UDC 621.391.14

CLASSIFICATION OF POINT FORMS AND ESTABLISH A LIBRARY FOR CODING THE SKELETON OF THE BINARY IMAGES

REN XUNHUAN, V.K. KONOPELKO

Belarusian State University of Informatics and Radioelectronics, Republic of Belarus

Submitted 30 October 2019

Abstract. In this paper, the methods for classifying points which are allowed to determining the types of two-dimensional vectors and can be used to code the skeleton of the binary image were analyzed. On the basis of [3–5], our research focused on the matrix which is *t* by *t*, in which there are only t elements are one. These elements can be called as point (pixel). An improved algorithm for classifying points is proposed. The result of the preprocessing point is a compressed library of point patterns.

Keywords: pattern recognition, square matrix, transposed group, classifying points.

Introduction

The field of pattern recognition is concerned with the automatic discovery of regularities in data through the use of computer algorithms and with the use of these regularities to take actions such as classifying the data into different categories. In 1872, Felis Klein in his famous "The Erlangen program" got the conclusion that in geometric space, if a set of objects can be classified, they must have some common features which can be extracted by implementing some transformation on these objects. Here given an example, two different matrices are equal if they both can translate to the same matrix though some elementary transformations of matrix respectively [1, 2].

In this paper, our research focused on the matrix which is t by t, in which there are only t elements are one. These elements can be called as point (pixel). The work is based on the research of the process of calculating the pattern point of the library is a complex calculate process, before processing the information, we need to reduce the pattern of point library in the initial stage.

The rest of the paper is organized as follows. In Section 2, a brief introduction of the classical method for classification numbers (points) will be presented. And in section 3, an improved algorithm which used to generate the patterns library from $t = 2:7$ has proposed. The conclusion will be given in Section 4.

The method for classification points

In [3–6] an exhaustive method for generating complete point vectors was proposed.

In statistics, where classification is often done with logistic regression or a similar procedure. The most primitive method to generate all possible point patterns through an exhaustive search, the point pattern can be equivalent to a matrix which is *t* by *t* and the set of possible patterns are represented by $A_t = C_{t^2}^t$. As can be seen from A_t, when $t = 2$, we need to analyze 6 possible patterns, then when $t = 7$ – about 90 million, as *t* increases, the amount of calculation increases exponentially. Therefore, in the following work, without changing the complete library patterns, we will reduce the computational complexity by reducing the total number of patterns.

Algorithm generating point patterns

The number of point patterns depends on the number of random permutation characters. When there exist two points – $t=2$, the set of point locations in the table consists of 6 different combinations. Fig. 1 shows these point patterns.

$$\underset{(a)}{\begin{array}{|c|c|}\hline 1 & 1 \\ \hline & \\ \hline \end{array}} \quad \underset{(b)}{\begin{array}{|c|c|}\hline & \\ \hline 1 & 1 \\ \hline \end{array}} \quad \underset{(c)}{\begin{array}{|c|c|}\hline 1 & \\ \hline 1 & \\ \hline \end{array}} \quad \underset{(d)}{\begin{array}{|c|c|}\hline & 1 \\ \hline & 1 \\ \hline \end{array}} \quad \underset{(e)}{\begin{array}{|c|c|}\hline 1 & \\ \hline & 1 \\ \hline \end{array}} \quad \underset{(f)}{\begin{array}{|c|c|}\hline & 1 \\ \hline 1 & \\ \hline \end{array}}$$

Fig. 1. The set of all patterns of the point at $t=2$

According to the definition, the two matrices are equivalent if they can be transformed into each other through the transformation. Select any one of the equivalent matrices as a representative, indicating this type of point pattern. Rules can be expressed as follows.

The rule for creating the library of point patterns:

1. Calculate the total number for each row (r) and column (c) and sort the results by size.
2. Calculation of rank for each matrix.
3. Calculating the number of intersections by row and column.
4. Calculating the sum and difference of the intersection coordinates.

