Cellular Nonlinear Networks to Analyze the Complexity of Foggy Paintings

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In this paper a new nonlinear signal processing technique, able to remove fog from color images exploiting the optical properties of the fog effect, is introduced. It is based on the use of cellular nonlinear networks (CNNs), a paradigm for nonlinear parallel image processing. The technique is applied to the analysis of several paintings by famous artists of different art movements, in which the presence of fog significantly affects the visual experience. The technique introduced distinguishes whether the fog is a natural element of the painted landscape or if it has been artificially added by the artist to express his or her own feelings.

1. Introduction

In this paper, a new method based on cellular nonlinear networks (CNNs) for investigating the role of fog in artwork is introduced and applied to analyze paintings in which the presence of fog is a characterizing element. The technique allows exploration of whether the fog has been intentionally added and so can be viewed as an enhancing element for the painting, allowing the onset of specific emotions in the observer [1, 2]. Thus, this paper aims to introduce a new nonlinear method that exploits the physical properties underlying the optical effects of fog and derives insights on the role of fog in paintings.

The proposed approach is based on a new algorithm implemented in CNNs, parallel analog programmable devices widely used in image processing [3], including the processing of artistic images [4, 5]. The approach tells whether fog in paintings is in accordance with physical laws, and therefore if it was really present in landscapes painted from life or if it was added by the artist for a specific aim.

The representation of fog has been considered from different perspectives in figurative art: from a rational approach, where fog is rep-

resented by means of its physical features, to imaginative representations, where fog is used to enhance the emotional effect on the observer. In fact, the ability of fog to cover and uncover elements, altering shapes and dimensions, makes it the vehicle of a new vision in which the artist can express his or her feelings and emotions. Fog may be also associated with macabre images enhancing the sadness of particular landscapes and suggesting the temporality of life or the "mal de vivre". The observer will, therefore, imagine what is veiled by the fog, causing his or her own sensitivity. Furthermore, fog seems to induce similar reactions in all humans [1], regardless of their own life experiences, and painters have often exploited these effects to guide the observer toward particular emotions.

Inferring the hidden aim of the artist who included fog in a painting is not a simple task. In fact, two aspects have to be considered: the specific painter's art movement and the geographical area in which the painter worked. Moreover, it should be inferred whether the artist represented a real foggy landscape or intentionally introduced fog to stimulate a particular emotive response from the observer.

The algorithm proposed in this paper allows for the elimination of fog from paintings on the basis of its physical features. Specifically, a suitable model of optical effects of fog on human vision has been considered and used to implement an efficient image processing algorithm that is able to revert the fog effects, removing them. The introduced algorithm has been implemented exploiting the parallel processing capabilities of CNNs and then used to evaluate the role of fog in visual art, thus distinguishing between real and imaginative fog in paintings.

The paper is organized as follows. In Section 2, the proposed CNN-based algorithm is introduced. In Section 3, several paintings characterized by the presence of fog are analyzed. Conclusions are drawn in Section 4.

2. Cellular Nonlinear Network-Based Algorithm for Fog Removal

Fog is a natural phenomenon characterized by the condensation of water vapor near the Earth's surface, resulting in decreased visibility caused by suspended water droplets that modify the optical properties of air. Fog occurs when air is supersaturated with water vapor. This happens in two different, often concurring, cases: when a mass of water is subjected to an intense evaporation, or when water vapor condensates in correspondence to a sudden temperature decrease.

An observer in a foggy landscape is reached both by direct radiation coming from the observed object and by that diffused by all the droplets lying between the object and the observer. Thus, the atmosphere acts like a source of light giving rise to the so-called *airlight* phenomenon. Airlight is also caused by a number of different natural

light sources such as a skylight or the light reflected by the ground or the water. Furthermore, diffusion caused by droplets attenuates the beam of light coming from the observed object, since it is scattered in different directions.

