering effects we have used some known objects: a Picker Thyroid phantom with one hot-simulated lesion and three cold-simulated ones and a brain slice phantom with two hot-simulated lesions and two cold-simulated ones. The criteria to compare the images are based on the lesions detectability and the edges sharpness quality.

3. Results and discussion

Figure 1 shows as an example the values of the MTF of the scintigraphic system obtained by the method described in Sec. 2. They correspond to different source-collimator distances. The values of the MTF and the limit frequency decrease if the distance from the object to the collimator increases.

The filter design is based on three factors: a) the filter shape (selection of the MTF at which the filter is adapted), b) the frequency of maximum transmission, and c) the limit frequency. A frequency of maximum transmission

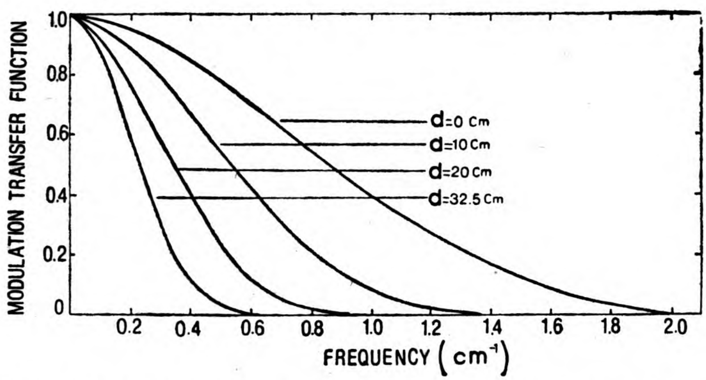

Fig. 1. Modulation transfer function of the scintigraphic system for different object-collimator distances (d)

is taken in such a way that the filter is equal to the inverse of the MTF for frequency values from zero to this maximum transmission frequency. To avoid the amplification of the noise, that is predominant for high frequencies, the filter is designed as a linear decreasing function from the frequency of maximum transmission up to the limit value of the transmitted frequencies (Fig. 2).

We have designed several filters differing in one or more of those three factors. These filters were applied to images obtained under different work conditions and the filtered images were compared by adequate observers.

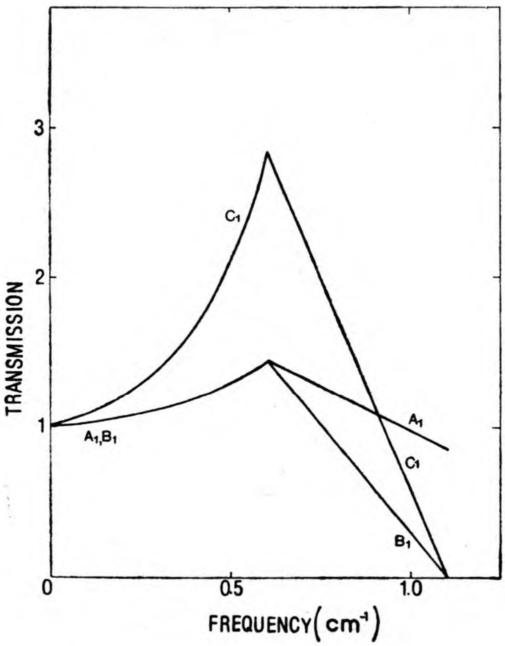

Fig. 2. Filters adapted to different system responses. The maximum transmission frequency is 0.6 cm^{-1} in all of them. Filter A_1 is adapted to the MTF and the limit frequency of the system when the object is in contact with the collimator. Filter B_1 is adapted to the same MTP as filter A_1 but its limit frequency is the corresponding one for the object-collimator distance of 10 cm. Filter C_1 is adapted to the MTF and the limit frequency of the system for a distance equal to 10 cm

To study the influences of the filter shape and the value of the limit frequency on the image filtering we have observed the effect of different filters adapted to different work conditions. In all of them the value of the frequency of maximum transmission is kept constant and equal to 0.6 cm^{-1}.

We applied these filters to images of a brain slice phantom obtained at distances from the object to the collimator equal to 10 and 20 cm. Images obtained through a scattering medium are also treated.