At first we reduce all possible patterns according to the above rules, and then calculate their transposition, and finally get the total pattern library of corresponding point *t*, from the Fig. 1, the subset of $\{a;b;c;d\}$ fall into the same category, expressed as 2.1 , the subset of $\{e;f\}$, as 2.2. Finally, calculate transposition of 2.1 and 2.2 we get the library of $t=2$ (Fig. 2).

$$\underset{(2.1)}{\begin{array}{|c|c|}\hline 1 & 1 \\ \hline & \\ \hline \end{array}} \quad \underset{(2.1^T)}{\begin{array}{|c|c|}\hline 1 & \\ \hline 1 & \\ \hline \end{array}} \quad \underset{(2.2)}{\begin{array}{|c|c|}\hline 1 & \\ \hline & 1 \\ \hline \end{array}}$$

Fig. 2. The set of generating patterns when $t=2$

Based on the reduced point pattern of $t=2$ adding a point, we generate the point pattern of $t=3$, and so on, until the generation of the point patterns for $t=7$, finally we get a $t=2:7$ reduced point pattern library (Fig. 3).

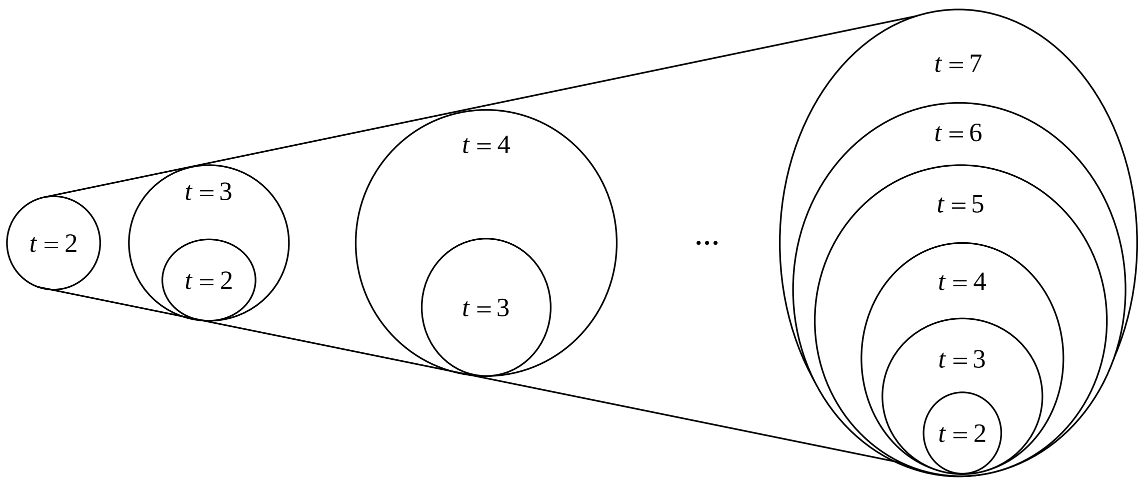

Fig. 3. Structure of the generated point patterns from $t=2:7$

In Fig. 4 and Fig. 5 show the process of $t=2$ generates the total point patterns for $t=3$.

