OLD MOVIE RESTORATION USING RATIONAL SPATIAL INTERPOLATORS

L. Khriji (1), *M. Gabbouj* (2), *G. Ramponi* (3), *and E. Decenciere Ferrandiere* (4)

(1) Electrical Engineering Department, E.N.I.M., Tunisia. e-mail: lazhar.kheriji@enim.rnu.tn
(2) Signal Processing Laboratory, TUT, P.O. Box 553 FIN-33101 Tampere, Finland
(3) DEEI, University of Trieste, Italy
(4) Centre de Morphologie Mathematique, Ecole des Mines de Paris, France

ABSTRACT

The restoration of old movies using the newly developed rational functions filters is considered. After localization of the stationary and random defects, a spatial rational interpolator scheme is proposed to reconstruct the missing data. The experimental results demonstrate the usefulness of the rational interpolator in an application involving the restoration of defects in old movies. The resulting edges obtained using the proposed interpolator are free from blockiness and jaggedness.

Keywords: Rational Filters, Interpolation, Rational Interpolator, Restoration, Old Movies.

1. INTRODUCTION

In the past few years, a number of research projects focused on the digital restoration of old movies, aiming to develop automatic algorithms for this purpose. Such a task has also been undertaken by the ESPRIT LTR project Noblesse, mainly by partners from the Center for Mathematical Morphology, Fontainebleau, France, and the University of Strathclyde, Glasgow, UK. Noblesse developed nonlinear models for image and image sequence description and analysis. In this effort, Decenciere Ferrandiere [1] has developed a complete system for automatic restoration. In general, old movies suffer from two types of defects which result in partial loss of information: namely stationary defects which are fixed and independent of the time variation and random defects, which vary from frame to frame in the image sequence. In both stationary and random cases, a detection- estimation scheme is adopted in [1]. The detection mechanism allows the localization of a defect while the estimation process restores the believed to be true gray-level values. Averaging techniques combined with morphological operators are used in the detection phase of local stationary defects; whereas, a novel scheme based on the concept of connected operators is used for the detection phase in the case of local random defects. A spatial morphological opening is used to interpolate the missing values in the case of stationary defects. On the other hand, both spatial and temporal interpolation schemes are proposed for the case of local random defects.

This paper introduces an alternative efficient adaptive algorithm to reconstruct missing information in an easy manner. We are not concerned here about the detection of damaged regions and therefore we assume that the locations of these regions have already been detected. The algorithm is based on rational filters which were recently proposed in [2]. It is well known, in fact, that a rational function (the ratio of two polynomials) has several properties [3] (i.e, it is a universal approximator and a good extrapolator, can be trained using an adaptive algorithm, and requires lower degree terms than Volterra expansions) which can make it very effective in many signal processing tasks. Moreover, the adaptive algorithm using this approach yields better interpolated images than those obtained with a number of linear and nonlinear techniques [2], [4]. Furthermore, the nonlinearity of the operator can reconstruct the defects ! which have been detected by the prelocalization step, without introducing overshoot artifacts in the restored images.

The algorithm is based on the fact that, although images are highly non-stationary signals, a strong correlation does exist between pixels belonging to the same region. For this reason, the interpolation of a defect should take into account the statistics and properties of the regions that hypothetically contain the defect. Thus, our interpolation algorithm first checks the existence of edges in order to take them into consideration; the edge orientation is estimated and the most convenient data to be used in the reconstruction of the missing pixels are selected (see Figs. 3, 4).

In our algorithm we assume that:

- The direction of edges does not change inside the defect region.
- The contrast of edges remains unaltered inside the defect region.

This is equivalent to assuming the stationarity of features of edges inside the defect region and permits an easy but effective reconstruction. The reliability of these assumptions depends on the size of the defect; therefore, the smaller the defect is, the more accurate the interpolation is.

2. THE ADAPTIVE ALGORITHM

We describe in the sequel the reconstruction method of the defect information after its localization.

