Document image binarization based on topographic analysis using a water flow model

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Algorithm

Local thresholding based on a water flow model

Image surface
3-D terrain

↓

Water flows down to the lower regions and fills valleys

↓

Thresholding process
by the amount of filled water
for character extraction

Abstract

- Local adaptive thresholding method
  - Based on water flow model
  - Image surface; 3-D terrain
- Water flow model
  - Pouring water onto the terrain surface
  - Flowing and filling valleys
  - Thresholding by the amount of filled water for character extraction

1. Introduction

- Segmentation algorithms
  - Based on discontinuity or similarity of gray values
    - Discontinuity: Abrupt changes in gray level (Edge detection)
    - Similarity: Thresholding, region growing, region splitting and merging
  - Watershed algorithms
    - Behavior of water; flowing down to lower regions
    - Dividing regions based on the minima that water approaches

2. Proposed local thresholding

- The proposed method
  - Enhancement process
    - Extracting the local characteristic of an input gray level image by simulating the behavior of rainfall
    - A lot of ponds on the terrain
    - Merging water filled ponds with one segment or extinguishing small ponds
    - Applying the labeling process to the generated ponds
    - Calculating the average water level of each pond

- Thresholding process
  - Thresholding the amount of filled water
  - Reflecting the local characteristics of an original terrain
  - Otsu's algorithm, a nonparametric and unsupervised automatic threshold selection method
- Otsu's method
  - Selecting the optimal threshold *k** maximizing the variance

$$\sigma_b^2 = a_1 a_2 (m_1 - m_2)^2 \tag{1}$$

where m_1, m_2 ; means of segment1 and 2
ratio a_j ; area of segment *j* to the total area

◆ Water flow model

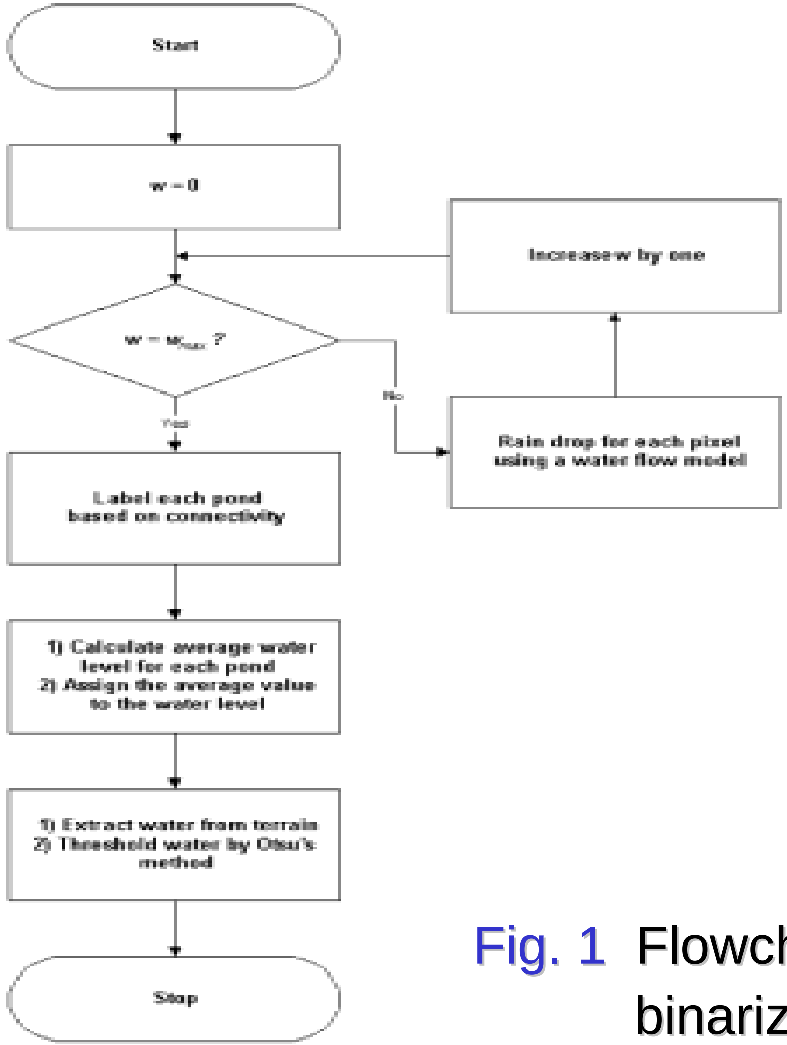


Fig. 1 Flowchart of the proposed binarization method.

– Water flow model

```
for all pixels (x,y)
begin
    set the current point (m,n) to (x,y)
    until f(m,n) is the minimum
    begin
        set (u,v) to (0,0)
        for all neighboring pixels (m+i,n+j), -s ≤ i, j ≤ s
            if f(m+i,n+j) < f(m+u,n+v) then set (u,v) to (i,j)
        set the current point (m,n) to (m+u,n+v)
    end
    increase f(m,n) by one unit
end
```

Fig. 2 Algorithm of the proposed water flow model.

