Performance measurements of thinning algorithms

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PERFORMANCE MEASUREMENTS OF THINNING ALGORITHMS

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Abstract

Thinning algorithms are widely used in many image processing tasks. Although requirements for these algorithms can differ from task to task, the main features remain. Massive research has been done in this area based on different principles so lots of options are available. A methodology is necessary to evaluate quality of used algorithms. This paper focuses on performance measurements of thinning algorithms used mainly for digitizing maps with road infrastructure.

Keywords**:** *thinning, skeleton, image processing, performance measurements*

1 INTRODUCTION

Thinning [1, 2, 3] is one of the most widely used methods for preprocessing binary images. It produces a skeleton, which represents original object by the set of lines that should correctly describe the main features. Although a lot of papers have been written on this subject, there is still a lack of tools which can be used for comparing algorithms and choosing the right one. Today, when new thinning algorithm or solution, which uses some kind of thinning, algorithm is presented; human experience and intuition are used to evaluate results and to make conclusions. Computers are usually not involved in evaluation and decision process. There are many reasons why computers should be included in this process. Exclusion of human factor errors, better potentials for automatization and easier comparison of algorithms between research teams are important.

The main characteristics and requirements for thinning algorithms are described in section 2 in the paper. In section 3, some methods for performance measurements are proposed. Section 4 shows the results and section 5 presents conclusions and ideas for future work.

2 REQUIREMENTS FOR THINNING ALGORITHMS

There are various skeletonization methods [3, 4] which can be used to create skeleton. There are few basic requirements that skeletonization methods should fulfill:

1. Skeleton should be one pixel thick.
2. Connectivity should be preserved.
3. Shape and position of the junction points should be preserved.
4. Skeleton should lie in the middle of a shape.
5. Skeleton should be immune to the noise (especially to boundary noise).
6. Excessive erosion should be prevented (length of lines and curves should be preserved).

Some more requirements may be defined for specialized tasks, but the enumerated basic requirements are most important features which skeletonization methods should have. Some of these features are contradictory so it is hard to fulfill all these requirements at once.

When it comes to vectorization of road maps we can divide these requirements into two categories:

1. Topology preserving.
2. Shape preserving.

Topology preserving means that shape and position of all existing junction points should be preserved and also no additional junction points should be created. This means that skeleton should be immune to noise and preserve connectivity, because both of these problems can create additional junction points. Shape preserving includes mediality, prevention of excessive erosion, one pixel thickness and also immunity to noise.

For road maps one of the biggest problems is to preserve shape and position of junction points, which is usually in contradiction with one pixel thick skeleton requirement.

This paper focuses on thinning methods. These methods use binary images where any pixel is either black (foreground) or white (background). Thinning is the process that usually deletes black outer pixels layer by layer until one pixel wide skeleton is created. Because of this concept, they are sometimes called iterative methods. Like any method, thinning has its cons and pros. Thinning algorithms usually don’t need much more additional memory to the memory which is used to store an image. This can be advantage dealing with large images. But on the other hand they are iterative so they have longer computation time. When it comes to quality of the skeleton they usually conserve connectivity and shape but they tend to be sensitive to boundary noise, and they very often produce unacceptable results in junction points.

3 PERFORMANCE MEASUREMENTS

As it was said earlier, except for computation run time, computers are usually not involved in process of performance measurements. There is not much research done in this area and there are practically no standards, which can be used to compare thinning algorithms and skeletonization methods as such. Although quite a lot of papers deal with thinning algorithms no standards have been used yet. Authors usually need to implement other algorithms to be able to compare the results with them.

In this paper there are three criteria for performance measurements proposed. They are: thinning rate, number of components and noise sensitivity.