2.1. Method

According to Fig.1 and in order to reconstruct the X sample at the central position, the interpolator operates on four consecutive alternate samples of known data, a_3, a_1, b_1 and b_3. The nonlinear interpolator has already been proposed in [2], [4], where a rational function is used in order to weight the contributions to X of its two adjacent samples (a_1 and b_1) according to the differences $(a_1 - b_3)$ and $(b_1 - a_3)$. The resulting operator is able to reconstruct sharp edges more accurately than a linear filter because it is able to roughly detect their position with sub-pixel accuracy.
The interpolated point X is computed as follows:

$$X = \alpha . a_1 + (1 - \alpha) b_1 \quad (1)$$

Where

$$\alpha = \frac{1 + k(a_1 - b_3)^2}{2 + k[(a_1 - b_3)^2 + (b_1 - a_3)^2]} \quad (2)$$

The parameter k is some positive constant and is used to control the amount of the nonlinear effect. The behavior of the proposed interpolator structure for different positive values of the parameter k is the following:

1: $k \simeq 0$, the form of the filter is given as a linear filter:

$$x = \frac{a_1 + b_1}{2} \quad (3)$$

2: For positive values of k, the $(a_1 - b_3)^2 + (b_1 - a_3)^2$ term perceives the presence of a detail and accordingly reduces the smoothing effect of the operator.

a3	a2	a1	X	b1	b2	b3

Figure 1: Samples considered for one dimensional interpolation. Sample X is to be constructed from samples a_3, a_1, b_1 and b_3

2.2. Algorithm

In order to apply the above interpolation scheme to defect interpolation, we will assume that defects are convex. This is true in most cases.

The first step of the algorithm consists in detecting the best edge orientation in the regions surrounding the defects. Pixels belonging to the regions in that direction (i.e., across the borders of different objects) should be used in the reconstruction of the lost pixels (see Fig. 4). Thus, big homogeneous or textured regions will be reconstructed directly avoiding processing delays or computational complexity. On the other hand, the satisfactory reconstruction of smaller homogeneous or textured regions, regions with small details, lines and edges requires a good edge detector (in our case a particular polynomial operator has been used: the p-th order statistical moment estimator [?]).

With reference to Fig.2 and after the detection of the edge orientation, let us consider the one dimensional interpolator described in the above subsection (the mask belongs to the best direction). Assuming that the defect width, $dx = 5$, and the available data are a_i's and the b_i's in the white boxes. We denote by $R(a3, a1, b1, b3)$ the computed value of Eq.(1).

Step–1: Compute the value of the sample at the central position X_0 using the four known samples (a_4, a_1, b_1, b_4). $X_0 = R(a_4, a_1, b_1, b_4)$.

In order to avoid the anti-aliasing effect, our interpolator takes into account the Nyquist rate requirement. This is why the periodicity is well respected.

Step–2: Compute temporarily:

- X_{-2} as a linear combination between a_1 and X_0: $x_{-2} = \frac{2a_1 + X_0}{3}$
- X_2 as a linear combination between b_1 and X_0: $x_2 = \frac{2b_1 + X_0}{3}$

Step–3: Compute the value of the sample X_1 by applying Eq.(1) using the four samples X_0, X_{-2}, X_2 and b_2: $X_1 = R(X_0, X_{-2}, X_2, b_2)$.

Step–4: Compute the value of the sample X_{-1} by applying Eq.(1) using the four samples a_2, X_{-2}, X_0 and X_2: $X_{-1} = R(a_2, X_{-2}, X_0, X_2)$.

Step–5: Recompute the value of the sample X_{-2} by applying Eq.(1) over the samples a_3, a_1, X_{-1} and X_1: $X_{-2} = R(a_3, a_1, X_{-1}, X_1)$.

Step–6: Recompute the value of the sample X_2 by applying Eq.(1) over the samples X_{-1}, X_1, b_1 and b_3: $X_2 = R(X_{-1}, X_1, b_1, b_3)$

The same algorithm and the same technique can be applied for any defect size dx by using the same procedure with respect to the Nyquist periodicity rule. The price paid is the time needed for finding the best edge orientation.

The above algorithm may also be applied to non-stationary defects. We are currently developing new masks and new interpolators for both random and stationary defects.