The attenuation of light beams together with airlight causes chromatic effects that modify the perception of the observer. A model describing the total fog effect on colors, as perceived by digital color image acquisition tools, is the dichromatic atmospheric scattering model introduced in [6, 7]. The dichromatic model takes into account both attenuation sources, that is, airlight and scattering, and can be written as:

$$
\begin{aligned}
\mathbf{E} &= p\,\hat{\mathbf{D}} + q\,\hat{\mathbf{A}} \\
p &= R\,e^{-\beta\,d} \\
q &= E_\infty\left(1 - e^{-\beta\,d}\right)
\end{aligned}
\tag{1}
$$

where $\mathbf{E} \in \mathcal{R}^3$ represents the observed color of a scene point in the presence of fog in the red, green, and blue (RGB) space; $\hat{\mathbf{D}} \in \mathcal{R}^3$, $\hat{\mathbf{A}} \in \mathcal{R}^3$ are unit vectors representing the color of the same scene point as seen in clear weather conditions; and the airlight color is p for the magnitude of direct transmission and q for the magnitude of airlight; E_∞ is the sky brightness; R is the radiance of the scene point on a clear day; β is the scattering coefficient of the atmosphere; and d is the distance of the scene point from the observer.

The dichromatic model can be applied to remove the effects of fog by suitably choosing its parameters [6]. In this paper, the dichromatic model is implemented in a CNN that processes grayscale images. For this reason, the RGB image is first split into the three channels, obtaining three grayscale images that can be processed separately by using the contrast or monochromatic model derived from the dichromatic model in equations (1) to mathematically identify the intensity E of a scene point as recorded by a monochrome camera [6]:

$$
E = R\,e^{-\beta\,d} + E_\infty\left(1 - e^{-\beta\,d}\right).
\tag{2}
$$

This model can be used to recover an abstract image without fog if R is found by inverting relation (2). The CNN algorithm implements the inverse relation of the monochromatic model. The model is based on single scattering, that is, turbulent blurring or scattering introduced by pollutants is not considered. Only scattering introduced by particles forming fog is removed through our algorithm.

The algorithm for the elimination of fog effects has been realized by using the classical CNN-universal machine (CNN-UM) paradigm [8], a programmable analog array computer based on the concept of CNNs.

In the CNN approach, each CNN cell elaborates one pixel of the image and evolves according to the dynamical model described in [9],

whose equations are:

$$\dot{\mathbf{x}}_{ij}(t) = -\mathbf{x}_{ij}(t) + \sum_{c(k,l)\in N_r(i,j)} A(i,j;k,l)\, y_{k\,l}(t) +$$
$$\sum_{c(k,l)\in N_r(i,j)} B(i,j;k,l)\, u_{k\,l}(t) + I \qquad (3)$$
$$y_{ij} = 0.5 * \left(\left| x_{ij} + 1 \right| - \left| x_{ij} - 1 \right| \right)$$

where A and B are called feedback and control templates, I is a bias term, $N_r(i,j)$ represents the set of r-neighbor cells of cell (i,j), and u_{ij} and y_{ij} are the input and output of the cell (i,j), respectively. Choosing a set of templates (A, B, I), the CNN can be programmed to perform a specific simple image processing task such as contour detection, edge extraction, and so on [8]. In order to perform complex tasks, a spatiotemporal algorithm is implemented by executing in cascade different sets of templates. This is the so-called CNN-UM. We now describe the CNN-UM algorithm that reproduces the monochromatic model for fog removal.

Since the aim of the algorithm is to remove fog from images according to optical laws, the first step is to invert the monochromatic model deriving the radiance R from equation (2):

$$R = \left[E - E_\infty \left(1 - e^{-\beta d} \right) \right] e^{\beta d} \qquad (4)$$

where E_∞ is assumed to be the RGB component of the white color, that is, $E_\infty = 255$. The atmospheric diffusion coefficient β takes different values corresponding to the fog density: higher values of β allow for the removal of dense fog and vice versa. Hence, β can be a space-variant quantity. This algorithm is applied to each of the three monochromatic images (each corresponding to one RGB channel) in which the original color image is split. Each cell is initialized with the corresponding normalized grayscale value of the image (i.e., in the CNN notation, -1 represents white, while 1 represents black).

The algorithm consists of two steps. The image to be processed is normalized according to the CNN notation and then split into the three RGB channels.

The input of the CNN is a grayscale image built according to:

$$U_{i,j} = \frac{E_\infty}{2} \left(1 - e^{-\beta d_{i,j}} \right) \qquad (5)$$

where $d_{i,j}$ represents the distance of pixel (i,j) from the imaginary observer plane. For the painting considered in this example, the image shown in Figure 1(a) has been used as input.
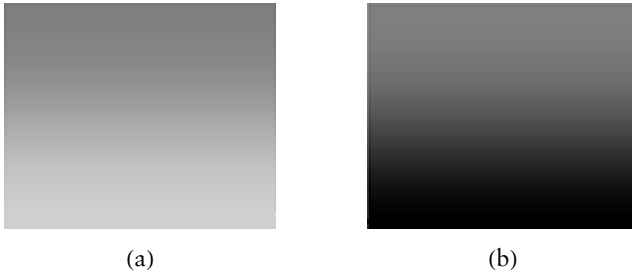
(a)　　　　　　　　　　　　　(b)

Figure 1. Images used by the CNN algorithm as (a) input for the first step and (b) the initial condition for the second step.

