Enhanced Cellular Automata for Image Noise Removal

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ABSTRACT

Cellular Automata (CA) are a type of complex systems based on simple and uniformly interconnected cells. They provide an excellent method to perform complex computations in a simple way. CA can be used in image processing, because of the simplicity of mapping a digital image to a cellular automata and the ability of applying different image processing operations in real time. Noise removal is considered to be an important application of image processing; digital images can be corrupted by different types of noise during the image acquisition or transmission. In this paper we propose a CA model that deals with two types of noise: salt and pepper noise, and uniform noise. Our results show that the proposed model removes more noise, compared with previous models.

1. INTRODUCTION

1.1 Noise in Digital images

Digital images may be corrupted by different types of noise during their acquisition or transmission. Some pixel values may be altered (become noisy pixels), while others remain unchanged. There are two common types of noise: uniform noise and salt and pepper noise.

In uniform noise, the corrupted pixel may take any value from 0 to the maximum allowed value (we are assuming a gray scaled image). In salt and pepper noise, the corrupted pixel may take just one of two different values: black or white.

In order to remove unwanted noise and enhance the image quality, the median filter has been used (Pitas et al., 1990; Astola et al., 1997; Gonzalez and Woods, 2008). The median filter is a nonlinear effective filter used in noise removal, whose main disadvantage is that it blurs fine details or destroys edges while filtering out the noise. To preserve details while noise is reduced, many researchers have proposed different ideas (Ko et al., 1991; Chen et al., 1999; Eng et al.,2000). With the median filter, the intensities of the neighboring pixels are sorted and a median value is assigned to the center pixel.

1.2 Cellular Automata (CA)

Cellular Automata (CA) are a decentralized computing model that provides an excellent platform for performing complex computations with the help of just local information. CA are made up of interconnected cells, each of which contains an automaton, a simple machine able to perform simple computations. Each automaton has a state, which changes with time based on the states of its neighboring cells (see figure 1) [9]. The CA model transition rule determines the neighborhood relationship between the automata. Each automaton changes its state (its value) at time (t) based on the state at the previous time (t-1) of its neighbor cells (see figure 2). Introduced by John Conway in 1970, the Game-of-Life (GOL) is the most widely known example of CA (Wolfram, 2002; Sarkar, 2000; Gardner, 1970) CA have many applications for a wide variety of fields.

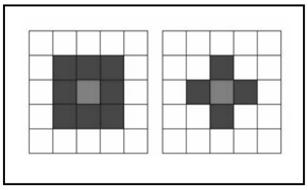

Figure 1.Common CA neighborhoods. MOORE (at the left) and Von Neumann (to the right).

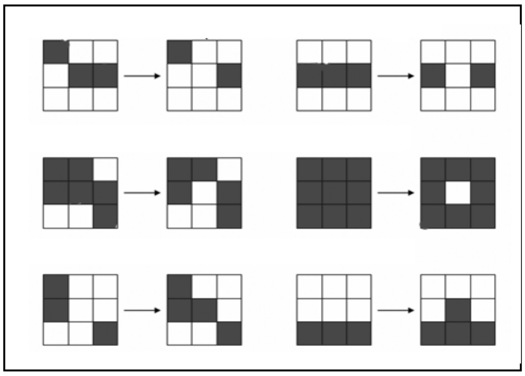

Figure 2. CA transition rule examples. The center automaton state will be:

0 if the cell has <=2 neighbors at state 1

0 if the cell has >=4 neighbors at state 1

1 if the cell has 3 neighbors at state 1

2. RELATED WORK

2.1 Uniform noise removal filter

In (Chang et al., 2008), the authors have proposed a new image-de-noising filter based on the standard median (SM) filter. In their method, a threshold and the standard median is used for noise detection and to change the original pixel value to a new value closer or similar to the standard median. Inspired by the Tri-State Median (TSM) (Chen et al. 1999), they have proved that their filter improves the SM filter, the Center Weighted Median filter (CWM) (Ko et al., 1991), and the TSM filter. In CWM, the value of the center pixel will be repeated several times. The number of times to be repeated is called the center weight. In the TSM filter:

$$TSM_{ij} = \begin{cases} X_{ij} & if \ \ T \geq d_1; \\ CWM_{ij} & if \ \ d_2 \leq T < d_1; \\ SM_{ij} & if \ T < d_2. \end{cases}$$

Where, $d_1 = \left| x_{ij} - SM_{ij} \right|$, $d_2 = \left| x_{ij} - CWM_{ij} \right|$ and T is a value between 0 and 255. Figure 3 shows Chang et al. proposed filter, where Xij is the center pixel value, WS is the number of the neighbors (usually 9), Ri is the ith element in the sorted neighbors sequence, rank(Xij) is the index of Xij in the sorted neighbors sequence, and the threshold value T equals 15.

