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# AN ALGORITHM FOR SCALING BINARY IMAGES FOCUSED ON CONNECTIVITY AND TOPOLOGY PRESERVATION

Xin Chen[1], Yong Feng[1] and Lianqiang Niu[2]

[1]School of Science
[2]School of Software
Shenyang University of Technology
No. 111, Economic and Technological Development Zone, Shenyang 110870, P. R. China
{ 491079175; 286606198; 769211311 }@qq.com

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Abstract. *Connectivity is a kind of very important feature for image analysis and recognition, but it is often inadvertently changed while an image is scaled. In order to preserve connectivity of the scaled images as far as possible, we propose an improved scaling algorithm for a binary image based on mask matching. In this algorithm, two groups of local masks corresponding scaling up/down operations are defined. Each mask determines a corresponding transformation for a type of connecting structure. An image is scanned in horizontal and vertical directions respectively, and all states of pixels which should be inserted or deleted can be decided by local connectivity and shape in a simple and straightforward manner for each scanning step. At the same time, the image can be scaled in an arbitrary ratio. The experimental results show that the algorithm has very strong ability to preserve connectivity and topology. Furthermore, the proportion and shape of the scaled image are closer to the original, and edges are clearer.*
**Keywords:** Binary image scaling, Mask matching, Connectivity preservation, Topological preservation

1. **Introduction.** Image scaling is an important image processing operation. According to the different application purpose, the scaling approaches can be divided into two categories named reconstruction algorithms and non-reconstruction algorithms. Reconstruction algorithms establish a continuous function by discrete sampling points, and calculate the function values at any position [1]. These approaches focus on visual effects of the resized image, so some abilities such as avoiding blurred edges and keeping the image details clear are emphasized. Relatively, the non-reconstruction algorithms obtain the interpolation points with the original information of neighbor pixels, and pay much more attention to the image content [2-10]. Some special purposes and requirements are demanded while a binary image is scaled such as preserving unchanged connectivity and topology of the scaled image. This is since that the connectivity information is used to identify the characteristics of the images in many domains such as OCR, map labeling, topographic maps recognition and fingerprint recognition.

Borgefors et al. [3] proposed a reduction algorithm based on intermediate gray, which aimed at improving shape preservation in lower resolutions. The approach is simple, but the destruction of the connectivity is more serious and there are some contradictions with the human vision and the edge fuzzy phenomenon. Jia et al. [4] improved the above algorithm (we call it J Algorithm). In the algorithm, sub-region division and number of foreground pixels are employed to establish some criteria, and then new pixels are obtained by these criteria and the connectivity of the original image. Since different strategies are adopted to deal with smooth regions and edge regions, the ability of connectivity preservation is improved. However, when an image with more sharp edges (e.g., line graph or text image) is scaled, the J Algorithm still brings a lot of connectivity changes in detail. Furthermore, it requires repeated comparison between scaled image and the original one, so the efficiency is lower. We have earlier proposed some different criteria to improve the ability to maintain connectivity [5].

Morales-Manilla et al. [6] proposed a resizing algorithm for binary geographic maps aimed at connectivity preservation (we call it M Algorithm). In the algorithm, two kinds of masks for magnification and reduction are defined. After inserting a column (row) or deleting a column (row) between every two adjacent columns (rows), the algorithm assigns some pixels in new column (row) with suitable values according to masks. For magnification operation, each mask describes a structure on how to insert a foreground pixel in the added column, and it is opposite to reduction operation. To magnify an image, the algorithm clears the target image first, and then copies $j$-th column (row) from original image to $k * j$-th column (row) in target image, where $k$ denotes a scaling ratio. Finally, the algorithm scans target image and matches every pixel with 6 magnification masks respectively to set the foreground color. The reduction operation employs the masks to determine all columns (rows) which may be deleted first, and then it randomly deletes a column (row) from them. This procedure is repeated until target size is gained or no column (row) can be deleted. M Algorithm can work well for maps in a high speed and preservation ability for connectivity and topology, but there are also some drawbacks. When a map is magnified, jaggies will occur for oblique lines, horizontal or vertical lines are stretched only in one direction, and all isolated points are not scaled up, etc. These make a mess of the quality of the image. In the reduction operation, connectivity is often damaged due to its improper masks (e.g., $M_7$ [6], two unconnected pixels will become connected after the middle column is deleted). In addition, an image is often unable to be reduced to target size since there are no enough columns (rows) which meet the requirements of masks, and deleting columns (rows) randomly always deforms the reduced image.