The objective of the first step is to perform the algebraic sum $E - E_\infty \left(1 - e^{-\beta d}\right)$. The following set of space-variant templates allows, in fact, the sum $X_{i,j}(0) - |U_{i,j}|$ to be obtained:

$$A = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}; \quad B = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 0 \end{pmatrix}; \quad I = 2\,X_{i,j}(0). \tag{6}$$

The image is obtained by merging the three outputs in the RGB space of the first step after 20 iterations. This is used as the input image for the second step.

In this step, the initial conditions are set as a grayscale image built according to:

$$X_{i,j}(0) = \frac{E_\infty}{2} \beta \, d_{i,j}. \tag{7}$$

In this case, the image shown in Figure 1(b) has been used as the initial condition.

The following set of space-variant templates has been applied to obtain the product of $U_{i,j} \, e^{X_{i,j}(0)}$:

$$A = \begin{pmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}; \quad B = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 2\,e^{X_{i,j}(0)} & 0 \\ 0 & 0 & 0 \end{pmatrix}; \quad I = 0. \tag{8}$$

The image resulting after 200 iterations is then normalized again to obtain the final image. The complete CNN algorithm is schematically summarized in Figure 2, where the painting *La nebbia sale* (The Fog Is Rising) by the contemporary Italian painter Alfio Cioffi has been processed.
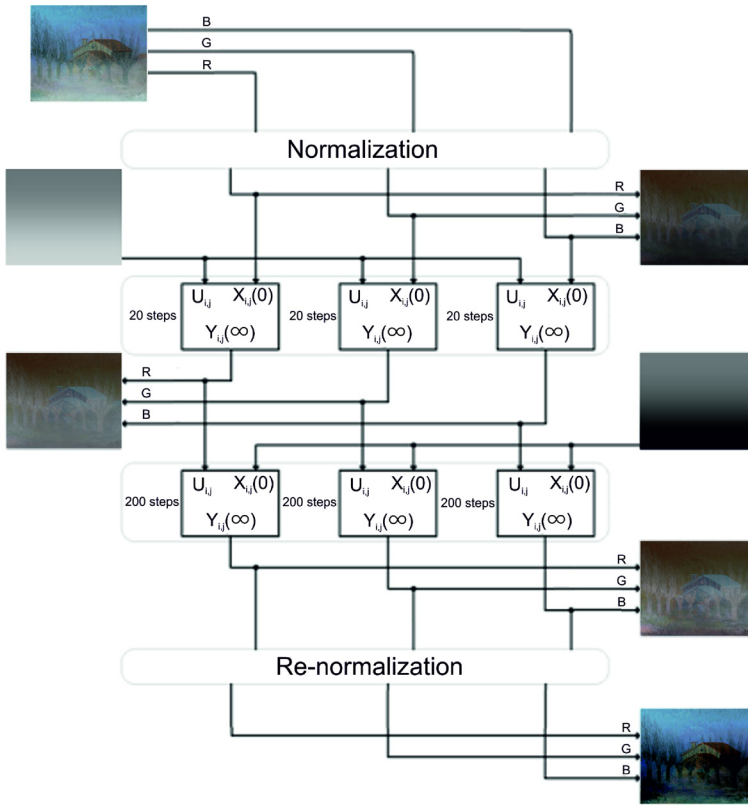
Figure 2. Schematic representation of the CNN algorithm.

3. Analysis of Paintings with Fog

As a first example, we consider another painting by Alfio Cioffi in Figure 3. (The left images show the original paintings, while the right ones show the result of the CNN processing.) It can be observed that the fog effect has been removed, indicating that the represented fog respected the physical laws underlying the optical effect of real fog. Even if fog has been removed, no further details are unveiled after fog removal. This can be an indication that fog was really present during the artwork production, that is, the subject has been painted from life.

Figure 3. Alfio Cioffi, *Il Po bianco* (The White Po), 2007, oil on canvas board, 35×50.