– Computational cost

$$NM\left[(2s+1)^2 D + w\right] \tag{2}$$

– An example of the search process

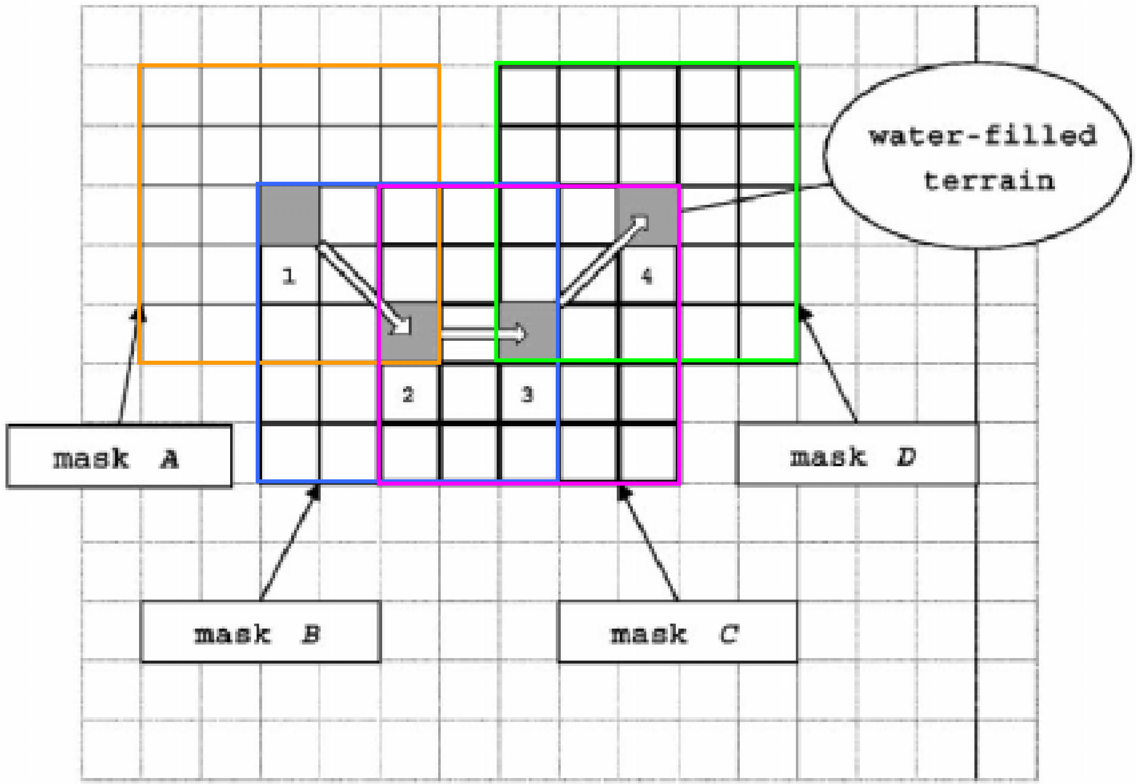


Fig. 3 Searching process of the lowest gray level (s=2).

◆ Binarization based on a water flow model

– Synthetic images

$$S_1(x,y) = A\,\mathrm{abs}\left[\left(-\frac{r^2}{U}+B\right)\cos\left(\frac{r^2}{V}\right)\right] \tag{3}$$

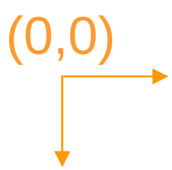
$$S_2(x,y) = A\left(-\frac{r^2}{U}+B+C\cos\left(\frac{r^2}{V}\right)\right) \tag{4}$$

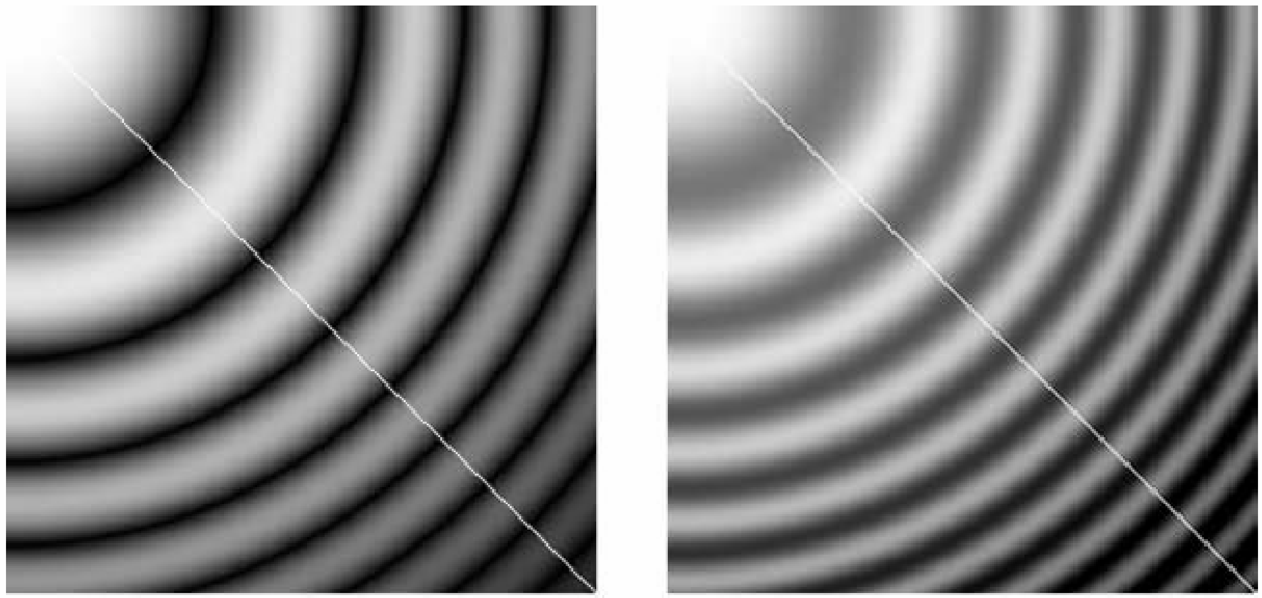
where U, V constants (terrain characteristics)

$r^2 = x^2 + y^2$, $(0,0)$ top left

A, B, C constants between 0 and 255 $(I = 256)$

– Synthetic images





(a) (b)

A=255, B=1.0
$U=1.5X10^5$, $V=5X10^3$

A=127, B=1.5, C=0.5
$U=9X10^4$, $V=2X10^3$

Fig. 4 Synthetic images for binarization.
(a) Synthetic image 1 (S_1), (b) synthetic image 2 (S_2).

