DESENSITISATION OF MEDICAL IMAGES RESTORATION UNDER CRUDE ESTIMATES OF MOBILE RADIO CHANNELS

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ABSTRACT

This paper presents an algorithm to reduce the sensibility of the Wiener restoration scheme with respect to wrong estimates of the parameters required in a regularisation problem, applied to the transmission of medical images over a mobile radio channel. Desensitised restoration is applied to blocks of transmitted information before decoding at the receiving site, including their corresponding FECs together with the information data (i.e., JPEG coded image). The proposed desensitisation algorithm improves the restoration with respect to a conventional Wiener filter when using wrong estimates of the required parameters, i.e., wrong estimate of the blurring caused by the multipath fading, noise and statistics of the original image (which are unknown in a real situation).

1. INTRODUCTION AND BACKGROUND

This paper presents an algorithm to desensitise the image restoration problem with respect to the required estimates in the process, applied to transmission of medical images. System reliability and good image quality are essential to tele-assistance and tele-diagnosis services in order to make it possible for a doctor the evaluation of patients' situation, diagnosis and medical treatment monitoring. Apart from bad capturing conditions and noise [1], under multipath fading and low coverage conditions in mobile communications, channel coding techniques (i.e., FEC) could become useless to decode properly, thus dropping some information blocks. A possible solution, among others (e.g., improving the Viterbi mechanisms), consists of restoring blocks of transmitted information before decoding at the receiving site, including their corresponding FECs together with the information data (i.e., JPEG coded image).

The restoration achieved on the basis of a Wiener scheme is an optimum since the restoration filter is the outcome of a minimisation process [2,3]. Nevertheless, the Wiener restoration scheme requires the estimate of some parameters related to the original image and the noise, as well as knowledge on the PSF function. If these estimates are correct, the restoration result is close to its optimum [4,5,6,7]. However, a real restoration process may be far from some type of knowledge about the parameters to be estimated. In the concrete case of the tele-assistance service proposed, the characterization of the mobile radio channel is unknown as well as the spectral characteristics of the original medical image.

This paper presents an iterative process to reduce the sensibility of the Wiener restoration scheme with respect to wrong estimates of the said parameters. The optimum number of iterations is proposed in order to maximise the relative increment of sensibility reduction achieved for a given regularisation degree. It is also demonstrated that the proposed iterative scheme desensitises primarily at the frequencies related to those eliminated by the low pass degradation filter, i.e., where its zeros would become poles in the restoration filter.

Applying this proposed method, better results are achieved than those obtained when using the same wrong estimates in the Wiener approach. Test results using wrong estimates of the PSF and the noise (characterization of transmission channel), together with a crude estimate of the original image demonstrate the desensitisation degree achieved.

2. RESTORATION MODEL

The classical stochastic regularisation approach for image restoration minimises a global restoration error. Assuming circular convolution, as well as a stationary model for the blur $\boldsymbol{h}$, the original image $\boldsymbol{y}$ and the noise $\boldsymbol{n}$, the said minimisation provides an optimum linear solution written as a scalar computation for each 2-D frequency component (w_i, w_j) in the Fourier Transform domain (using DFT) as,

$$\hat{Y}(w_i,w_j) = G(w_i,w_j)\, X(w_i,w_j) = \frac{H^*(w_i,w_j)}{\left|H(w_i,w_j)\right|^2 + C(w_i,w_j)}\, X(w_i,w_j) \quad (1)$$

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which is the Wiener restoration approach where $C(w_i,w_j)=\dfrac{S_{nn}(w_i,w_j)}{S_{yy}(w_i,w_j)}$, $\hat{Y}=DFT(\hat{\boldsymbol{y}})$, $X=DFT(\boldsymbol{x})$, $H=DFT(\boldsymbol{h})$, G is the well-known Wiener filter [2], and S_{yy} and S_{nn} are the respective spectral densities of the original image $\boldsymbol{y}$ and the noise matrix $\boldsymbol{n}$. Common assumptions for the latter consider Gaussian noise for $S_{nn}(w_i,w_j)$ and presume that the spectral density $S_{yy}(w_i,w_j)$ of the original unavailable image $\boldsymbol{y}$ is not very different from the spectral density $S_{xx}(w_i,w_j)$ of the degraded image $\boldsymbol{x}$, therefore $S_{yy}(w_i,w_j) \approx S_{xx}(w_i,w_j)$ [3]. Nevertheless, the sensibility of (1) to wrong estimates is very high; e.g., relatively small deviations from the real (unknown) value of $C(w_i,w_j)$ make (1) to yield results very far from the desired optimum, so the quality of the restored images will be very low.