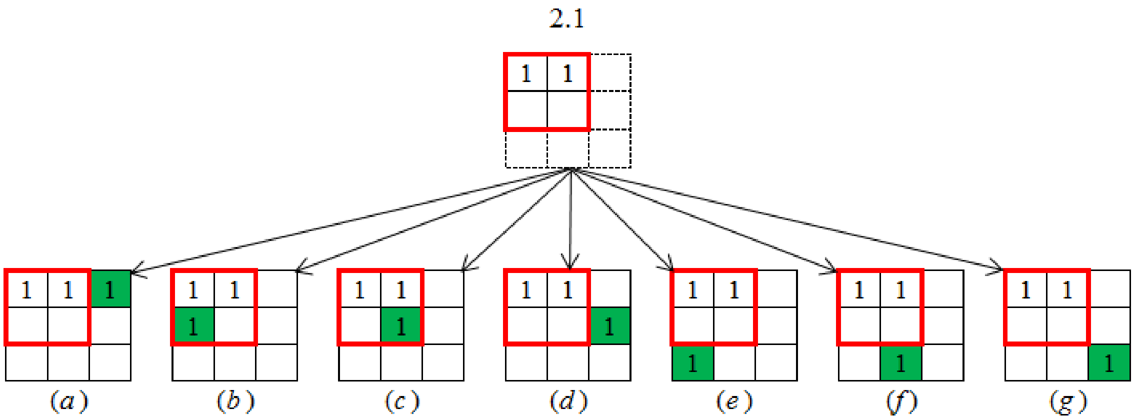

Fig. 4. From point patterns 2.1 obtain a subset point patterns of $t=3$

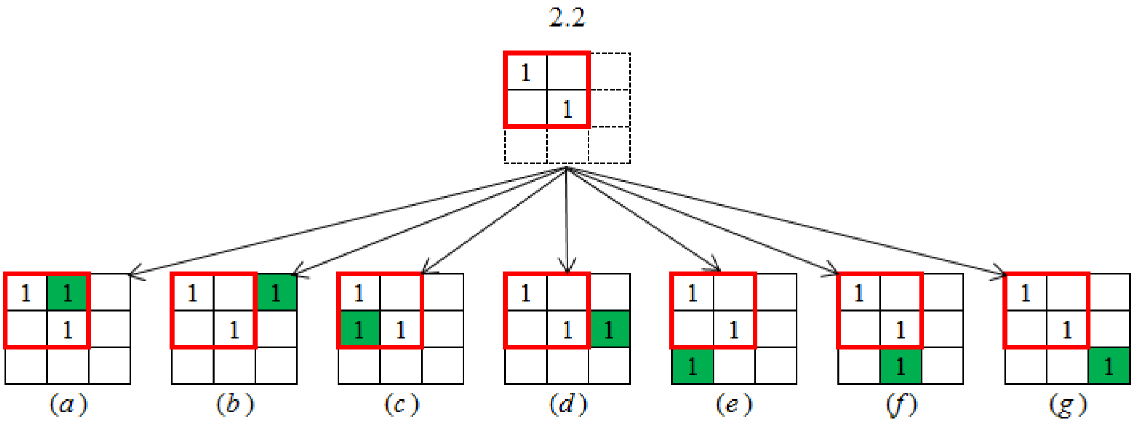

Fig. 5. From point patterns 2.1 obtain a subset of $t=3$

According to the above rules, from Fig. 4 and Fig. 5 form four different patterns A_{com}. Compute the row (string) and the column which has "1" and record the string as s_i and the column as c_j. Here, $s_1 \geq s_2 \geq ... \geq s_i ... \geq s_n; c_1 \geq c_2 \geq ... \geq c_i ... \geq c_n$. In the set of 2.1 $\{b;c;e;f\}$ are the same as the set of 2.2 $\{a;c\}$, they match through a transposition of rows and columns. From the above Fig. we obtain 4 patterns for $t=3$, all of the reduced pattern set denoted by A_{red}, then from the set A_{red} can derive A_{red}^T, as a result we obtain compressed point patterns $A_{pat} = A_{red} \cup A_{red}^T$, when $t=3$, $A_{pat3} = A_3 \cup A_3^T$, as shown in Fig. 6.

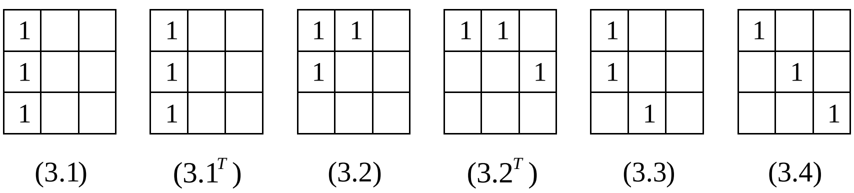

Fig. 6. The total pattern set when $t=3$

In Fig. 6 it is shown the set of $t=3$, the transposition of 3.2 has not changed, it is still itself. We only need to continue to keep it in the library.

The association of the reduced point pattern from $t=2$ to $t=4$ is listed in the Tabl. 1.