– Profiles along the diagonal direction

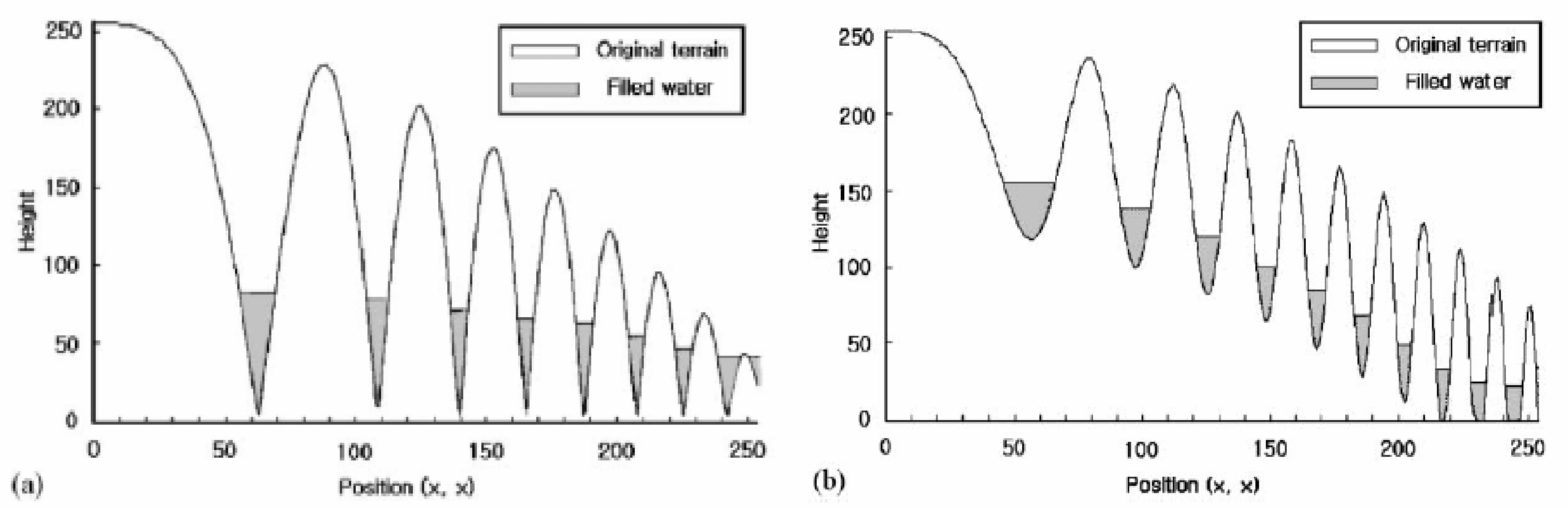


Fig. 5 Profiles of the original terrain and water filled terrain of synthetic images S_1 and S_2 (w=10). (a) S_1, (b) S_2.

– Final results of the proposed thresholding method

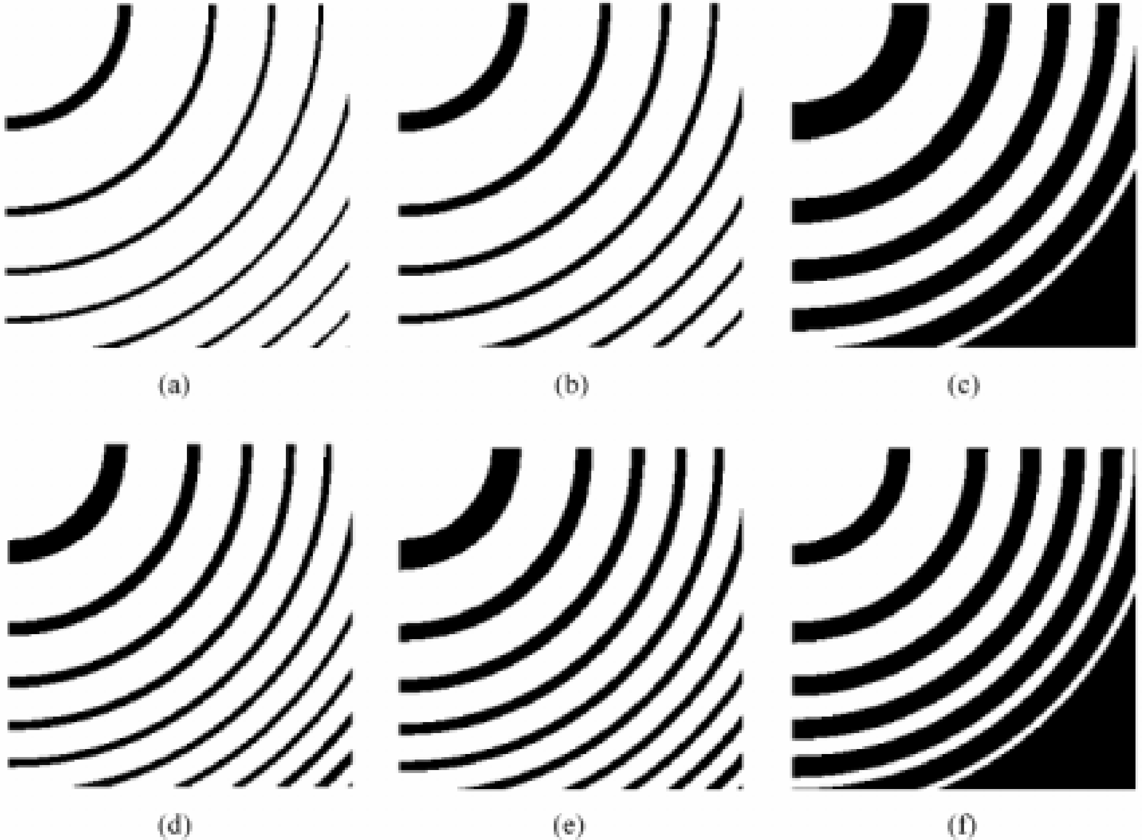


Fig. 6 Binarization results.