Figure 2: Example of real detected defects with large $dx = 5$. Only the data in the white boxes are available.

3. EXPERIMENTAL RESULT

Several images have been employed to assess and to test the performance of our nonlinear operator for the reconstruction of the defects detected in an old movie (as an example see Fig. 5). The interpolated images are presented for visual comparison since in many cases they are the best qualitative measure of performance for image processing algorithms. Fig. 5(top) displays the original frames of the two test sequences which are damaged with defects of a different shape and size. Fig. 5(medium) shows the location of the defects as detected by Decenciere Ferrandiere [1]. Finally, Fig. 5(bottom) shows the images interpolated by the proposed rational operator.

As shown in Fig. 5, the quality of the processed images is significantly better than that of the original ones. Furthermore, the proposed technique performs slightly better than the one presented in [1]. Edges and lines are well reconstructed and the texture continuation is smoother. The processing time remains small since the operator is applied only in the lost parts. Moreover, the rational interpolator requires only few operations. One drawback might prove to be the defects which are located close to the image borders, since they cannot be reconstructed perfectly and remain jagged.

4. CONCLUSIONS

The reconstruction step of the detected defects from old movies using a nonlinear operator based on rational filters has been investigated in this paper. The detected stage of the defects has been realized by Decenciere Ferrandiere in [1]. Some processed images are presented in Figs. 5 and 6 for subjective comparison. Our spatial technique achieves line, edge and smooth texture continuation with high probability. In the case of stationary defects, the performance of the proposed algorithm is better than the one presented in [1] with an increase in computational complexity. In the case of random defects, we achieved nearly the same performance in the reconstruction step, but we did not use of any motion estimation, making the present scheme much faster and suitable for real time implementations.

5. REFERENCES

[1] E. Decenciere Ferrandiere, "Restauration Automatique de Films Anciens",*PhD Thesis*, Ecole Nationale Superieure des Mines de Paris, Centre de Morphologie Mathematique, Fontainebleau, France, 1997.

[2] L. Khriji, F. Alaya Cheikh and M. Gabbouj, "High Resolution Digital Resampling Using Vector Rational Filters", *Optical Engineering Journal*, Special Issue on Sampled Imaging Systems, to appear (May 1999).

[3] H. Leung, S. Haykin, "Detection and Estimation Using an Adaptive Rational Function Filters", *IEEE Trans. on Signal Processing*, vol.42, no. 12, pp. 3365-3376, Dec. 1994.

[4] S. Carrato, G. Ramponi and S. Marsi, "A Simple Edge-Sensitive Image Interpolation Filter," *Proc. Third IEEE Intern. Conf. on Image Processing*, ICIP-96, Lausanne (CH), Sept. 16-19, 1996.

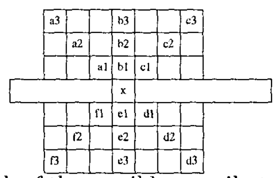

Figure 3: Mask of the possible contributed pixels in the interpolation process of the defect of width $dx = 1$.

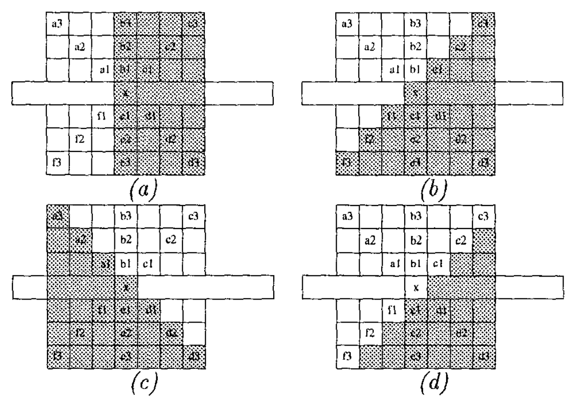

Figure 4: Position of the edge of an object with respect to the interpolation mask. *(a)* vertical edge, *(b)* diagonal edge (45 degree), *(c)* diagonal edge (135 degree), *(d)* diagonal edge outside the mask center.