Table 1. **The association of the reduced point pattern from $t=2$ to $t=4$**

The reduced basis point pattern of t	The obtained point pattern of $t+1$		
2.1	3.1	3.2	3.3
2.2	3.4	–	–
3.1	4.1	4.2	4.3
3.2	4.4	4.5	4.6
3.3	4.7	4.8	4.9
3.4	4.10	–	–

The structure of the reduced point pattern set from 3.1 to 5.11 is shown in Fig. 7.

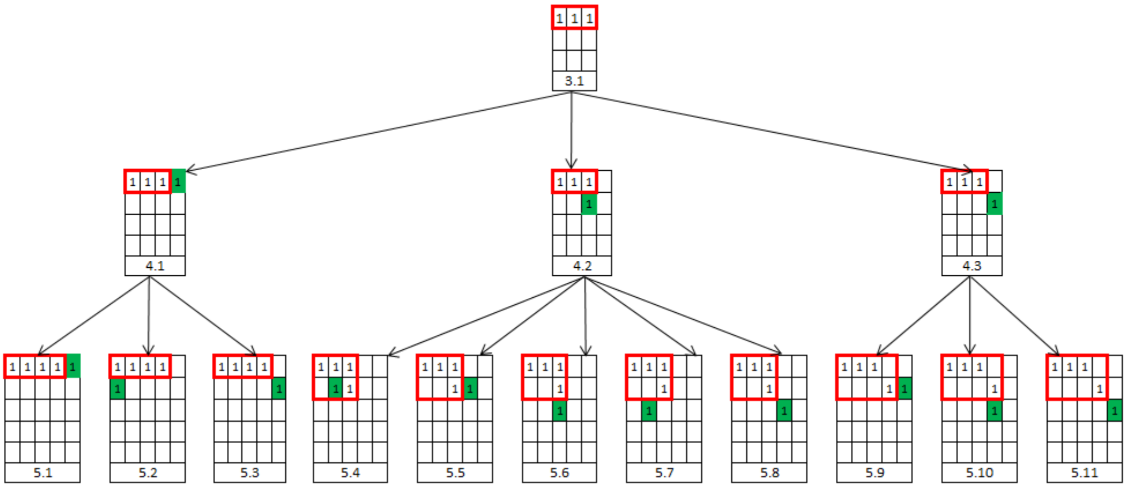

Fig. 7. From 3.1 obtain the reduced subset of $t=5$

Based on these definitions and guidelines, algorithm has been constructed as listed below.

Algorithm Generate point patterns

Input: t

Output: A_{pat}

Initialization: $t=2$

While $t \leq N$ program do

Step 1: On the basis of matrix $t \times t$, we obtain the general total sets $A_{tot} - (t+1) \times (t+1)$.

Step 2: according the rules reduce the set of A_{tot} and get the patterns of A_{red}.

Step 3: calculate the transpose of set A_{red}^T.

Step 4: calculate the set of point pattern – A_{pat}, $A_{pat} = A_{red} \cup A_{red}^T$.

Step 5: $t = t+1$.

End while

Return A_{pat}

Then we will compare the performance of these methods in the computation experiment.

The computation experiment

The asymptotic growth of the original algorithm is faster than our improved algorithm (Tabl. 2), which means that the computational complexity of our new method is lower than the previous method.

Table 2. **Performance comparison of the methods of forming the total point patterns**

Method of generating the total patterns	The total number of generating patterns					
	2	3	4	5	6	7
Search algorithm	6	84	1820	53130	1947792	85900584
Fast algorithm	2	14	52	210	620	2193

The numbers of the feature point pattern extracted from all original point patterns are far less than the numbers of the original error, which will help to decrease the computational complexity (Tabl. 3).

Table 3. **The number of point patterns depending on the matrix of t**

The number of patterns of square matrix t	The reduced number of generating patterns					
	2	3	4	5	6	7
Reduced patterns A_{red}	2	4	10	20	51	119
Patterns set A_{pat}	3	6	16	34	90	214

Due to the limited space, reduced set A_{red} from $t=4$ to $t=5$ are listed in the Tabl. 4, those patterns whose transpose is equal to themselves are marked by the blue shadow.