(a) w=1 ($k^*=8, S_1$), (b) w=5 ($k^*=18, S_1$), (c) w=140 ($k^*=140, S_1$),
(d) w=1 ($k^*=4, S_2$), (e) w=5 ($k^*=11, S_2$), (f) w=125 ($k^*=122, S_2$).

3. Simulation results and discussions

◆ Experiments

(a) (b) (c)

Fig. 7 Real test images for binarization. (a) T1, (b) T2, (c) T3.

– Profiles of the test images

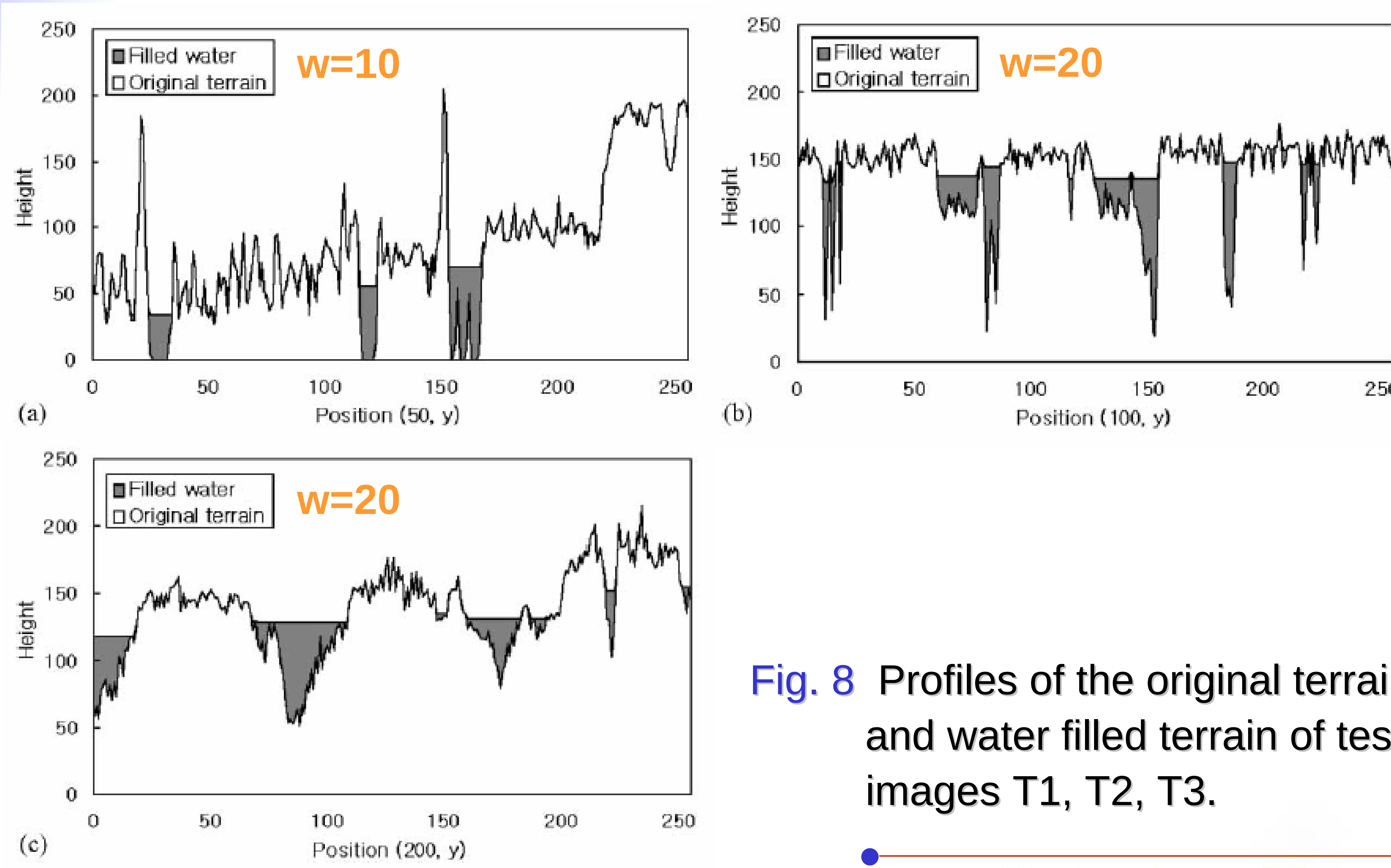


Fig. 8 Profiles of the original terrain and water filled terrain of test images T1, T2, T3.