Thinning rate (*TR*) is the basic criteria. Many algorithms are using rules and templates, which are based on finding triangles to remove excessive pixels. This principle is used by this equation:

$$TTC = \sum_{i=1}^{n} \sum_{j=1}^{m} TC(P[i][j])$$

where:

- *TTC* stands for total triangle count
- *n*, *m* are dimensions of picture
- *P[i][j]* is black pixel with coordinates *i*, *j*
- *TC* is function which counts number of black triangles which can be created from *P[i][j]* and its neighboring pixels (see Fig.1)

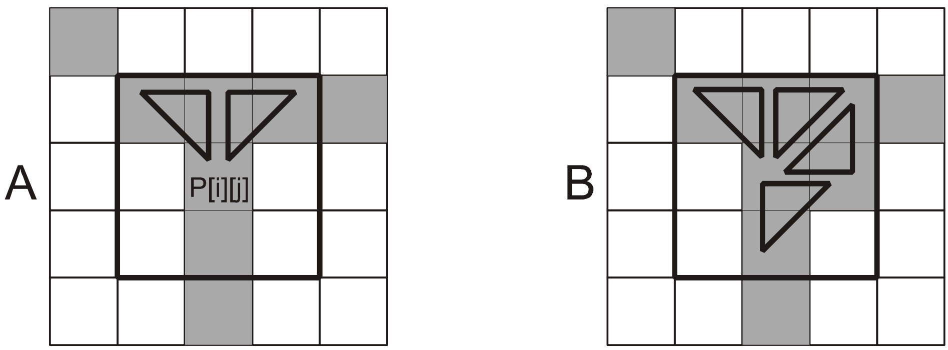

Figure 1 A: *TC* = 2, B: *TC* = 4

The *TR* is defined as follows:

$$TR = 1 - \frac{TTC_T}{TTC_O}$$

where:

- TTC_T stands for total triangle count of thinned image
- TTC_O stands for total triangle count of original image

When *TR* = 1 image is perfectly thinned, when *TR* = 0 image is not thinned at all.

Number of components (*NOC*) criteria counts number of separated regions in skeleton. It is designed to measure connectivity of the output skeleton. The 8-connectivity flood-fill algorithm can be used to measure the connectivity.

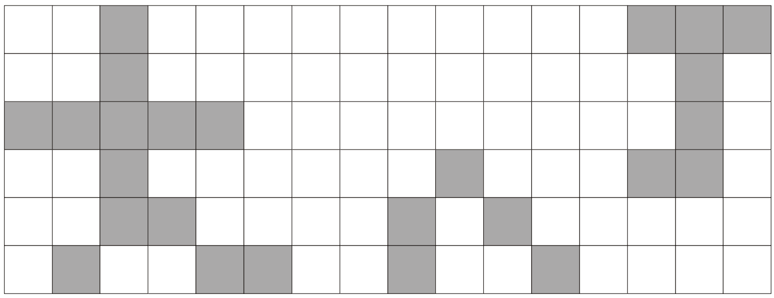

Figure 2 Image with 3 components (*NOC* = 3)

Noise sensitivity (*NS*) criteria measure immunity of skeleton to a boundary noise. Immunity to noise is very important feature of thinning algorithms because it influences both topology and shape preservation. Noise sensitivity can also detect other undesirable behavior, which will be explained later.

$$NS = \sum_{i=1}^{n} \sum_{j=1}^{m} N(P[i][j])$$

$$N(P[i][j]) = \begin{cases} 1 & if \quad CN(P[i][j]) > 2 \\ 0 & else \end{cases}$$

where:

- *P[i][j]* is black pixel with coordinates *i*, *j*

- *n*, *m* are dimensions of picture

- *CN* is connectivity number which counts number of color changes (black to white or white to black) in neighborhood of pixel *P[i][j]* (see fig.3)