A different example is represented by the painting *La battaglia di Pavia* (Battle of Pavia) by Gherardo Poli (1676–1739), an artist of landscapes in which real elements are transformed in fictitious representations (Figure 4). In this case, the subject is an event that occurred in 1525. After the CNN processing, several hidden details emerge from the fog, demonstrating that fog has been added artificially, even if its effects are carefully reproduced. Furthermore, it can be observed that smoke over Pavia is preserved after the fog removal.

Figure 4. Gherardo Poli, *La battaglia di Pavia* (Battle of Pavia), oil on canvas, 84×128, Musei Civici di Pavia.

As a further example, the famous painting *Der Wanderer über dem Nebelmeer* (Wanderer above the Sea of Fog), shown in Figure 5, is considered. In this case, the CNN processing does not allow the removal of fog, indicating that it does not respect the optical laws of real fog. Fog is an additional fictitious element intentionally introduced by the artist who, according to [10], wanted to use the wanderer's gazing into the sea of fog to express a sort of self-reflecting feeling.

Figure 5. Caspar David Friedrich, *Der Wanderer über dem Nebelmeer* (Wanderer above the Sea of Fog), oil on canvas, 98×75, Kunsthalle Hamburg.

4. Conclusions

In this paper, a new technique to remove fog effects from images according to their optical properties has been introduced and applied to the analysis of several paintings with fog. The optical properties of the fog have been described by the so-called dichromatic model. By considering an implementation of the inverse dichromatic model on a cellular nonlinear network-universal machine (CNN-UM), an algorithm for fog removal has been designed. Since it is based on the optical properties of the fog, the algorithm can be used to determine if the fog in the painting has been painted from life or intentionally added by the painter. Therefore, the introduced technique may be used as a tool to gain new insights on the role of fog in paintings. The analysis presented demonstrates that the approach is suitable for distinguishing between cases of real fog and imaginary fog. In the latter case, fog is used by the painter to inspire in the observer a specific mood.

Obviously, the proposed tool cannot give definitive answers, since a complete study involves a deep knowledge of the painters, their art movements, and the scenario in which they operate, but it can be useful to determine whether or not fog has been painted according to physical laws. In fact, interesting results have been obtained by processing a set of paintings by different artists and art movements, in some cases unveiling hidden features and details.

References

[1] S. Zeki, *Inner Vision: An Exploration of Art and the Brain*, Oxford, UK: Oxford University Press, 2000.

[2] A. Bonito Oliva, *Il tallone di Achille: Sull'arte contemporanea (Campi del sapere)*, Feltrinelli, 1988.

[3] L. O. Chua and T. Roska, *Cellular Neural Networks and Visual Computing: Foundations and Applications*, Cambridge, UK: Cambridge University Press, 2005.

[4] M. Bucolo, A. Buscarino, L. Fortuna, M. Frasca, and M. G. Xibilia, "From Dynamical Emerging Patterns to Patterns in Visual Art," *International Journal of Bifurcation and Chaos*, **18**(1), 2006, pp. 51–81. doi:10.1142/S021812740802015X.

[5] P. Arena, M. Bucolo, S. Fazzino, L. Fortuna, and M. Frasca, "The CNN Paradigm: Shapes and Complexity," *International Journal of Bifurcation and Chaos*, **15**(7), 2005, pp. 2063–2090. doi:10.1142/S0218127405013307.

[6] S. G. Narasimhan and S. K. Nayar, "Vision and the Atmosphere," *International Journal of Computer Vision*, **48**(3), 2002, pp. 233–254. doi:10.1023/A:1016328200723.

[7] S. G. Narasimhan and S. K. Nayar, "Interactive (De)weathering of an Image Using Physical Models," in *Proceedings of IEEE Workshop on Color and Photometric Methods in Computer Vision*, October 2003. http://www.ri.cmu.edu/pub_files/pub4/narasimhan_srinivasa_g_2003_4/narasimhan_srinivasa_g_2003_4.pdf

[8] T. Roska and L. O. Chua, "The CNN Universal Machine: An Analogic Array Computer," *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, **40**(3), 1993, pp. 163–173. doi:10.1109/82.222815.

[9] L. O. Chua and L. Yang, "Cellular Neural Networks: Applications," *IEEE Transactions on Circuits and Systems*, **35**(10), 1988, pp. 1273–1290. doi:10.1109/31.7601.

[10] M. E. Gorra, *The Bells in Their Silence: Travels through Germany*, Princeton, NJ: Princeton University Press, 2004.