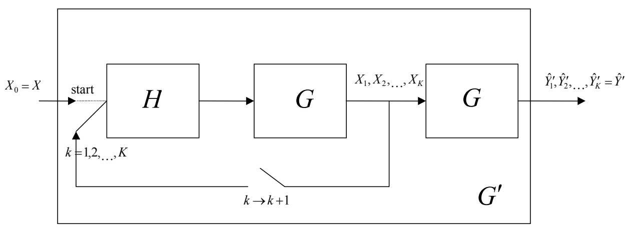

Figure 1 - Proposed restoration scheme

In order to simplify notation, the reference to the element (w_i,w_j) of the matrices in the frequency domain will be removed from all formulae throughout the remainder of this paper. Nevertheless, it must be taken into account that all mathematical expressions involving matrices in the Fourier Transform domain will be scalar computations for each frequency component (w_i,w_j).

The aim is to build a new restoration filter G' on the basis of G whose sensibility with respect to H and C is smaller than that of G. This filter G' will provide another replica $\hat{\mathbf{y}}'$ of the original image, whose Fourier Transform $\hat{Y}' = DFT(\hat{\mathbf{y}}')$ can be written as,

$$\hat{Y}' = G'X = G'(HY+N) = G'HY + G'N \qquad (2)$$

In order to achieve this purpose, G' is built on the basis of applying an iterative process of degradations and restorations, using H and G, respectively. This process is graphically explained in Figure 1. The input at any iteration k ($k=1,2,\ldots,K$) is an image $\mathbf{x}_{k-1}$ ($X_{k-1}=DFT(\mathbf{x}_{k-1})$) where $X_0 = X = HY+N$ (that is to say, the degraded image). The corresponding output is an approach $\hat{\mathbf{y}}'_k$ to $\hat{\mathbf{y}}'$ ($\hat{Y}'_k = DFT(\hat{\mathbf{y}}'_k)$). After the last iteration K, we will have $\hat{Y}'$ of (2) as $\hat{Y}' = \hat{Y}'_K$. A criterion will be adopted to define this total number of iterations K.

We can write G' at any iteration k as,

$$G' = G(GH)^k = \frac{(H^*)^{k+1}H^k}{(H^*H+C)^{k+1}} \qquad (3)$$

3. SENSIBILITY OF THE RESTORATION FILTERS

3.1. Condition establishment

Let us compute and compare now the sensibilities of G and G' with respect to the estimates and assumptions required in the restoration process, that is, the estimates about the original image and the mobile channel. From (1), an increment dG and dG' can be computed respectively as,

$$dG = \frac{\partial G}{\partial H}dH + \frac{\partial G}{\partial C}dC$$
$$dG' = \frac{\partial G'}{\partial H}dH + \frac{\partial G'}{\partial C}dC = \frac{\partial G'}{\partial G}\left(\frac{\partial G}{\partial H}dH + \frac{\partial G}{\partial C}dC\right) \qquad (4)$$

Dividing expressions of (4) and taking into account (3), we find the condition for the new filter G' to be less sensitive than G with respect to wrong estimates of H and C as a function $Z(k)$,

$$dG' < dG \Leftrightarrow \frac{dG'}{dG} = \frac{\partial G'}{\partial G} = Z(k) = (k+1)(GH)^k < 1 \quad (5)$$

By definition, in the presence of noise, that is to say, real restoration conditions, $C > 0\ \forall (w_i,w_j)$. From (1),

$$0 \le GH < 1 \Rightarrow 0 \le (GH)^k \le GH < 1,, \forall (w_i,w_j), \forall k \ge 1 \quad (6)$$

As a result of (6), we can conclude that the relative sensibility function $Z(k)=(k+1)(GH)^k$ of (5) is such that, regardless of the value of the produce GH, G' is less sensitive than G if the number of iterations k is high enough. Under this hypothesis, we could increase the value of k as much as we wish in order to prevent poor restoration results under wrong estimates of H and C. But this is not true; let us find now which could be a recommended number of iterations.