In this paper, based on the idea originated from [6], we proposed an improved binary images scaling algorithm depending on mask matching. By constructing more extensive masks, the algorithm can scale an image up/down in any scaling ratio on the condition that all connectivity of local regions is preserved. The scaled images present good visual effects and have little loss of features. At the same time, a high efficiency can be achieved.

The rest of this paper is organized as follows. Section 2 describes the implementation details of the scaling algorithm. Section 3 shows testing results of several algorithms and discusses the effectiveness of our algorithm. The conclusions are given in Section 4.

## 2. The Proposed Algorithm.

For a $W \times H$ binary image, we use $I(i,j)$ to denote the pixel value at $(i,j)$, where $0 \le i \le W-1$ and $0 \le j \le H-1$. In order to preserve connectivity and topology of the scaled image as far as possible, here we present a set of improved masks and scaling criteria. The main strategy is to scale line up or down in two directions to maintain the shape of the image, and to make insert or delete operations as little loss of local connectivity as possible.

### 2.1. Image magnification.

According to the basic relationship among the pixels [11], we can consider the state of the relevant columns of pixels only in a neighborhood of $3 \times 2$ when the image is magnified. In our algorithm, only three masks $M_1$, $M_2$, and $M_3$ are constructed for magnification process as shown in Figure 1. Among them, the current pixel is located in $(i,j)$; value 1, 0 and $s$ denote the initial state of an original foreground pixel, the initial state of a new pixel in an inserted column, and the new foreground pixel in an inserted column respectively. Besides, $*$ denotes the pixel with an arbitrary value. The criteria constructed by the three masks are described as follows.

**Criterion 1.** The mask $M_1$ sets $I(i,j)$ to a foreground pixel, in order to preserve the connectivity between the foreground pixel $I(i-1,j)$ and $I(i+1,j)$.

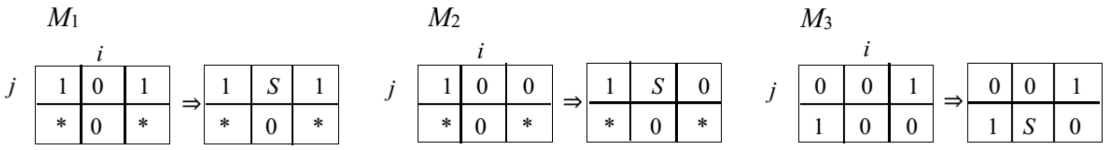


Figure 1. Masks of the magnification

**Criterion 2.** The mask $M_2$ sets $I(i,j)$ to a foreground pixel. Partial reason is to meet connectivity requirement, that is, a foreground pixel $I(i,j)$ can keep $I(i-1,j)$ and $I(i+1,j+1)$ connected or disconnected according to their original relation. At the same time, the pixel $I(i-1,j)$ is also widened proportionally in the horizontal direction.

**Criterion 3.** The mask $M_3$ sets $I(i,j+1)$ to a foreground pixel, in order to preserve the connectivity between the foreground pixel $I(i-1,j+1)$ and $I(i+1,j)$.

For the magnification operation, we scan the image horizontally first and then vertically, which is to enlarge the image width first and then its height. For each scan step, we insert a blank line in the original image to resize first, and then calculate and set the foreground pixels based on the criteria 1$\sim$3 to restore the local connectivity. A magnification operation with large-scale may be achieved by multistage amplification. The description of the horizontal magnification is shown in Figure 2.

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Input: original image $I$, image size $W \times H$, resizing ratio $k$ $(1 \le k \le 2)$.
Output: scaled image $A$, image size $[W \times k + 0.5] \times H$, $[x]$ denotes the rounding of $x$.
{
  establish $A$ and set all pixels of $A$ with background value;
  **for** $(i \leftarrow 1;\ i < W;\ i \leftarrow i+1)$ {
    copy $i$-th column from $I$ to $[k \times i + 0.5]$-th column in $A$;
    **for** $(i \leftarrow 1;\ i < [W \times k + 0.5];\ i \leftarrow i+1)$ {
    **if** (the $i$-th column is a new inserted column) {
      **for** $(j \leftarrow 0;\ j < H;\ j \leftarrow j+1)$
        **foreach** $t \in \{M_1, M_2, M_3\}$
          match the current pixel and set foreground color to it if necessary;}
    }
  }
}

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Figure 2. Procedure to scale the image up in the horizontal direction

For all pixels $I(i,j)$ of the last row $(j = H-1)$, it only needs to match the revised masks $M_1$, $M_2$ to ensure that the masks are bounded in the image range, and does not need to match $M_3$. The revision to masks $M_1$ and $M_2$ can be simply achieved by deleting the last line from them. Of course, this can also be replaced by adding a virtual line in the image.

