Abstract

Cellular neural networks (CNNs) were developed by Chua and Yang in 1988. The CNN concept was inspired from the architecture of cellular automata and neural networks. The performance of a CNN depends on template parameters. CNNs can be applied to various types of image processing by changing the template. However, little has been reported on the sharpening of blurred images by using a CNN. In this study, we propose an algorithm to sharpen blurred images. Then, we apply the proposed algorithm to the input images and investigate the performance by simulations.

1. Introduction

In recent years, an increasingly information-based society has developed. In general, a von Neumann computer is used for information processing. However, a von Neumann computer cannot process a range amount of information in real time. Therefore, neural networks were proposed. Which are based on the human nervous system. Cellular neural networks (CNNs) were introduced by Chua and Yang in 1988 [1]. CNNs have been successfully used for various high-speed parallel signal processing applications such as image processing and pattern recognition [1]. A CNN was paired with neural networks with cellular automata by Chua in 1988 [2]. A CNN consists of cells connected to each other and its structure resembles the structure of an animal’s retina [3]. Therefore, CNNs have been used in various image processing applications. The performance of a CNN depends on template parameters. The template represents strength of connection between each cell. The template consists of the feedback and feedforward templates and the threshold. If the template works exactly, we can investigate complex image processing. Additionally, various applications of image processing and pattern recognition using CNNs have been reported.

Unsharp masking (USM) is a digital image processing method used to sharpen images. In USM, first, the input image is smoothed. Secondly, a difference image between the input image and the smooth image is created. Finally, the output image is obtained as a combination of the input and difference images. However, little sharpening of blurred images by using CNNs has been reported.

In this study, we propose an algorithm to sharpen blurred images by using CNNs. To confirm the effectiveness of our proposed method, we evaluate simulation results.

2. Cellular Neural Networks (CNNs)

In this section, we describe the basic structure and processing flow of a simple CNN. The basic circuit unit of a CNN is called a cell. The cell consists of linear and nonlinear elements. The CNN is formed from an array of many cells. We show a two-dimensional CNN composed of $M \times N$ cells arranged in M rows and N columns in Fig. 1. Figure 2 shows the circuit of the cell.

![Figure 1: Structure of CNN](image)

A cell is coupled with only adjacent cells. Adjacent cells interact with one another. Cells that do not couple with only adjacent cells have an indirect effect. The range which cells effect one cell is defined by a neighborhood. We describe the state and output equations of a cell below.
State Equation:
\[
\frac{dv_x(ij)}{dt} = -v_x(ij) + \sum_{k=i-r}^{i+r} \sum_{l=j-r}^{j+r} A(i,j,k,l)v_y(kl)(t) \\
+ \sum_{k=i-r}^{i+r} \sum_{l=j-r}^{j+r} B(i,j,k,l)v_u(kl)(t) + T \tag{1}
\]

Output Equation:
\[
v_y(ij)(t) = \frac{1}{2}(|v_x(ij)(t) + 1| - |v_x(ij)(t) - 1|) \tag{2}
\]

In Eq. (1), \( A \) is the feedback template, \( B \) is the feedforward template, and \( T \) is the threshold. The performance of the CNN is determined by their values.

When we process an image by using a CNN, we should determine the size of the neighborhood of the system. When the neighborhood is large, the amount of information in the neighborhood is large. Moreover, noise works easily. Generally, the size of the neighborhood used for image processing is 3 × 3. Figure 4 shows a block diagram of image processing with a CNN.

3. Proposed Method

Here, we describe the proposed algorithm using the CNN. The proposed algorithm is composed of six steps and its flowchart is shown in Fig. 5.

The processing steps of the proposed method are described as follows.

- **Step 1 (Edge Detection):** The input image is sharpened.
- **Step 2 (Heat Diffusion):** The sharpened image is blurred to subtract the heat diffused image from the sharpened image.
- **Step 3 (Logic Difference):** The sharp lines of the sharpened image are detected.
- **Step 4 (Logic OR with NOT):** The sharp lines that cannot be detected in the logic difference step are detected.
- **Step 5 (Edge Detection):** The sharp lines detected in the previous step are enhanced.
- **Step 6 (Logic OR):** The cell’s value of the sharpened image is added to that of the enhanced edge detected image. Each step size is 0.05 [\( \tau \)].
4. Simulation Results

We show the simulation results of the proposed algorithm and USM. Figure 5 shows how the image is processed in the proposed algorithm and USM. The templates used in the proposed algorithm are described as follows [4].