As an example of the results that we have obtained, Fig. 3a shows the image of the brain slice phantom taken at a distance equal to 10 cm. It has been processed with filters A_1, B_1 and C_1 of Fig. 2 and the filtered images are shown in Figs. 3b, c and d. No great difference is observed between the filtered images, except that Fig. 3b is slightly noisier. This effect corresponds to the fact that filter A_1 allows the pass of higher frequencies than the others do, with the consequent increase of noise that is predominant at high frequencies.

In order to study the influence of the frequency value of maximum transmission on the filtering results we designed several filters with different values of this frequency. The MTF at which they are adapted and the limit frequency are kept constant. Two different object-collimator distances are considered and the existence of a scattering medium is also taken into account.

Figure 4 shows, as an example, three filters adapted to the MTF of the system for an object-collimator distance equal to 20 cms. The limit frequency is 0.8 cm^{-1} and the maximum transmission frequencies are 0.3, 0.4 and 0.5 cm^{-1} (filters A, B and C, respectively).

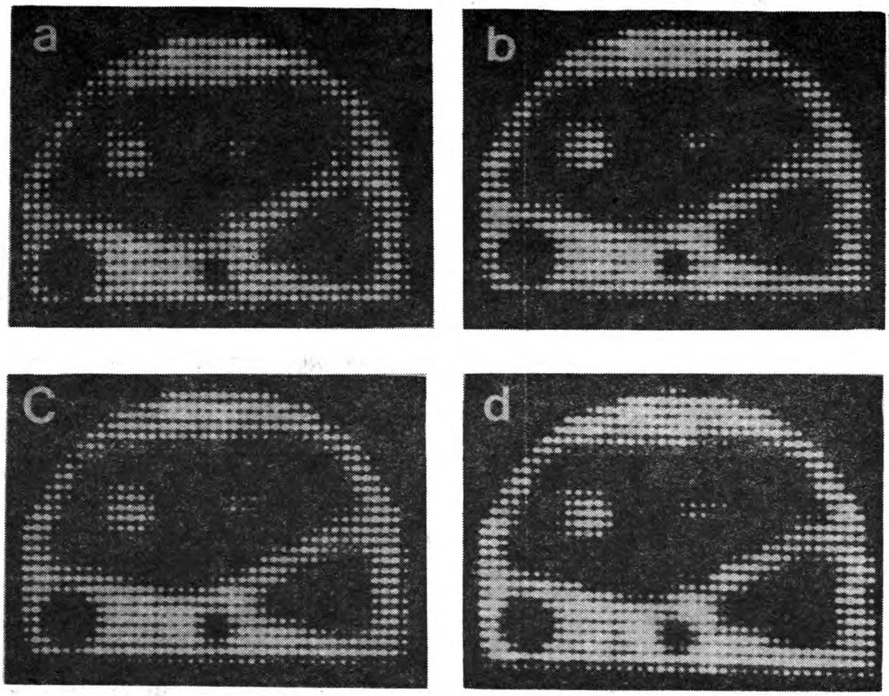

Fig. 3. a) Image of a brain slice phantom at a distance of 10 cm; b, c and d image (a) filtered with filters A_1, B_1 and C_1 of Fig. 2

In Figure 5 the image obtained with the scintigraphic system at this object-collimator distance is compared to the images filtered with filters A, B and C of Fig. 4. It is observed that the filters B and C (Figs. 5c and d) give better detectability for the small cold-simulated lesion than filter A (Fig. 5b), but filter C leads to some irregularities on the edges (Fig. 5d).

The MTF for a great distance from the object to the collimator decreases quickly versus the frequency and so for maximum transmission frequencies near limit frequency, the filter has a steep slope on the transmission versus frequency curve. In those cases the final image becomes very sensitive to small variations on the maximum transmission frequency. It explains that the fil-

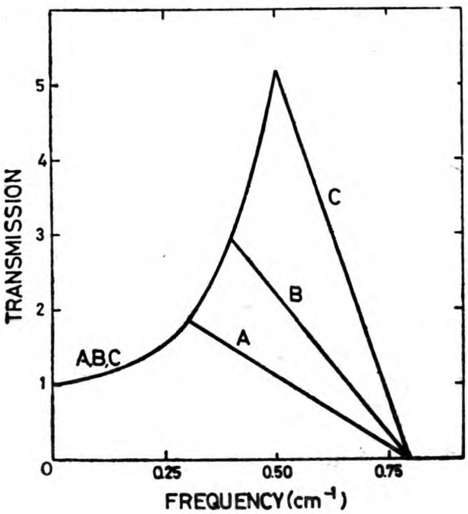

Fig. 4. Filters adapted to the MTF and the limit frequency of the system for a distance of 20 cm. The frequencies of maximum transmission are: 0.3, 0.4 and 0.5 cm^{-1}