2.2. **Image reduction.** As shown in Figure 3, our reduction masks are constructed with various sizes. All connected and unconnected relations among those columns included in a $3 \times 4$ neighborhood of the current pixels are considered in these masks. Since we can delete any specified column with no local connectivity changes based on these masks, this guarantees that we can reduce the image to the desired scale. In Figure 3, the column including the current pixel $I(i,j)$ is to be deleted. The criteria reflected by these masks are described as follows.

**Criterion 4.** The masks $M_4 \sim M_{12}$ handle the case where all pixels in the masks are not locally connected with each other since all pixels of the $i$-th column are background pixels, and there are 3, 2, and 4 foreground pixels in its four neighboring pixels respectively. In

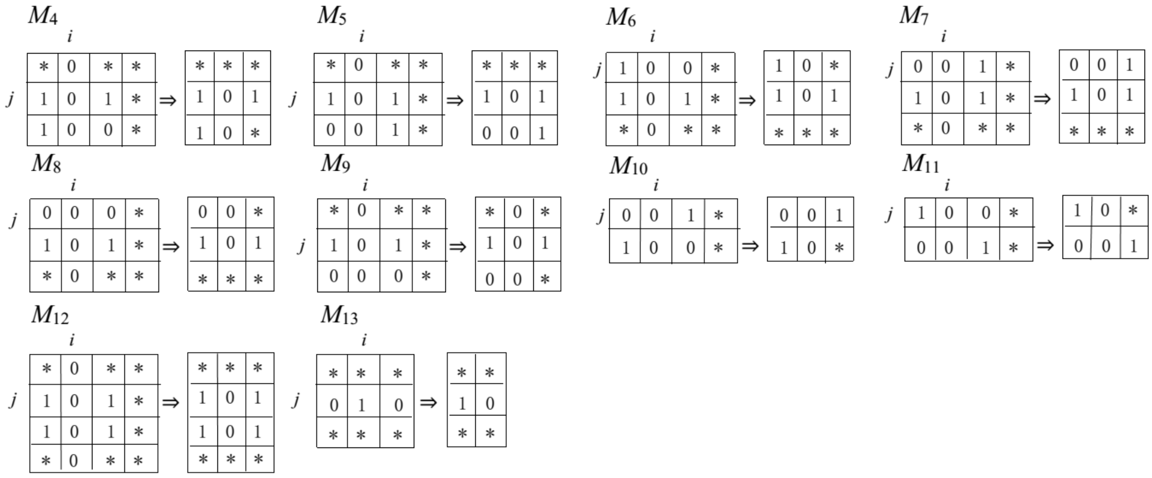


FIGURE 3. Masks of the reduction

these cases we copy the pixels $I(i+1,j)$ to a $I(i+2,j)$ if $I(i+1,j)$ is a foreground pixel, and also copy the pixels $I(i+1,j+1)$ to a $I(i+2,j+1)$ if $I(i+1,j+1)$ is a foreground pixel.

**Criterion 5.** The mask $M_{13}$ describes the case where the current pixel $I(i,j)$ is a foreground and its adjacent pixels in $I(i-1,j)$ and $I(i+1,j)$ are all background pixels. We let $I(i-1,j)$ be a foreground pixel if $(I(i-1,j-1) \vee I(i,j-1) \vee I(i+1,j-1)) \wedge (I(i-1,j+1) \vee I(i,j+1) \vee I(i+1,j+1))$ equals 1. In the other words, we set foreground color to the pixel $I(i-1,j)$ to maintain the connectivity between the $(j-1)$-th row and the $(j+1)$-th row.

Similar to magnification operation, the reduction operation also scans the image horizontally first and then vertically. A reduction operation with large scale may be achieved by multistage reduction. The description of the horizontal reduction is shown in Figure 4.