– 1st exprerimental results

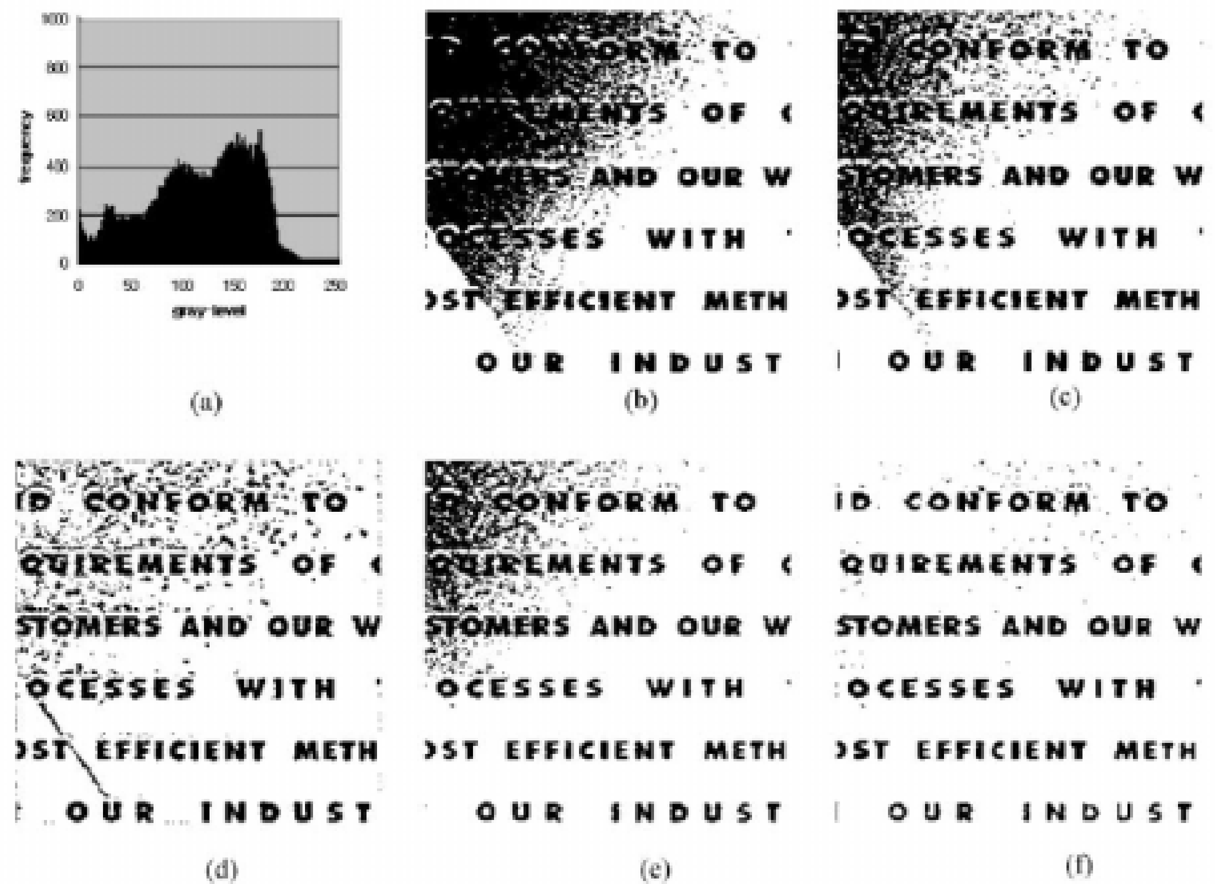


Fig. 9 Binarization results of Fig. 7(a).

(a) Histogram, (b) Otsu’s method, (c) Nakagawa and Rosenfield’s method, (d) Niblack’s mehod, (e) Liu and Srihari’s method, (f) proposed method.

– 2nd exprerimental results

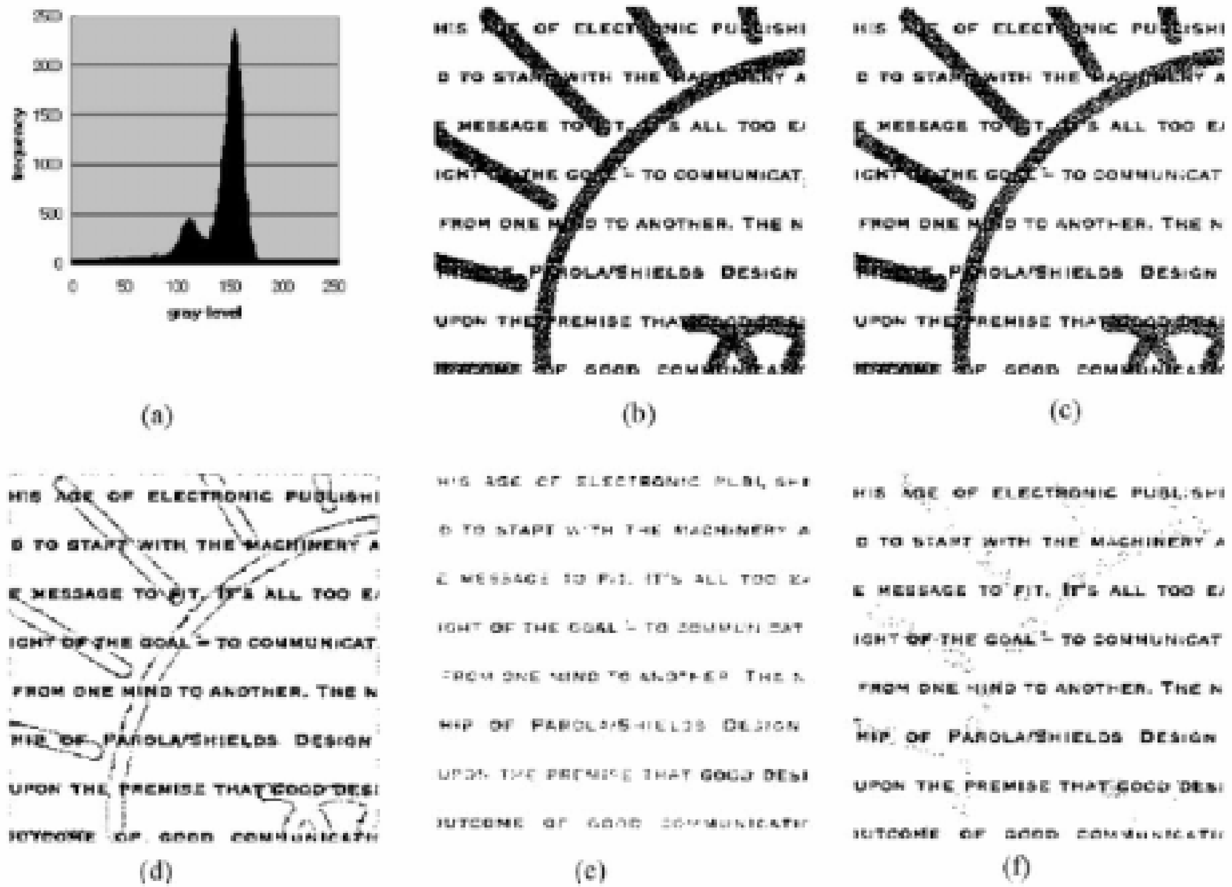


Fig. 10 Binarization results of Fig. 7(b).

(a) Histogram, (b) Otsu’s method, (c) Nakagawa and Rosenfield’s method, (d) Niblack’s mehod, (e) Liu and Srihari’s method, (f) proposed method.