Chang et al proposed filter

$$AM_{ij} = \begin{cases} \left\lfloor SM_{ij} - \left| R_{\frac{WS+1}{2}} - R_{\frac{WS-1}{2}} \right| \mathrm{X} \dfrac{rank(X_{ij}) - \frac{WS+1}{2}}{\frac{WS-1}{2}} \right\rfloor & if \ \ rank(X_{ij}) \leq \dfrac{WS+1}{2}; \\ \left\lceil SM_{ij} - \left| R_{\frac{WS+1}{2}+1} - R_{\frac{WS+1}{2}} \right| \mathrm{X} \dfrac{rank(X_{ij}) - \frac{WS+1}{2}}{\frac{WS-1}{2}} \right\rceil & if \ \ rank(X_{ij}) > \dfrac{WS+1}{2}. \end{cases}$$

Followed by:

$$AM_{ij} = \begin{cases} AM_{ij} & if \ \left| X_{ij} - AM_{ij} \right| \geq T ; \\ X_{ij} & if \ \left| X_{ij} - AM_{ij} \right| < T . \end{cases}$$

Figure 3. Chang et al. filter

2.2 Salt and paper noise CA de-noising model

In (Liu et al, 2008), the authors proposed a novel de-noising algorithm based on CA to filter images with salt-pepper noise. Their CA local transition function is based on Moore neighborhood. They have evaluated their approach by using the hamming distance to compare it with the classical median filter, and showed that their algorithm has better de-noising effects, especially when the noise density is bigger than 40%. Figure 4 shows their transition function.

3. THE PROPOSED CA MODEL

We introduce a novel CA model for noise removal. Our proposed model deals with both types of noise; salt and pepper noise and uniform noise. We first detect the type of noise by computing the histogram of the noisy image. If the most frequent values in the image histogram are black or white, we conclude that the image contains salt and pepper noise, otherwise it contains uniform noise. The next step is removing the noise by using the CA transition rules described in figure 5.

Our proposed CA model checks the noise type and response correctly for each type. If the noise type is uniform noise, we exclude the maximum and minimum values from the neighbors then compute the median of the remaining values, after that assign it to the current automaton state. If the noise type is salt and pepper, we check if the current state has black or white color which means it may corrupted by noise, then we compute the median of the neighbors that don't have black or white values and assign this median for the current automaton state, if all the neighbors has black and white values we take the average of them and assign the average to the current automaton state.

Liu et al CA transition rule

```
1. Check value of current cell Xi, j
   And values of its neighbor.
2. if X_i,j ≤ max (neighbors) and
      X_i,j  > min(neighbors)  then
3.    X_i,j stay the same.
4. elseif max(neighbors)= min(neighbors)or
      neighbors have only two states
     (max(neighbors),min(neighbors))
      then
5.   if min(neighbors)≠0 then
6.      X_i,j=min(neighbors)
7.   elseif max(neighbors)≠255 then
8.      X_i,j=max(neighbors)
9.   else  X_i,j stay the same
10.else
11.    m = mean(neighbors except
       Max(neighbors) and min(neighbors))
12.    if  abs(X_i,j –m)<threshold
13.        X_i,j stay the same
14.    else
15.        X_i,j =m
16.    end
17. end
18. end
19. end
20. end
```

Figure 4. Liu et al CA transition function

4. EXPERIMENTS AND RESULTS

We have implemented CA simulators for our proposed idea, for Liu et al. procedure, and for Chang et al. filter, using the well known MATLAB 7.6.0 software (Matlab, web reference). We have used two standard images in our experiments, namely Lena and Boats, as well as one of our own images (Jan), which has more details and edges, and hence makes a good test example. In this paper, however, for space reasons, we only show the Lena results.

We have compared our model with both models in (Chang et al., 2008) and (Liu et al, 2008). We have used the same measurements that they used, namely Mean Squared Error (MSE) and Hamming Distance (HD). It is well-known that when these measures are small, the technique is considered to be better. They are defined as:

$$MSE = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(a_{ij} - b_{ij})^2}{m*n}\ ; \ HD = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}(a_{ij}^2 \oplus b_{ij}^2)}{m*n}$$

where a is the original image and b is the resulting image. Both images are the same size (m x n).

```
1. Check value of current cell X_i,j
     and values of its neighbor.
2. if uniform noise
3.   mx=max(neighbors);
4.   mn=min(neighbors);
5.   if X_i,j ==mx or X_i,j ==mn
  //take the median value of the
neighbors
6.        y=SM_ij;
7.      end
8. else // salt and peppers noise
9.    if (X_i,j ==0)or ( X_i,j ==255)
10.       if there are neighbors
              that are not 0 nor 255
              X_i,j= The median of step 10;
11.       else
11.           X_i,j= mean(Neighbors);
          end
12.    end
13.end;
```