**Heat Diffusion template:**

\[
A = \begin{bmatrix}
0.1 & 0.15 & 0.1 \\
0.15 & 0 & 0.15 \\
0.1 & 0.15 & 0.1 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}, \quad T = 0
\]

**Edge Detection template:**

\[
A = \begin{bmatrix}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
-1 & -1 & -1 \\
-1 & 8 & -1 \\
-1 & -1 & -1 \\
\end{bmatrix}, \quad T = 0
\]

**Logic Difference template:**

\[
A = \begin{bmatrix}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}, \quad T = -1
\]

**Logic OR with NOT template:**

\[
A = \begin{bmatrix}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 \\
0 & -1 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}, \quad T = 1
\]

**Logic OR template:**

\[
A = \begin{bmatrix}
0 & 0 & 0 \\
0 & 2 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 0 \\
\end{bmatrix}, \quad T = 1
\]

Figure 6 shows images processed by the proposed method and USM. Figure 6(a) shows the original image. The input image contains a bridge, a lake and a forest. Figure 6(b) shows the simulation result obtained when heat diffusion is applied to the input image with 100 iterations. The overall image is blurred. Figure 6(c) shows the simulation result obtained when edge detection is applied to the input image. The overall image is sharpened compared with that in Fig. 6(c). Figure 6(d) shows the simulation result obtained when heat diffusion is applied to the sharpened image. The sharpened lines of the lake and forest background are sharpened. Figure 6(e) shows the simulation result when the logic difference is applied to the sharpened and obtained heat-diffused image. The sharpened lines of the lake and forest background are sharpened. Figure 6(f) shows the simulation result obtained when logic OR with NOT is applied to the sharpened and heat-diffused image. The sharpened image contains a bridge, a lake and a forest. Figure 6(g) shows the simulation result obtained when logic OR with NOT is applied to the sharpened and heat-diffused image. The left side of the forest, which was not detected in Fig. 6(e), was detected. Figure 6(h) shows the simulation result obtained when edge detection is applied to the enhanced image. The lines of the sharpened image are enhanced compared with those in Fig. 6(g). Figure 6(i) shows the simulation result obtained when logic OR is applied to the sharpened and enhanced image. Not many unclear objects remain. On the other hand, in Fig. 6(i), more unclear objects remain than in Fig. 6(h).

We process another image by the proposed method and
USM. Figure 7(a) shows the original image. The input image contains a woman and a reticulated background. Figure 7(b) shows the simulation result obtained when heat diffusion is applied to the input image with 100 iterations. The overall image is blurred. Figure 7(c) shows the simulation result obtained when edge detection is applied to the input image. The overall image is sharpened compared with that in Fig. 7(c). Figure 7(d) shows the simulation result obtained when heat diffusion is applied to the sharpened image. The overall image is blurred compared with that in Fig. 7(c). Figure 7(e) shows the simulation result obtained when the logic difference is applied to the sharpened and heat-diffused image. The lines of the reticulated background are sharpened. Figure 7(f) shows the simulation result obtained when the logic OR with NOT is applied to the sharpened and heat-diffused image. The left side of a background, which was not detected in Fig. 7(e), was detected. Figure 7(g) shows the simulation result obtained when edge detection is applied to the enhanced image. The lines of the sharpened image are enhanced compared with those in Fig. 7(g). Figure 7(h) shows the simulation result obtained when logic OR is applied to the sharpened and enhanced image. Not many unclear objects remain. On the other hand, in Fig. 7(i), more unclear objects remain than in Fig. 7(h). We evaluated the simulation results using the structural similarity (SSIM), which evaluates the changes in pixel values, constants, and structure between the target images. An SSIM closer to 1 indicates greater similarity similar to the target image. In Tab. 1, we show the SSIM of each output image.

| Figure | SSIM  |
|--------|-------|
| 6(h)   | 0.6388|
| 6(i)   | 0.4833|
| 7(h)   | 0.7276|
| 7(i)   | 0.6053|

Figures 6(h)(i) are compared with Fig. 6(a), and Figs. 7(h)(i) are compared with Figure 7(a) in terms of similarity. Figs. 6(h) and 7(h) are processed by in terms of the proposed method, and Figs. 6(i) and 7(i) are processed by USM. From Tab. 1, the SSIM obtained with using the proposed method is higher than that obtained by USM. From these simulation results, the proposed method is more effective than USM.

5. Conclusion

In this study, we proposed an algorithm for sharpening blurred images by using a CNN. Moreover, we investigated the sharpening of blurred images by USM. Then, we evaluated similarities from the simulation results. Our proposed method is more effective than USM. In future works, we would like to investigate the performance for other images.

References

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