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Input: original image $I$, image size $W \times H$, resizing ratio $k$ $(0.5 \le k \le 1)$.
Output: reduced image $A$, image size $[W \times k + 0.5] \times H$.
{
  **if** $(k = 0.5)$ $s \leftarrow 2$; **else** $s \leftarrow W - 2/W * (1-k)$; //span between deleted columns
  **for** $(i \leftarrow 1;\ i < W-1;\ i \leftarrow i+s)$
    **for** $(j \leftarrow 0;\ j < H-1;\ j \leftarrow j+1)$ {
      **foreach** $t \in \{M_4, \cdots, M_{13}\}$
        match the current pixel and modify pixels values;
      }
  create image $A$ and clear all pixels of $A$ with background color;
  copy all remaining columns of image $I$ to image $A$;
}

---

FIGURE 4. Procedure to scale the image down in the horizontal direction

For all pixels $I(i,j)$ located in the rows with $j = 0$ and $j = H-2$, we should revise the masks to prevent the operation from crossing the image boundary.

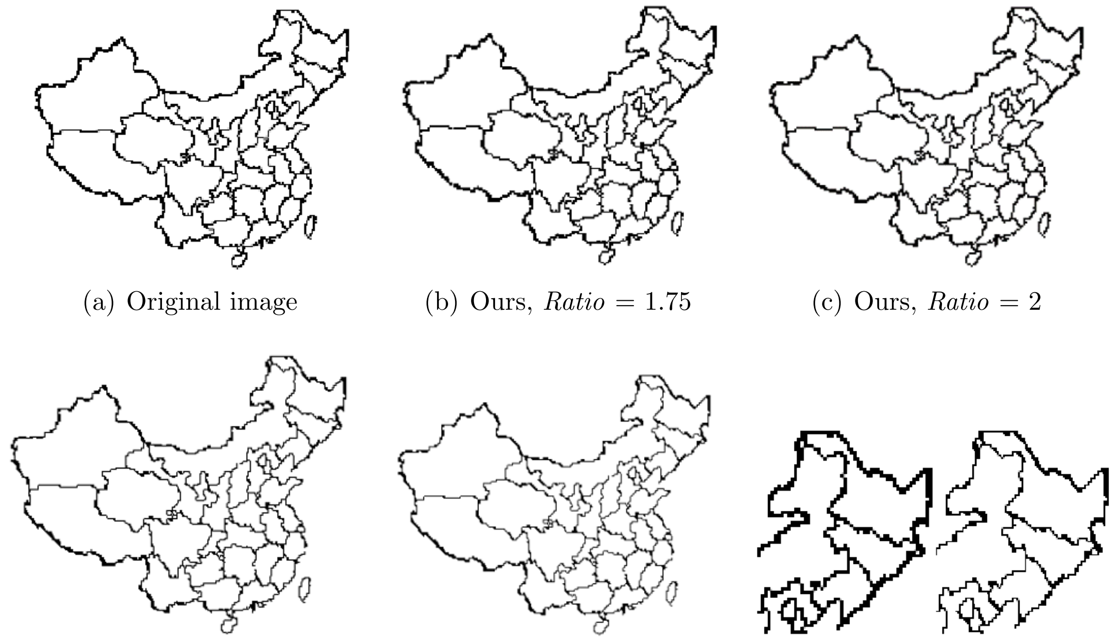
(1) For $j = 0$, we delete all the first lines of the $M_4$, $M_5$, $M_9$, $M_{12}$ and do not match the $M_{11}$ and $M_{13}$, with other masks remaining unchanged.

(2) For $j = H-2$, we delete all the last lines of the $M_6$, $M_7$, $M_8$, $M_{12}$, with other masks remaining unchanged.

Of course, we can also add two virtual boundary lines in the image.

3. **Experimental Results.** In order to compare the effectiveness of the algorithm, several major scaling algorithms for binary images are compared by coding them in C++, and we make a subjective evaluation based on human visual and an objective evaluation according to the BMSE [12] respectively. Due to the space limitations, only several main algorithms aimed at connectivity preservation are tested, including J Algorithm [4], M Algorithm [6] and the proposed algorithm, in which J Algorithm is only used for image reduction. Testing images include geographic images, text images and house images.

Figure 5 shows a geographic image and its magnified results in ratio 1.75 and 2 gained by the M Algorithm and the proposed algorithm. Two algorithms can both preserve the image connectivity well. However, comparing the local details shown in Figure 5(f), we can see that the lines in the magnified image gained by the proposed algorithm (left image) are more uniform, and closer to the original image in proportion. Relatively, the lines of image gained by the M Algorithm (right image) appear uneven and poor visual effects.