– 3rd exprerimental results

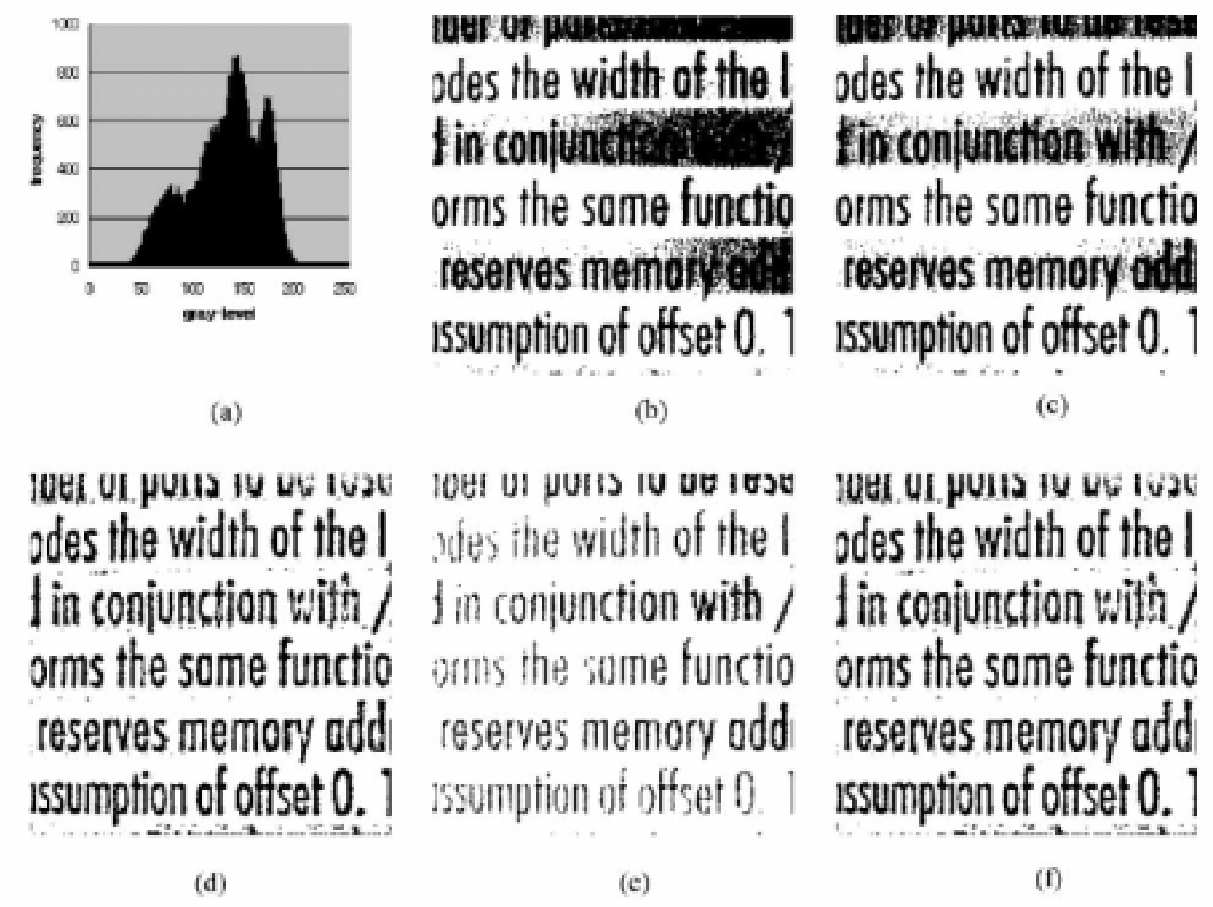


Fig. 11 Binarization results of Fig. 7(c).

(a) Histogram, (b) Otsu’s method, (c) Nakagawa and Rosenfield’s method, (d) Niblack’s mehod, (e) Liu and Srihari’s method, (f) proposed method.

- Visual criteria
  - Evaluation process: Blind test
  - Broken text (5): Existence of undesirable gaps in text, Small gaps are given high scores
  - Blurring of text (5): Low rate of blurring is desirable
  - Loss of complete text (5): A large number of losses are not desirable
  - Noise in background area (5): A small number of false objects is desirable

– Performance comparison of various segmentation

Table 1
Scores for quantitative performance comparison of each binarization method[a]

Test image	Method				
	M_1	M_2	M_3	M_4	M_5
T_1	14	14	15	14	17
T_2	14	14	15	12	16
T_3	14	15	16	14	16
T_4	15	16	16	17	18
T_5	19	19	17	19	19
T_6	15	15	16	14	15
T_7	15	15	16	16	17
T_8	19	19	18	20	20
T_9	17	17	17	17	18
T_{10}	14	15	16	14	16
Total score	156	159	162	157	172

[a] M_1: Otsu's method, M_2: Nakagawa and Rosenfeld's method, M_3: Niblack's method with postprocessing, M_4: Liu and Srihari's method, M_5: proposed method.

