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Cellular neural network template for rotation of grey-scale images

G. Costantini, D. Casali and R. Perfetti

A method for grey-scale image rotation using cellular neural networks (CNNs) is proposed. The rationale of the method is the conversion of image rotation into a *small rotation* followed by a sequence of translations of pixel blocks. The same programmable 3×3 space-varying template can be used in both cases.

Introduction: Cellular neural networks (CNNs) are spatial array processors with massive computational power and suitable for VLSI implementation [1, 2]. One of the most promising areas of application of CNNs is image processing. In the literature we can find a huge number of CNN templates (the elementary connection pattern of each cell) performing different and specialised image processing tasks. One of the most difficult operations for CNN processing is image rotation, due to the non-local character of this transformation. Some solutions have been proposed, but they are often limited to some peculiar situations such as the rotation of binary images [3, 4]. Moreover, sometimes an image translation of a non-integer number of pixels is required. Using the template proposed here, we can obtain both rotation of the image around any point, and translation of an integer or non-integer amount of pixels, this being with only one very general CNN template working on grey-scale images.

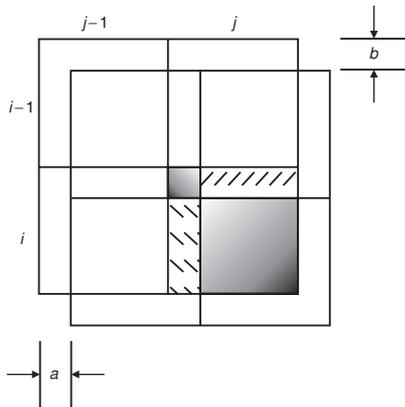


Fig. 1 Illustration of fractional translation

Translation: Translation of an image by a fraction of a pixel is illustrated in Fig. 1. We denote with $a < 1$ the fractional translation to the right, with $b < 1$ the fractional translation downwards. In this case there is a partial overlap of four neighbouring pixels over the 'new' pixel (i, j) ; the overlapping pixels are $(i - 1, j - 1)$, $(i - 1, j)$, $(i, j - 1)$ and (i, j) itself. The intensity $u(i, j)$ of the pixel after translation can be computed as a weighted sum of four contributions:

$$u^{\text{new}}(i, j) = u^{\text{old}}(i - 1, j - 1)ab + u^{\text{old}}(i - 1, j)(1 - a)b + u^{\text{old}}(i, j - 1)a(1 - b) + u^{\text{old}}(i, j)(1 - a)(1 - b) \quad (1)$$

The above formula can be generalised to obtain the translation of arbitrary $\Delta x, \Delta y \in [-1, +1]$ and can be implemented using a CNN where the input to cell $C(i, j)$ corresponds to the pixel intensity $u(i, j)$. The feedback template is $\mathbf{A} = \mathbf{0}$, and the input template is

$$\mathbf{B}(\Delta x, \Delta y) = \begin{bmatrix} abVH & (1 - a)bV & abV(1 - H) \\ a(1 - b)H & (1 - a)(1 - b) & a(1 - b)(1 - H) \\ ab(1 - V)H & (1 - a)b(1 - V) & ab(1 - V)(1 - H) \end{bmatrix} \quad (2)$$

where $V = 1$ if $\Delta y > 0$, $V = 0$ otherwise; $H = 1$ if $\Delta x > 0$, $H = 0$ otherwise; $a = |\Delta x|$; $b = |\Delta y|$. When $\Delta x, \Delta y = \pm 1$, we have an integer translation of one pixel in the horizontal and vertical directions.