3.2. Recommended number of iterations

Let us remind that the goal is to reduce the value of the relative sensibility function $Z(k)$, so let us look for a maximum of efficiency of the incremental complexity introduced in the restoration process by increasing the number of iterations from k to $k+1$. In other words, let us look for a maximum of the relative increment of sensibility reduction achieved for the corresponding value of the product GH, when we increase the number of iterations from k to $k+1$.

For this purpose, it can be easily demonstrated that we can define a function $R(k)$ providing the relative increase of sensibility increment of the iterative restoration process at iteration k and look for its maximum:

$$R(k) = \frac{\partial^2 Z(k)}{\partial k^2} = (GH)^k \left[2 + (k+1)\log_e(GH)\right]\log_e(GH) \quad (7)$$

GH	0,20	0,25	0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80
K	1	1	1	2	2	3	3	4	5	6	7	9	12
Z(k=K)	0,46	0,43	0,41	0,41	0,41	0,42	0,43	0,45	0,49	0,53	0,60	0,69	0,84

Table 1 – Total number of iterations K recommended as a function of GH

The position of the maximum of *R(k)* depends on the value of *GH*. Hence, this maximum determines the recommended number of iterations as $K = K(GH)$, and can be computed by means of the first derivative of *R(k)*. It can be demonstrated that the result is

$$K = -\left(1 + 3\left(\log_e(GH)\right)^{-1}\right) \quad (8)$$

By means of the second derivative of and taking into account that $K \geq 1$ and that we require $Z(k = K) < 1$, it can be easily demonstrated that the condition of existence of the maximum of *R(k)* can be written as

$$0.84 > GH > 0.14 \quad (9)$$

Table 1 shows the total number of iterations $K = K(GH)$ recommended by (8) within the range given by (9). As well, Table 1 also shows the corresponding desensitisation values of $Z(k = K)$ as defined by (5).

4. RESULTS

The proposed desensitisation mechanism yields a different number of iterations for every pair (w_i, w_j) due to its dependence on the product GH, which is, likewise, variable with each frequency component. Therefore, $K(w_i, w_j) = K\left[GH(w_i, w_j)\right]$.

By using the expression of (8), we achieve a value of K for those pairs whose related GH is within the range given by (9). Thus, a criterion will be adopted for choosing a number of iterations for the rest of frequencies. Owing to the increasing tendency of K with respect to GH, all pairs whose corresponding GH exceeds 0.84 are associated with a constant number of iterations, equal to the maximum value of K reached by those within the range. Respectively, the minimum number value of K computed within the range is applied to those under 0.14.

The JPEG encoded medical image shown in Fig. 2 has been selected to test the proposed method. The received image blurred by defocusing and noise in simulation of the described channel (GSM-UMTS with low coverage) is shown in Fig. 3. In the absence of better propagation models for mobile radio channels, we have used a degradation filter representing the distortion introduced in the transmitted image due to the effects of multipath fading (as a mask for linear convolution), this being one of the components that characterise a mobile radio channel [8]. Gaussian noise has been added in the radio channel as BSNR = 0 dB.

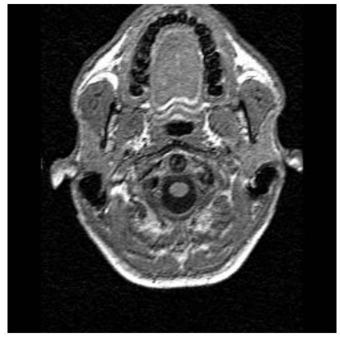

Figure 2 – Original image

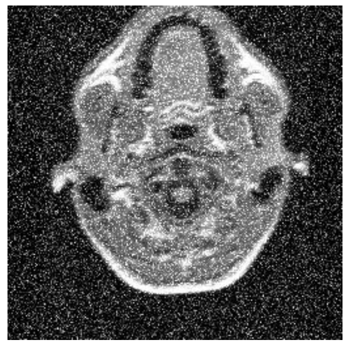

Figure 3 – Blurred image, BSNR = 0 dB

The restoration is applied to the information blocks entering into the receiving site, previous to decoding, and thus affecting both to the JPEG blocks and their corresponding FECs within the transmission frames. The results of the proposed method are compared with those obtained by the application of the Wiener approach (1) using both real values and wrong estimates for multipath fading effects (different linear convolution mask than the one used in the degradation model). The variance of noise used in the restoration is much lower than its real value, and the spectral characteristics of the degraded image are supposed to be the same as those of the original image. The tests are given in terms of the improvement in SNR (*ISNR*), which is the ratio between the mean squared error of the original image $\boldsymbol{y}$ with respect to the degraded image $\boldsymbol{x}$ and that of the original image $\boldsymbol{y}$ with respect to the restored image $\hat{\boldsymbol{y}}$ [2] as shown in (10).