- ◆ Character extraction
  - – Character extraction from Fig. 9

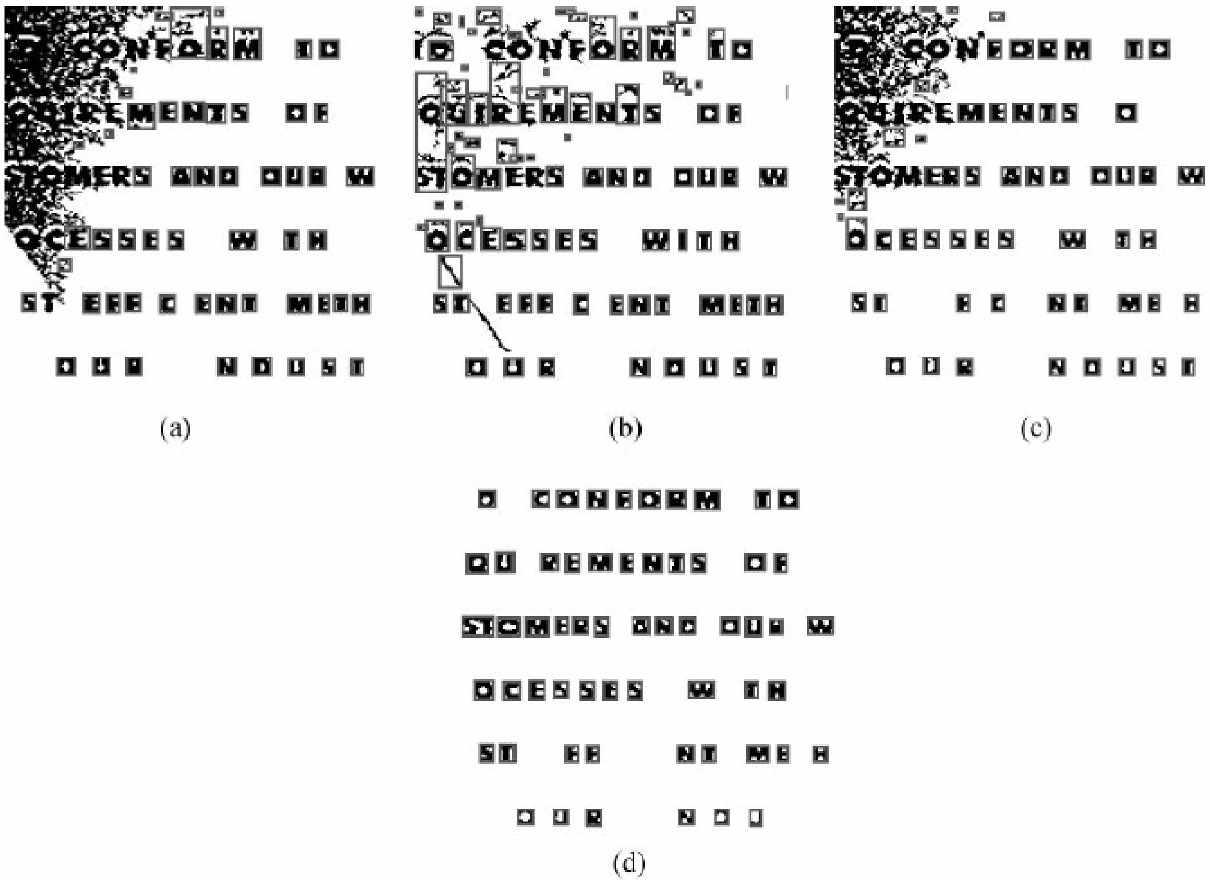


Fig. 12 Character extraction results from Fig. 9 (c), (d), (e), (f).

– Character extraction from Fig. 10

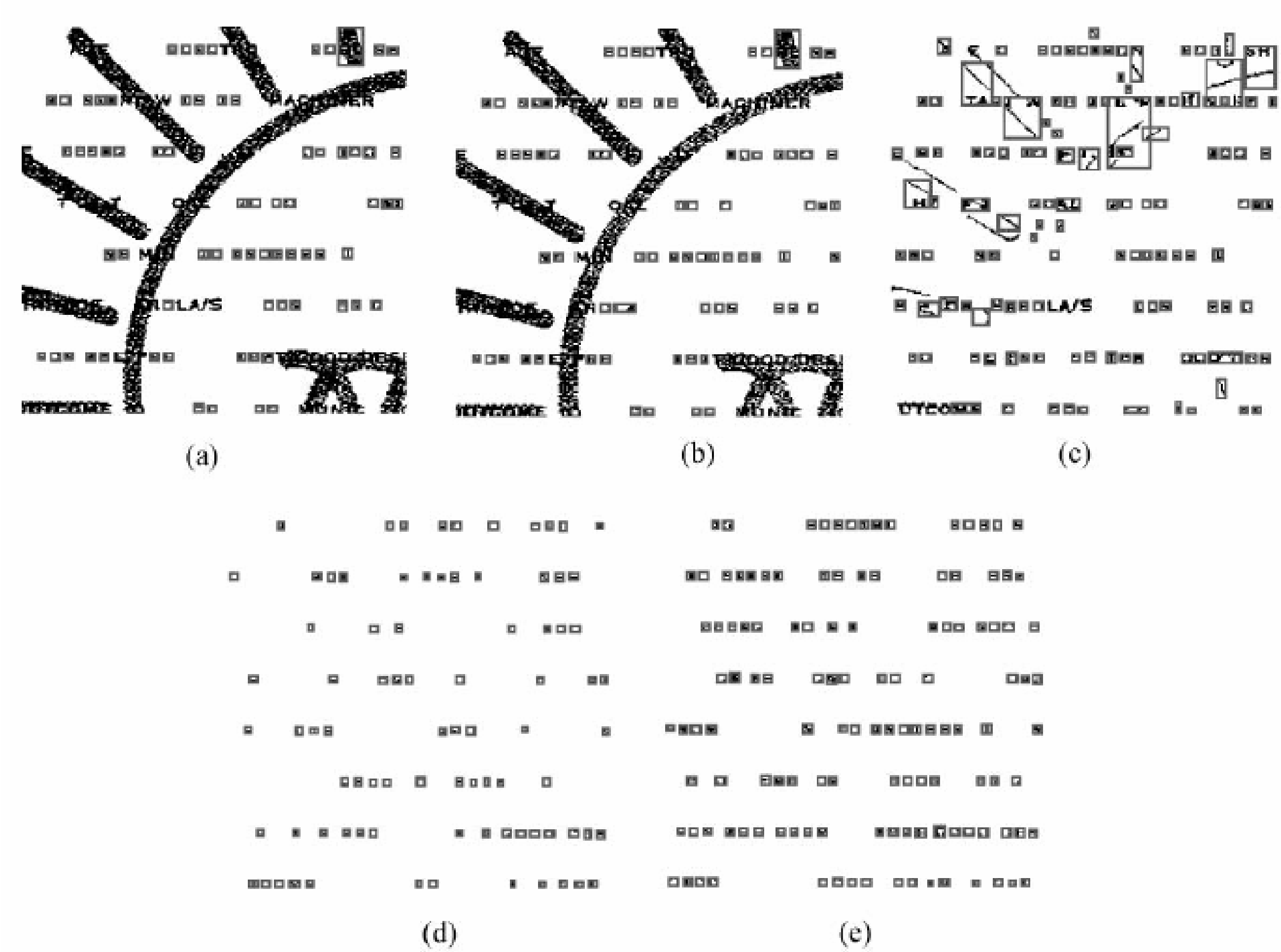


Fig. 13 Character extraction results from Fig. 10 (b), (c), (d), (e), (f).