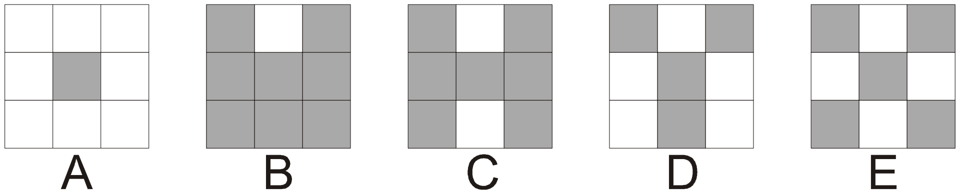

Figure 3 A: CN = 0, B: CN = 1, C: CN = 2, D: CN = 3, E: CN = 4

The connectivity number (*CN*) is used in estimation of *NS*. *CN* is very often used also in process of finding junction points. Every change in topology (which is not caused by connectivity change) creates additional junction points. Generally this is caused by boundary noise, but other undesirable features of thinning algorithms can cause it. Although most junction points have $CN > 2$, they sometimes can occur at places where $CN = 2$. When this happens there is usually junction point with $CN > 2$ in neighborhood (if skeleton is thin enough) witch will be counted by *NS* measurements (see fig.4) so this is not a problem. But it should be noted that *NS* is not number of junction points in skeleton.

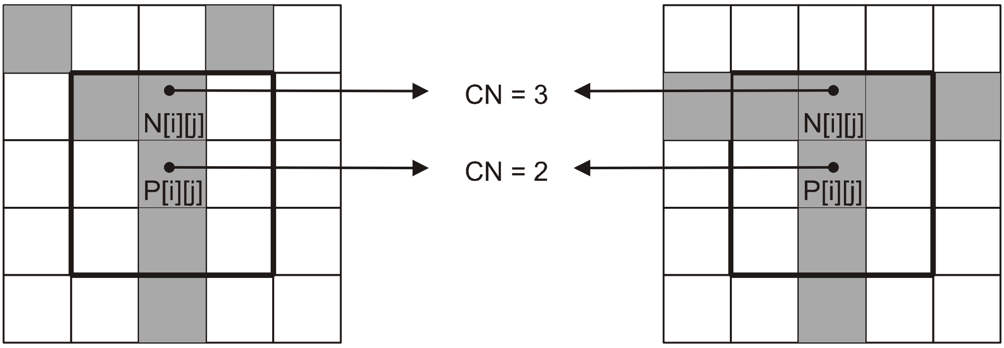

Figure 4 Junction points with CN = 2 and their neighborhoods

4 RESULTS

For purpose of this paper Zhang-Suen's (Z-S) thinning algorithm and Holt's staircase removal post processing algorithm [3] were tested. Three test cases (images) were used. All of them were created from the same grayscale source image using different threshold values [5]. First threshold value produces smooth binary image which is used in test case 1. Second threshold value produces undesirable boundary noise and is used in test case 2. In test case 3 additional boundary noise was added to the picture.

Table 1 - test case 1

	TTC	***TR***	***NOC***	***NS***
original image	66 480	0.0000	1	1
Z-S alg.	693	0.9896	1	62
Z-S + Holt´s alg.	111	0.9983	1	62