Figure 5. The proposed CA transition function

We should notice that MSE is more accurate than HD, because it computes the degree of difference between the two images, while HD gives only the number of different pixels in the two images. According to its purpose, we compare our model with (Chang et al., 2008) in terms of uniform noise and with (Liu et al, 2008) in terms of salt and pepper noise. For each image we have added different percentages of noise with ratios equal to 5%, 10%, 25%, 50%, 75%, 90% and 95% of the image size.

For each ratio we have produced two noisy images: one with "salt and pepper" noise, and one with "uniform" noise. We have run the simulation for each image for five iterations and recorded the results (the corrected image and the two error measurements, MSE and HD).

The results, illustrated in figures 6-9 and tables 1-2, show that our model is better than the previous models in terms of the two measurements factors, namely, MSE and HD. The time complexity is constant, O(1), because of the parallelization that CA provide which is considered as a main advantage of CA in term of performance. We should also note that the best measurement is the human eye, especially when there is a clear difference between the resulting images.

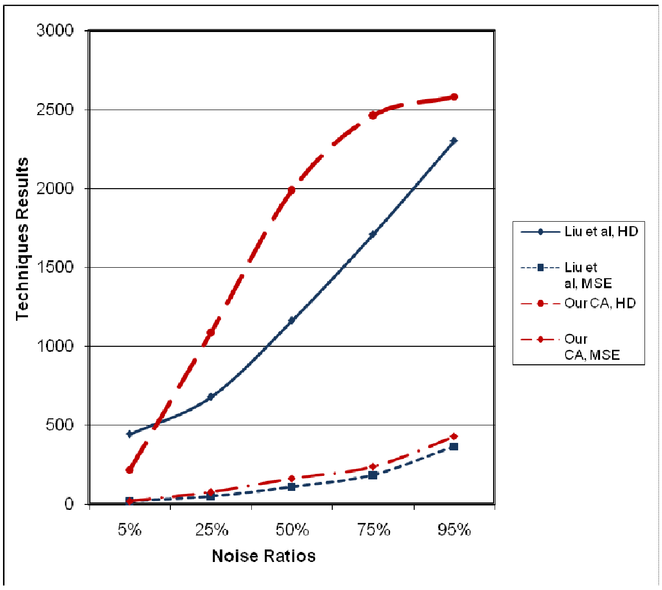

Figure 6. Comparison between our model and Liu et al. (Salt and pepper noise)

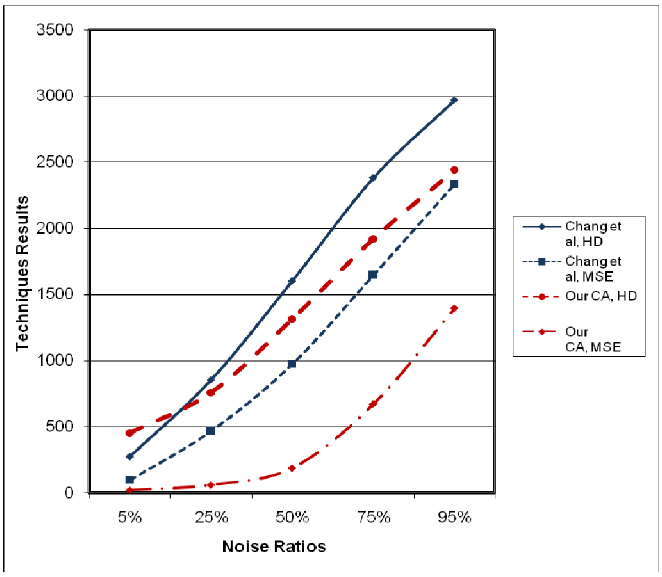

Figure 7. Comparison between our model and Chang et al. (Uniform noise)

Table 1: Sample of the results (Salt & Pepper noise)