Small rotation: Image rotation corresponds to a movement of pixels

from their original positions. After a rotation of an angle φ around a point (O_x, O_y) , the new co-ordinates of a point (x, y) can be computed as follows:

$$x' = O_x + (x - O_x) \cos \varphi - (y - O_y) \sin \varphi \quad (3a)$$

$$y' = O_y + (x - O_x) \sin \varphi + (y - O_y) \cos \varphi \quad (3b)$$

To obtain such a rotation, the pixel with $x = j$ and $y = i$ should be moved by the following quantities:

$$\Delta x(i, j) = O_x + (j - O_x) \cos \varphi - (i - O_y) \sin \varphi - j \quad (4a)$$

$$\Delta y(i, j) = O_y + (j - O_x) \sin \varphi + (i - O_y) \cos \varphi - i \quad (4b)$$

Let us consider a rotation angle φ such that $|\Delta x| \leq 1, |\Delta y| \leq 1$, for every i, j . We call this kind of rotation *small rotation*. If we have an image with m rows and n columns, and we want to rotate it around one of its corners, with a simple trigonometric computation we can show that every angle φ such that $|\varphi| \leq \varphi_L = \arctan(1/\max(m, n))$ will satisfy the condition of small rotation. If we rotate the image around a generic point (O_x, O_y) inside the image, we can have a greater φ_L , namely $\varphi_L = \arctan(1/\max(m - O_y, n - O_x))$. For small rotation, we can apply the template (2), where Δx and Δy are computed using expressions (4). In this case, however, the values of Δx and Δy depend on the co-ordinates (i, j) of the cell, so the template is space-varying.



Fig. 2 Original Lenna image (256 x 256)



Fig. 3 Lenna image rotated -10° , before applying the correction (a detail shown)

Rotation: When $|\varphi| > \varphi_L$, the translation template will have $a > 1$ and $b > 1$; in this case we can replace a with $a - \text{floor}(a)$, and b with $b - \text{floor}(b)$, where $\text{floor}(x)$ is the largest integer less than or equal to x . As a result, every pixel will have a 'wrong' position: e.g. if the correct horizontal displacement is Δx , it is moved by $\Delta x - \text{floor}(\Delta x)$ (only the fractional part is obtained). However, this position error can be corrected in a systematic way due to the following facts. The whole image is decomposed into many regions; every region (excluding that containing the centre of rotation) is characterised by an integer position error, both in the horizontal and the vertical components; the position error is the same for every pixel in that region. The original Lenna image is shown in Fig. 2 and the regions can be seen in Fig. 3 where a detail is shown of the image in Fig. 2 after a small rotation corresponding to the fractional part of the rotation with $\varphi = -10^\circ$ and centre given by the upper left corner.



Fig. 4 Lenna image rotated -10° after correction and filtering

The regions are arranged in oblique rows and columns, with slopes $(\sin \varphi)/(1 - \cos \varphi)$ and $(\cos \varphi - 1)/\sin \varphi$. The column of regions that contains (O_x, O_y) has a correct vertical position; the nearest one must be translated by one pixel, the second by two, and so on. The row of regions that contains (O_x, O_y) has a correct horizontal position, the nearest one must be translated by one pixel, and so on. In summary, we suggest the following steps:

Step 1: Compute Δx and Δy using (4).

Step 2: Apply the small rotation corresponding to the fractional part of Δx and Δy , using template (2).

Step 3: Correct the position of every single region translating it horizontally and vertically using template (2) with $\Delta x, \Delta y = \pm 1$, until it reaches the right location.

This method gives some sporadic errors along the edges between the regions. The number of regions (and so the number of edges) increases with the rotation angle φ . More exactly, for an image of dimensions m, n , with $w = \max(m, n)$, the number of region edges along the largest side is $\text{floor}(\varphi/\varphi_L)$, so for $\varphi > w\varphi_L$ every pixel is a region edge, and the image is almost unrecognisable; for $\varphi < \varphi_L$ we have no errors at all; for $\varphi_L < \varphi < w\varphi_L$ we have some degradation of the image that is proportional to the angle φ . These errors can easily be corrected with lowpass filtering, followed by highpass filtering to compensate for the edge smoothing effect. The resulting image degradation is negligible, as shown in the example in Fig. 4, where both filters have been implemented with CNN templates ($\mathbf{A} = 0$):

$$\mathbf{B}_{LP} = \frac{1}{9} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \quad \mathbf{B}_{HP} = \begin{bmatrix} -0.04 & -0.12 & -0.04 \\ -0.12 & 1.57 & -0.12 \\ -0.04 & -0.12 & -0.04 \end{bmatrix}$$

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