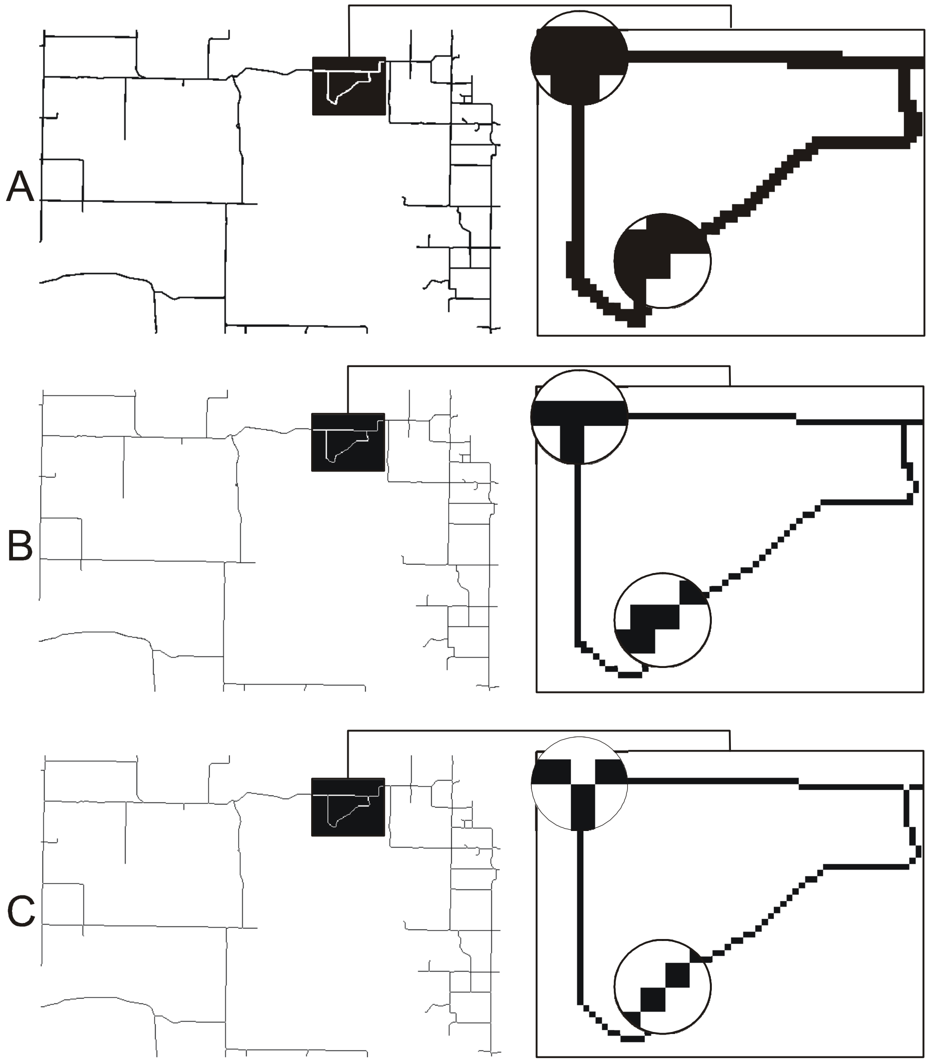

Figure 5 Test case 1 (A: original image, B: result of Z-S algorithm, C: result of Z-S algorithm post processed by Holt’s algorithm)

Table 2 - test case 2

	TTC	*TR*	*NOC*	*NS*
original image	26937	0.0000	1	123
Z-S alg.	1065	0.9604	1	64
Z-S + Holt´s alg.	120	0.9955	1	64

Table 3 - test case 3

	TTC	*TR*	*NOC*	*NS*
original image	54267	0.0000	1	216
Z-S alg.	930	0.9829	1	73
Z-S + Holt´s alg.	141	0.9974	1	73