Method	5% noise		25% noise		50% noise		75% noise		95% noise	
Generation 1	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Liu et al	444.38	18.767	680.3	49.24	1164.35	121.9	1710	880.6	2301	5917
Our CA	220.36	21.749	1089.3	91.68	1990.25	178.8	2544	847.5	3918	5428
Generation 2	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Liu et al	802	26.401	1042.3	57.61	1488.4	109.9	1949	196.4	2302	2847
Our CA	551.42	20.505	1341.8	79.95	1989.48	163.8	2462	246.2	3112	2597
Generation 3	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Liu et al	1073.4	30.647	1296.1	62.44	1662.21	113.2	2019	185.8	2446	1114
Our CA	878.44	25.071	1636.4	78.34	1989.48	163.8	2461	239	2601	1038
Generation 4	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Liu et al	1268	34.143	1467.5	65.4	1662.21	115.2	2096	186.4	2446	503.1
Our CA	1103.8	27.784	1842.7	79.31	1989.48	163.8	2461	239	2601	522
Generation 5	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Liu et al	1415.3	37.08	1591.9	68.5	1880.14	117	2161	187.2	2495	366.7
Our CA	1245.5	30.253	1966	81.82	1989.48	163.8	2461	239	2579	427.9

Table 2: Sample of the results (Uniform noise)

Method	5% noise		25% noise		50% noise		75% noise		95% noise	
Generation 1	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Chang et al	275.29	98.056	854.87	477.7	1602.47	1050	2381	1838	2968	2597
Our CA	452.22	27.667	756.52	277.4	1312.68	898.9	1920	1767	2440	2563
Generation 2	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Chang et al	300.51	99.151	901.64	469	1697.08	983.2	2559	1692	3245	2430
Our CA	785.96	21.653	1002	102.5	1457.19	463.5	2017	1184	2527	1962
Generation 3	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Chang et al	311.23	99.898	925.37	470.5	1746.37	974.7	2672	1660	3398	2374
Our CA	1017.6	21.653	1239.3	67.12	1635.57	289.3	2131	897.5	2606	1652
Generation 4	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Chang et al	315.34	99.896	937.2	471.9	1774.83	975.6	2738	1650	3484	2348
Our CA	1164.3	23.681	1397.2	60.94	1773.6	218.5	2232	752.2	2675	1488
Generation 5	HD	MSE	HD	MSE	HD	MSE	HD	MSE	HD	MSE
Chang et al	316.95	100.31	941.93	472.7	1789.56	977.4	2777	1646	3537	2334
Our CA	1262.4	26.129	1494.3	61.06	1863.93	188.1	2300	670.9	2727	1394

5. CONCLUSION AND FUTURE WORK

In this paper we have introduced a novel CA model for image noise removal. Our model deals successfully with both "salt and pepper" noise and "uniform" noise. We have shown that our model is better than Chang model, and almost as good as Liu model. Our CA model has successfully removed the two types of noise in different ratios. As a future work, we will enhance the current proposed model in terms of performance and accuracy, besides generalizing it to deal with more noise types.

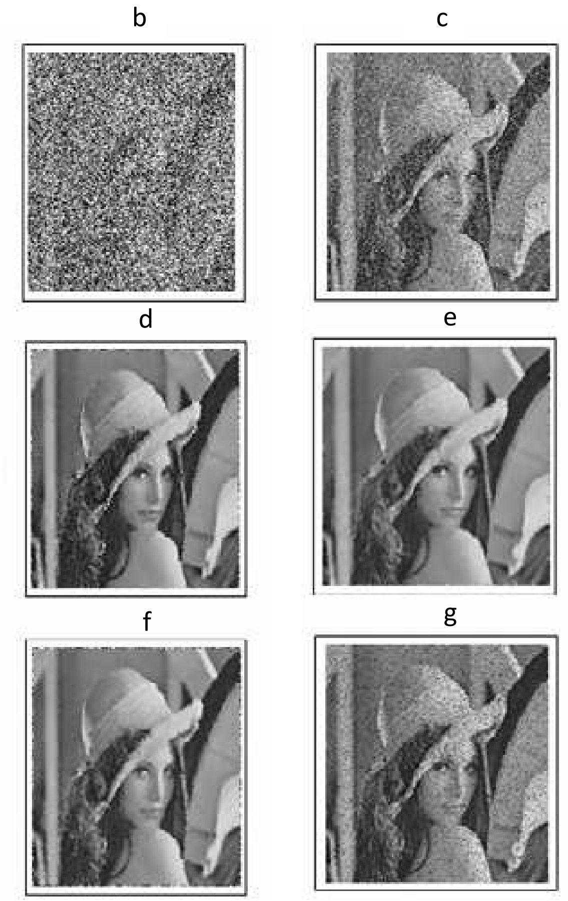

Figure 8. Another Sample of the results.
a. Original Lena image.
b. Lena image with 75% of salt and pepper noise.
c. Lena image with 25% of uniform noise.
d. Result of applying our CA model on b.
e. Result of applying our CA model on c.
f. Result of applying Liu et al filter on b.
g. Result of applying Chang et al filter on c.

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