$$ISNR = 10 \cdot \log_{10}\left\{\frac{\sum_{i,j}\left[y(i,j) - x(i,j)\right]^2}{\sum_{i,j}\left[y(i,j) - \hat{y}(i,j)\right]^2}\right\} \quad (10)$$

Table 2 shows that the results obtained with the proposed method have got lower sensibility with regard to the wrong estimates of the parameters. The *ISNR* value is appreciably better than those obtained when using the same wrong estimates in the Wiener approach, as well as closer to their respective optima. The estimate of the original image after the proposed restoration method is shown in Fig. 4.

	ISNR (dB)
Wiener using real values	9.00
Wiener using wrong estimates	- 7.32
Iterative proposed with the same wrong estimates	2.78

Table 2 – Results of different methods of restoration

We can compute now the function $Z(k)$ and detect the frequency pairs (w_i, w_j) where desensitisation is reached, that is to say, $Z(k) < 1$. Figure 5 shows a binary image where desensitised frequencies are white coloured and the remainder of them appear black coloured. Let us define a desensitisation parameter given by the percentage of pairs which validate the condition of (5) compared with total spectrum. This is also shown in Figure 5 (77.19%).

Even more, looking at the aspect of Figure 5, we can conclude that the desensitised frequencies are related to those eliminated by the low pass degradation filter (that is to say, zeros which become poles in the restoration filter). Therefore, it means that the restoration process provides a sensibility reduction where it is more likely to have magnified noise effects and, consequently, accomplishes better results than those obtained when using the same wrong estimates in the Wiener approach. As a result, the restoration becomes significantly improved in real terms of desensitisation, much more than the said value of 77.19%.

5. CONCLUSIONS

This paper has proposed an algorithm to desensitate the image restoration problem with respect to the required estimates in the process. Apart from bad capturing conditions and noise, under multipath fading and low coverage conditions in mobile communications, channel coding techniques (i.e., FEC) could become useless to decode properly, thus dropping some information blocks. A possible solution, among others (e.g., improving the Viterbi mechanisms), consists of restoring blocks of transmitted information before decoding at the receiving site, including their corresponding FECs together with the information data (i.e., JPEG coded image).

The proposed desensitisation algorithm improves the restoration with respect to a conventional Wiener filter when using wrong estimates of the required parameters, i.e., wrong estimate of the blurring caused by the multipath fading, noise and statistics of the original image (which are unknown in a real situation).

As an application, medical images transmission is essential to tele-assistance and tele-diagnosis services in order to make it possible for the doctor the evaluation of patients' situation, diagnosis and medical treatment monitoring. The adverse conditions described before could cause that the images are not received by the doctor, which could be critical for the patient depending on the circumstances. Our approach makes it possible that the FEC starts to work again, and the quality of the JPEG transmitted image is significantly improved with respect to noise.

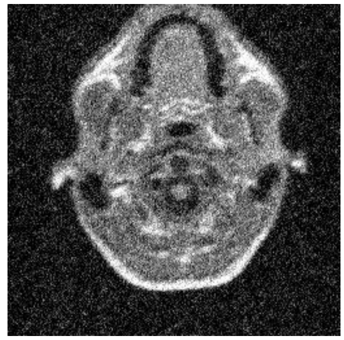

Figure 4 – Replica of the original image after restoration with the proposed method

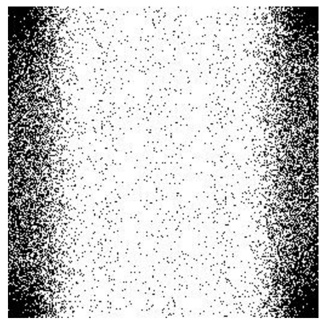

Figure 5 – $Z(k)$; 77. 19 % desensitised

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