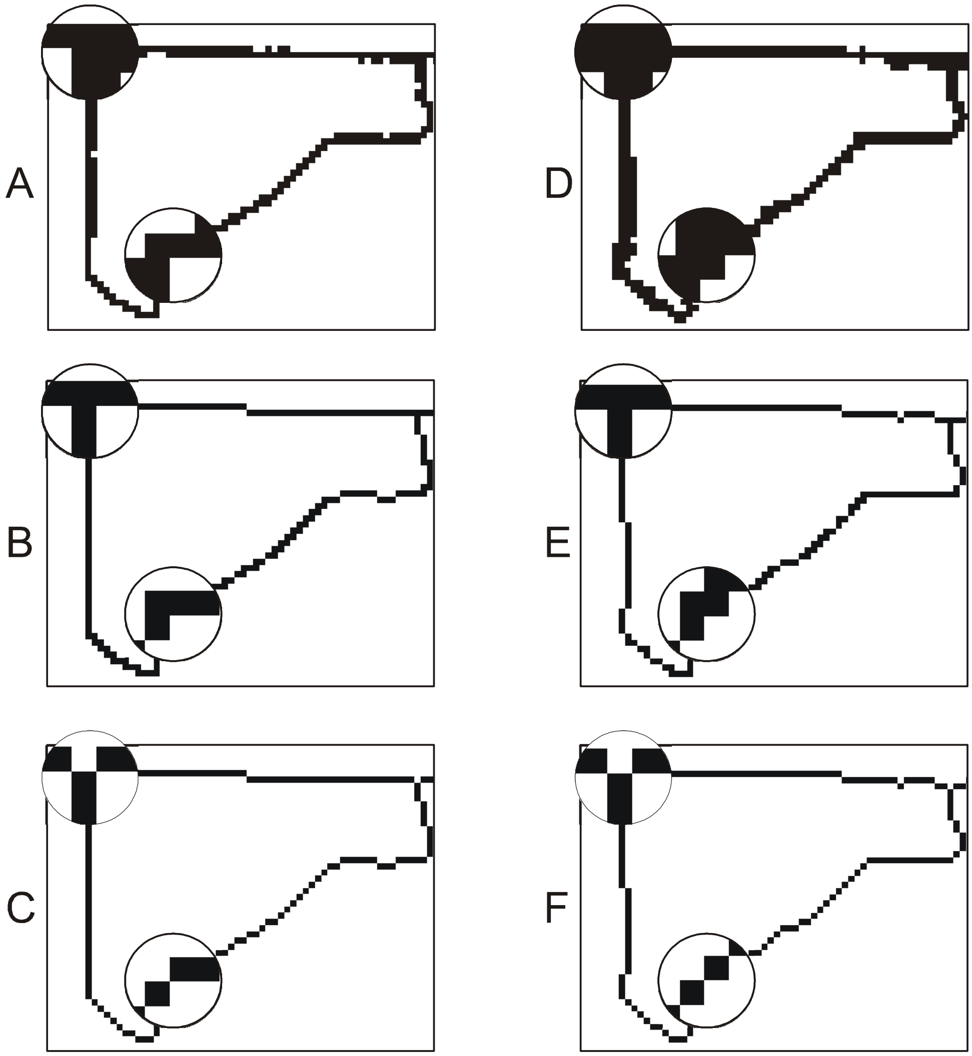

Figure 6 Test case 2 on left (A,B,C) and test case 3 on right (D,E,F) (A,D: original images, B,E: results of Z-S algorithm, C,F: results of Z-S algorithm post processed by Holt's algorithm)

It is possible to see from the results in the included tables, that Z-S algorithm preserves connectivity (*NOC*) and shows good results in *NS* measurements. Some additional junctions are created in the third test case, but the input image has poor quality and in the real situations some pre-processing would be used [6] to increase quality of the image. However, *TR* is between 0.9604 and 0.9896 for all three cases, which is not good enough for vectorization of road maps and probably for all tasks which are dependent on the thin skeleton. It is possible to obtain an improvement by using Holt´s post processing algorithm which is designed to remove excessive pixels from the skeleton. The main disadvantage of this approach is that the shape of some junction points especially so-called “T” junctions may be changed. This is known as a contradictory problem presented in section 2.

5 CONCLUSION

Three criteria for performance measurements of thinning algorithms were presented in this paper. These criteria were designed mainly for vectorizing of road maps but they can be widely used for any line type shapes (shapes of which the length is much larger than the thickness). They represent good starting point towards creating more elaborated methods for this problem. There are more skeleton features (shape and position of junction points, line length preservation etc.) which need to be measured too. According to my personal opinion it is necessary to create series of predefined test cases with known results in order to be able to measure all these features. This approach would mainly allow comparing shape and position of junction points with known results.

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