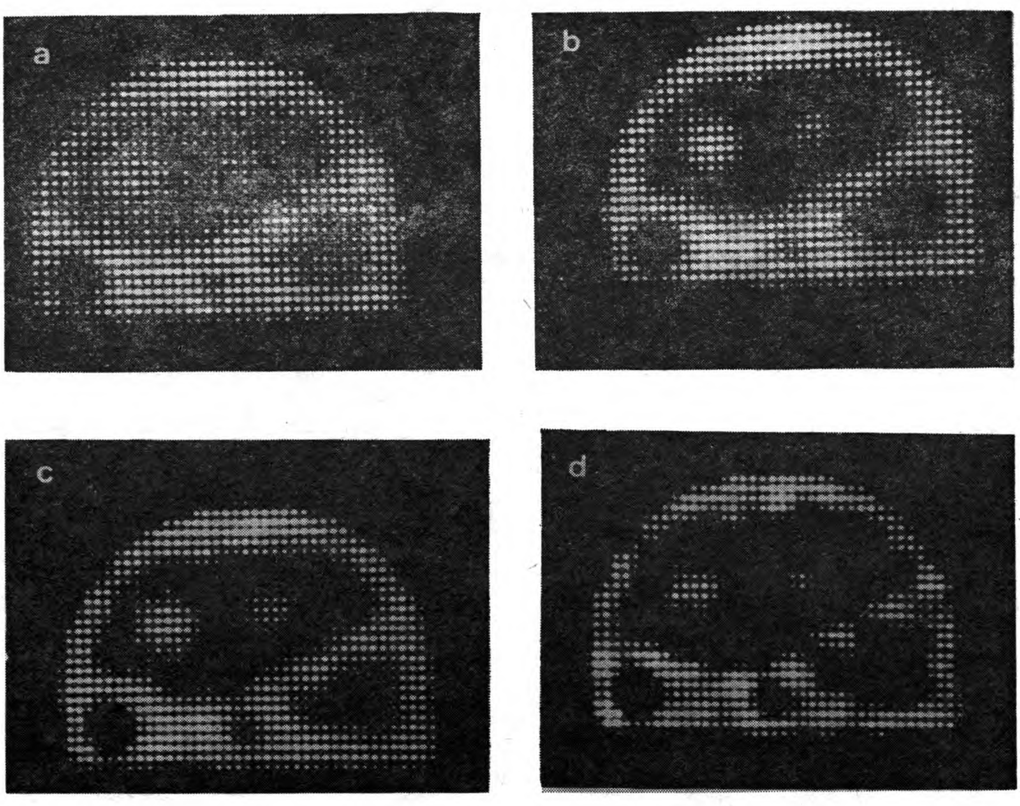

Fig. 5. a) Image of a brain slice phantom at a distance of 20 cm; b, c and d image (a) filtered with filters *A*, *B* and *C* of Fig. 4

tered image is better in Fig. 5c than in Fig. 5d that corresponds to a filter (filter *C*, Fig. 4) whose frequency of maximum transmission is near the limit frequency and the transmission value reaches a too high value.

We can deduce from all the results obtained that it is correct to choose the frequency of maximum transmission for a value of the filter in the range of transmission of 2.5 to 3 approximately. A higher value for the maximum transmission frequency produces much higher amplification for some frequencies and decreases the image quality.

Finally, we can conclude that the best filtering effects appear when the filter is adapted to the MTF of each particular case. The filter is matched to the inverse values of the MTF up to a correct value of the maximum transmission frequency and its limit frequency coincides with the limit frequency of the system. The value of the maximum transmission frequency should not be near the limit frequency and the filter must not present a great discontinuity.

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Усиление сцинтиграфичечкого изображения путем численного фильтрования

Описан численный метод усиления изобажения, который компенсирует модуляционную передаточную функцию (MTF) сцинтиграфической системы.