– Character extraction from Fig. 11

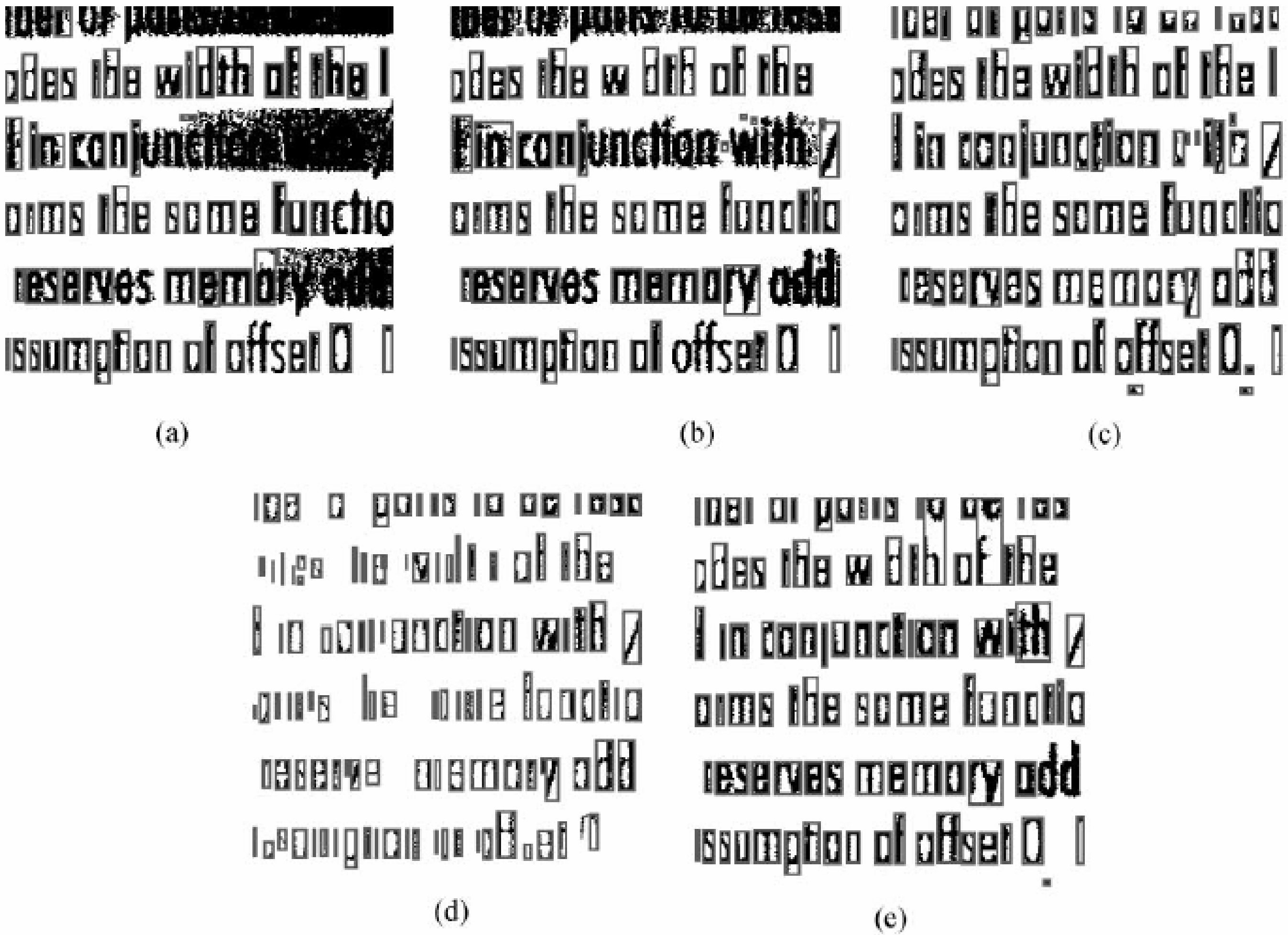


Fig. 14 Character extraction results from Fig. 11 (b), (c), (d), (e), (f).

– Performance comparison of character extraction

Table 2
Character extraction rate for binarized document images obtained by each binarization method (%)[a]

Test image	Method				
	M_1	M_2	M_3	M_4	M_5
T_1	—	67	70	66	86
T_2	39	43	51	19	64
T_3	62	65	93	44	89
T_4	87	89	86	85	90
T_5	84	86	86	83	85
T_6	33	35	63	11	70
T_7	76	76	77	69	85
T_8	97	97	92	98	98
T_9	91	87	82	74	88
T_{10}	36	38	77	21	37
Average rate	67	68	78	57	79

[a] M_1: Otsu's method, M_2: Nakagawa and Rosenfeld's method, M_3: Niblack's method with postprocessing, M_4: Liu and Srihari's method, M_5: proposed method.

4. Conclusions

- Water flow approach to thresholding
  - Physical property of water
    - Deep valleys are filled with dropped water
    - Smooth plain regions keep up dry
  - Effective especially local or uneven illuminations
- Further research
  - Selection of the optimal amount of water