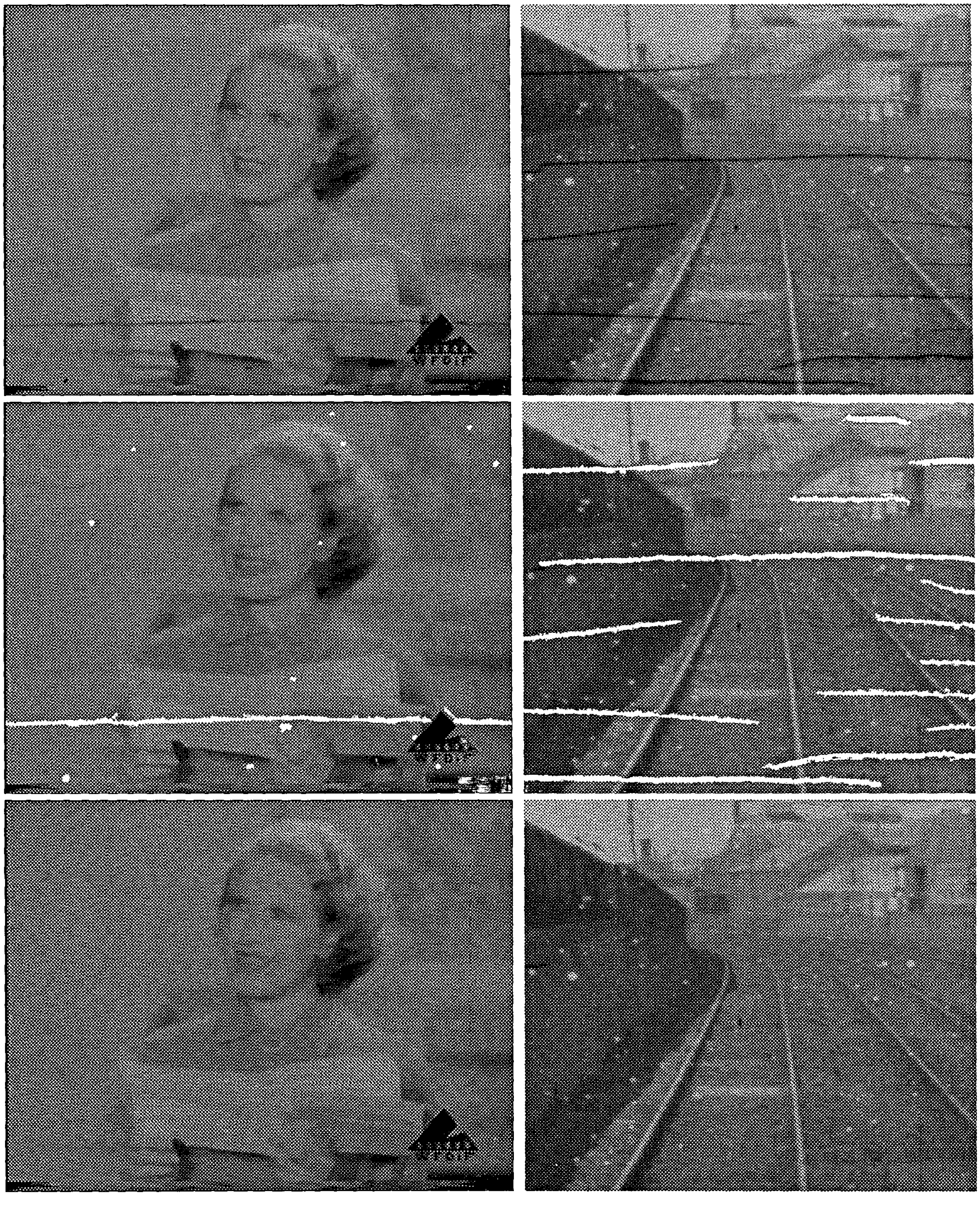

Figure 5: Two test images. Original frames (Top), results of the detection of crackles and dark random defects (medium), restored images using the proposed rational interpolator (bottom).