Table 4. **The library of reduced point patterns from $t=4$ to $t=5$**

$t=4$ and $t=5$					
4.1	$\begin{array}{|c|c|c|c|}\hline 1&1&1&1\\\hline &&&\\\hline\end{array}$	4.2	$\begin{array}{|c|c|c|c|}\hline 1&1&1&\\\hline 1&&&\\\hline\end{array}$	4.3	$\begin{array}{|c|c|c|c|}\hline 1&1&1&\\\hline &&&1\\\hline\end{array}$
4.4	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline 1&1&&\\\hline &&&\\\hline\end{array}$	4.5	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline 1&&1&\\\hline &&&\\\hline\end{array}$	4.6	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline &1&&\\\hline &&1&\\\hline\end{array}$
4.7	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline &&1&1\\\hline &&&\\\hline\end{array}$	4.8	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline &&1&\\\hline &&1&\\\hline\end{array}$	4.9	$\begin{array}{|c|c|c|c|}\hline 1&1&&\\\hline &&1&\\\hline &&&1\\\hline\end{array}$
4.10	$\begin{array}{|c|c|c|c|}\hline 1&&&\\\hline &1&&\\\hline &&1&\\\hline &&&1\\\hline\end{array}$	5.1	$\begin{array}{|c|c|c|c|c|}\hline 1&1&1&1&1\\\hline &&&&\\\hline &&&&\\\hline &&&&\\\hline\end{array}$	5.2	$\begin{array}{|c|c|c|c|c|}\hline 1&1&1&1&\\\hline 1&&&&\\\hline &&&&\\\hline &&&&\\\hline\end{array}$
5.3	$\begin{array}{|c|c|c|c|c|}\hline 1&1&1&1&\\\hline &&&&1\\\hline\end{array}$	5.4	$\begin{array}{|c|c|c|c|c|}\hline 1&1&1&&\\\hline 1&1&&&\\\hline\end{array}$	5.5	$\begin{array}{|c|c|c|c|c|}\hline 1&1&1&&\\\hline 1&&&1&\\\hline\end{array}$

Extension of the Tabl. 4

5.6	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline 1&&&&\\ \hline 1&&&&\\ \hline\end{array}$	5.7	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline 1&&&&\\ \hline &1&&&\\ \hline\end{array}$	5.8	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline &&1&&\\ \hline &&&1&\\ \hline\end{array}$
5.9	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline &&&1&1\\ \hline &&&&\\ \hline\end{array}$	5.10	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline &&&1&\\ \hline &&&1&\\ \hline\end{array}$	5.11	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&1&&\\ \hline &&&1&\\ \hline &&&&1\\ \hline\end{array}$
5.12	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline 1&1&&&\\ \hline &&1&&\\ \hline\end{array}$	5.13	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline 1&&1&&\\ \hline &1&&&\\ \hline\end{array}$	5.14	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline 1&&1&&\\ \hline &&&1&\\ \hline\end{array}$
5.15	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline &1&&&\\ \hline &&1&1&\\ \hline &&&&\\ \hline\end{array}$	5.16	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline &1&&&\\ \hline &&1&&\\ \hline &&&1&\\ \hline\end{array}$	5.17	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline &&1&1&\\ \hline &&&&1\\ \hline &&&&\\ \hline\end{array}$
5.18	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline &&1&&\\ \hline &&1&&\\ \hline &&&1&\\ \hline &&&&\\ \hline\end{array}$	5.19	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&1&&&\\ \hline &&1&&\\ \hline &&&1&\\ \hline &&&&1\\ \hline &&&&\\ \hline\end{array}$	5.20	$\begin{array}{\|c\|c\|c\|c\|c\|}\hline 1&&&&\\ \hline &1&&&\\ \hline &&1&&\\ \hline &&&1&\\ \hline &&&&1\\ \hline\end{array}$

From the Tabl. 4 select the patterns with unit-pixel connect in the Tabl. 5.