(a) Original image (b) Ours, *Ratio* = 1.75 (c) Ours, *Ratio* = 2

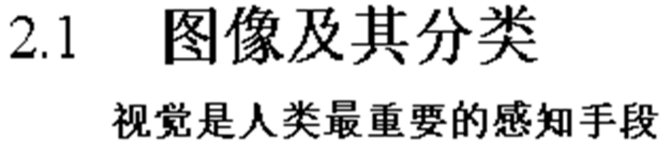
(d) M Algorithm, *Ratio* = 1.75 (e) M Algorithm, *Ratio* = 2 (f) Local details contrast

Figure 5. Comparison results of a magnified geographic image

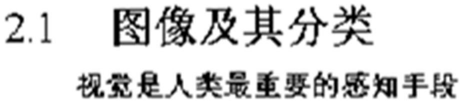
Figure 6 shows a text image and its reduced results gained by three algorithms. Limited by the J Algorithm and the M Algorithm themselves, Figure 6 only shows the images reduced to 0.75 times and 0.5 times. Due to the uncertainty of the reduction ratio and the randomness of the deleted columns (rows) in the M Algorithm, the reduced image shows a serious distortion and uneven distribution of image and can only achieve a lower level of connectivity preservation. Many redundant foreground pixels are kept in the image gained by J Algorithm, and it is also not sufficient to preserve connectivity. Our reduction image is superior to those obtained by other two algorithms in vision, and connectivity is also kept better.

For comparing the performance of the algorithms quantitatively, we reduce a house image and a text image in different ratios, and then magnify them to the original size again, shown in Figure 7.

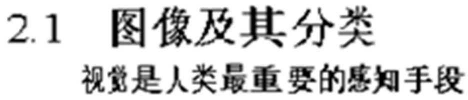
Although the pixel-counting test [13] can be used as an evaluation standard for the image quality of pyramid construction, it is rougher for general scaling operation. In this paper, an improved *BMSE* proposed in [12] is employed for quantitative evaluation.



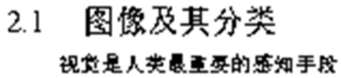

(a) Original image



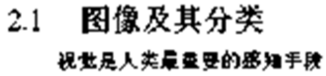

(b) Ours, *Ratio* = 0.75




(c) M Algorithm, *Ratio* = 0.75

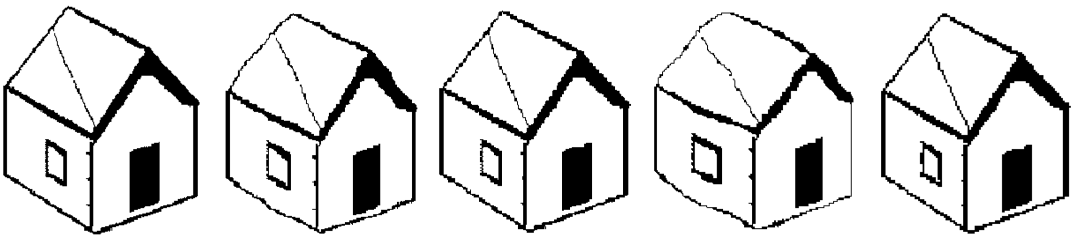



(d) Ours, *Ratio* = 0.5




(e) J Algorithm, *Ratio* = 0.5

FIGURE 6. Comparison results of a reduced text image



(a) Original image (b) M Algorithm (c) ours (d) M Algorithm (e) Ours

(f) Original image (g) M Algorithm (h) Ours (i) M Algorithm (j) Ours

FIGURE 7. Restoration of two images (*Ratio* = 0.75 for (b), (c), (g), (h), and *Ratio* = 0.5 for (d), (e), (i), (j))

In this method, the characteristics of human vision are combined with *MSE* to get a quality criterion. This can be explained that the distances from modified pixels after restoration to black and white boundary will have different impacts on human vision. By adding impact factors $DIM(x, y)$ to *MSE*, we can obtain the quality criterion *BMSE* and standardized $BMSE'$ as follows:

$$BMSE = \sum_{i=0}^{W-1} \sum_{j=0}^{H-1} DIM(i,j)\left(I(i,j) - I'(i,j)\right)^2 \tag{1}$$

$$BMSE' = \frac{BMSE}{\sum\limits_{i=0}^{W-1} \sum\limits_{j=0}^{H-1} |I(i,j) - I'(i,j)|} \tag{2}$$

where $I'$ denotes the scaled image, and the method to calculate $DIM(x, y)$ sees also [12].

Evaluations results are shown in Table 1.