Table 5. **The patterns with unit-pixel connect from $t=3$ to $t=5$**

$t=3$					
3.1	$\begin{array}{\|c\|c\|c\|}\hline 1&1&1\\ \hline &&\\ \hline &&\\ \hline\end{array}$	3.3	$\begin{array}{\|c\|c\|c\|}\hline 1&1&\\ \hline &&1\\ \hline &&\\ \hline\end{array}$	3.4	$\begin{array}{\|c\|c\|c\|}\hline 1&&\\ \hline &1&\\ \hline &&1\\ \hline\end{array}$
$t=4$ and $t=5$					
4.1	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&1&1&1\\ \hline &&&\\ \hline\end{array}$	4.3	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&1&1&\\ \hline &&&1\\ \hline\end{array}$	4.7	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&1&&\\ \hline &&1&1\\ \hline\end{array}$
4.8	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&1&&\\ \hline &&1&\\ \hline &&1&\\ \hline &&&\\ \hline\end{array}$	4.9	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&1&&\\ \hline &&1&\\ \hline &&&1\\ \hline &&&\\ \hline\end{array}$	4.10	$\begin{array}{\|c\|c\|c\|c\|}\hline 1&&&\\ \hline &1&&\\ \hline &&1&\\ \hline &&&1\\ \hline\end{array}$

Extension of the Tabl. 5

<table>
<tr><td>5.1</td><td><table><tr><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td><td>5.3</td><td><table><tr><td>1</td><td>1</td><td>1</td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td>1</td></tr></table></td><td>5.9</td><td><table><tr><td>1</td><td>1</td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td>1</td></tr></table></td></tr>
<tr><td>5.10</td><td><table><tr><td>1</td><td>1</td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr></table></td><td>5.11</td><td><table><tr><td>1</td><td>1</td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td>1</td></tr></table></td><td>5.17</td><td><table><tr><td>1</td><td>1</td><td></td><td></td><td></td></tr><tr><td></td><td></td><td>1</td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td>1</td></tr></table></td></tr>
<tr><td>5.18</td><td><table><tr><td>1</td><td>1</td><td></td><td></td><td></td></tr><tr><td></td><td></td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td><td>5.19</td><td><table><tr><td>1</td><td>1</td><td></td><td></td><td></td></tr><tr><td></td><td></td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td>1</td></tr><tr><td></td><td></td><td></td><td></td><td></td></tr></table></td><td>5.20</td><td><table><tr><td>1</td><td></td><td></td><td></td><td></td></tr><tr><td></td><td>1</td><td></td><td></td><td></td></tr><tr><td></td><td></td><td>1</td><td></td><td></td></tr><tr><td></td><td></td><td></td><td>1</td><td></td></tr><tr><td></td><td></td><td></td><td></td><td>1</td></tr></table></td></tr>
</table>

Conclusion

In this paper, we analyze methods for generating the library of point patterns, all the possible patterns are accessible in our library which implies coding the image in the future is feasible. The improved method has reduced the time of generating all the possible patterns. We select the patterns with unit-pixel connect in our library and in the next stage we will code the binary skeleton image by using parts of our library.

References

1. Klein F. // Comparative review of the latest geometric research (Erlangen program) /on the foundations of geometry: Collection of classical works on Lobachevsky's geometry and the development of its ideas. M.: 1956. P. 399–434.
2. Hardy G.Y, Wright E.M. An introduction to the theory of Numbers. Berlin. 1973.
3. Konopelko V.K., Lipnitsky V.A, Spichekova N.V. // Dokl. BGUIR. M.: BSUIR, 2010. P. 112–117.
4. Konopelko V.K., Lipnitsky V.A, Spichekova N.V. // Dokl. BGUIR. M.: BSUIR, 2010. P. 40–46.
5. Konopelko V.K., Lipnitsky V.A, Spichekova N.V. // Dokl. BGUIR. M.: BSUIR, 2011. P. 17–25.
6. Konopelko V.K., Smolyakova O.G. // Dokl. BGUIR. M.: BSUIR, 2008. P. 19–28.
7. Konopelko V.K., Smolyakova O.G. // Dokl. BGUIR. M.: BSUIR, 2008. P. 142–153.