As we can see, better values of *MSE*, *BMSE* and $BMSE'$ under different ratios mean that desired results can be achieved by our algorithm compared with M Algorithm. In

Table 1. Evaluation results of scaling quality for images in Figure 7

| Image | House | | | | Text | | | |
|---|---|---|---|---|---|---|---|---|
| Reduction Ratio | 0.75 | | 0.5 | | 0.75 | | 0.5 | |
| Algorithm | Ours | M Alg. | Ours | M Alg. | Ours | M Alg. | Ours | M Alg. |
| *MSE* | 0.01 | 0.07 | 0.05 | 0.14 | 0.01 | 0.08 | 0.04 | 0.09 |
| *BMSE* | 916 | 7380 | 4007 | 21001 | 204 | 2978 | 972 | 3381 |
| $BMSE'$ | 1.00 | 1.62 | 1.24 | 2.26 | 1.00 | 1.18 | 1.13 | 1.88 |

fact, as the larger reduction ratio, the image quality gained by M algorithm deteriorates significantly, such as more uneven lines and more substantial deformation. More importantly, the connectivity is not able to be kept correctly. In contrast, the quality degradation of reduced image gained by our algorithm is not obvious, and the ability to preserve connectivity is stronger.

4. **Conclusions.** In this paper, we proposed an improved algorithm for scaling binary images based on mask matching aimed at improving connectivity preservation as far as possible. The basic idea of the algorithm is to use the masks to match pixels in the image, and then inserted pixels or deleted ones can be calculated by considering the connectivity relationship among the current pixel and the surroundings as well as scaling ratio synthetically. Different from the existing methods, our algorithm does not need to find special columns or rows to be deleted, so an image can be reduced in an arbitrary ratio with high efficiency. What is important is that the overall locally connected relations are treated in our masks, so the connectivity of the scaled images is better preserved. In addition, our scaled images present clearer edges, and are closer to the original image in the proportion. However, fuzzy phenomenon may appear in the details for large scale reduction operations. This is due to that for small sizes, the algorithm in order to preserve connectivity, and then more foreground pixels are reserved. Variable and richer masks need to consider more factors, such as the size of the current image and scaling ratio.

## REFERENCES


[1] Y. Li and H. Xia, Image resizing via bi-quadratic B-spline interpolation, *J. Image and Graphics*, vol.16, no.10, pp.1937-1943, 2011.

[2] S. Avidan and A. Shamir, Seam carving for content-aware image resizing, *ACM Trans. Graphics*, vol.26, no.3, pp.10-18, 2007.

[3] G. Borgefors, G. Ramella and G. di Baja, Multiresolution representation of shape in binary images, *Lecture Notes in Computer Science*, vol.1176, pp.49-58, 1996.

[4] X. Jia, D. Wang, Y. Wu et al., A shrinking technique for binary images to preserve connectivity, *J. Computer-Aided Design & Computer Graphics*, vol.22, no.11, pp.1952-1958, 2010.

[5] L. Niu, M. Peng and S. Zhang, A reducing algorithm for binary images focused on topology and connectivity preservation, *ICIC Express Letters, Part B: Applications*, vol.6, no.7, pp.1781-1788, 2015.

[6] L. Morales-Manilla, G. Sanchez-Diaz and R. Soto, An image resizing algorithm for binary maps, *Proc. of the 5th Mexican International Conference in Computers Science*, Washington DC, pp.126-132, 2004.

[7] H. Alain, D. François and Z. Djemel, A simple scaling algorithm based on areas pixels, *Lecture Notes in Computer Science*, vol.5112, pp.53-64, 2008.

[8] J. Xie, P. Li, T. Liu et al., A new interpolation algorithm for digital maps based on content division, *Computer Engineering & Science*, vol.30, no.2, pp.55-57, 2008.

[9] X. Chen, H. Huang and M. Kang, Algorithm of image zoom based on the plane and spherical interpolation, *J. Henan University (Natural Science)*, vol.43, no.3, pp.320-323, 2013.

[10] J. Chang and X. Wu, Self-adaptive amending algorithm of image zooming-out based on weighted averaging image sub-block, *Computer Engineering and Applications*, vol.45, no.7, pp.181-183, 2009.

[11] R. Gonzalez and R. Woods, *Digital Image Processing*, 3rd Edition, Public House of Electronics Industry, Beijing, 2011.

[12] X. Zhang, F. Zhang and J. Zhang, Quality evaluation of binary images, *Computer Engineering & Science*, vol.32, no.6, pp.52-54, 2010.
[13] G. Borgefors, G. Ramella, G. di Baja et al., On the multiscale representation of 2D and 3D shapes, *Graphical Models and Image Processing*, vol.61, no.1, pp.44-62, 1999.