The methods of homotopic skeletonization of bit-mapped drawings of parts of sea transport

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Abstract. Solution of the problem of recognition and vectorization of parts of sea transport requires formation of skeletonized images, homotopic (geometrical primitives, topologically equivalent in shape and their coherence) to parts' shapes.

The author has performed a comparative analysis of the best methods of parallel, topological skeletonization of the area objects, based upon application of space extractors. The analysis showed that the methods existing in the investigated objects zone possessed typical drawbacks, expressed in iterative distortions of primitive topology and their compositions.

The objective of the article is to through the light upon the developed methods of improvement of topological equivalence of the resulting skeletons to the shapes of the parts of sea transport, by means of gradual correction of typical distortions of skeletons.

The developed methods assumes correction of skeleton's iterative distortions by modified extractors of the principal method of skeletonization and restoration of the resulting skeleton by extractors of restoration of homotopic skeleton, on the basis of developed rules of its reconstruction.

Execution of the proposed method was carried out on example of the basic method Wu R.Y. & Tsai W.H. Examples of the results of skeletonization of parts' drawings were given, verifying efficiency of the proposed methods. The methods can be adapted to the methods of topological skeletonization of area objects, based upon application of space extractors.

Keywords: drawing, shape, skeleton, extractor ,distortion coherence, homotopic character.

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INTRODUCTION

According to the principles, laid in the basis of skeletonization objects' of bit-mapped area images the following groups of methods can be singled out: approximation of the boundary of an area figure by a polygon [1 − 3], path-tracing method [9], stripes graphs [5], tracking of pixels [1, 2, 6], distance maps method [10], wave method [7], method of topological thinning [11 − 16].

The analysis of merits and flaws of each group of methods showed that methods of parallel iterative topological thinning Rutovitz, Pavlidis, Wu&Tsai et al.), ensuring skeletons of better quality seemed to be most promising in the zone under investigation.

These methods are based on placing space extractors on the local neighbourhood of the points of bit-mapped image withy the objective of extracting "simple dots, extraction of which does not infringe structural similarity and integrity of the skeleton of part's shape [10]. The methods belonging to this group differ in their sets of extractors, the criteria of images dots affiliation with the skeleton and ways of dots testing on correspondence with such criteria.

Still, from the point of view of the analyzed objects zone, the existing methods possess, in spite of their merits [1, 9, 10, 17], a common substantial drawback, emerging as violation of homotopic character of the resulting skeleton, as compared to the original part's shape on the drawing, particularly:

- distortion of topology of right angles of the skeleton at iterative parallel thinning of part's shape;
- in violationв of skeleton's coherence at the process of thinning of part's shape;
- in violation of skeleton's topology in the points of intersection of geometrical primitives of the shape;
- in sensibility of skeleton's topology to local properties of the shape (thickness, for instance).

THE OBJECTIVE AND METHODS

The objective is development of the methods of topological skeletonization of drawings of sea transport parts, ensuring homotopic character of skeletons with original parts' shapes, by means of correction of typical distortions, by application of basic methods of skeletonization.

A substantial increase of skeleton's structural correspondence to the part's shape is reached by gradual application of the developed set of methods:

- At the first stage at iterative thinning of a part a correction of iterative distortions of skeleton with modified extractors of the basic method of skeletonization is performed;
- at the second stage, after the entire skeleton has been obtained, reconstruction of the skeleton is performed with restoration homotopic extractors, on the basis of the developed instructions for reconstruction of distorted zones of intersections of geometrical primitives.

Correction of the skeleton is supposed to be performed with the aid of the designed extractors, in accordance with the following principle:

- the aperture of a "simple" dot, removed by a basic method is compared to the nuclei of the developed set of correcting and restoring extractors with a possibility of their turning by angles, divisible by 90°;
- in case of coincidence of the dot's aperture with the nucleus of any extractor the skeleton is corrected, in accordance with the developed instructions for adoptions of solutions, specific for each type of skeleton's distortions.

THE RESULTS AND COMMENTS

Among the methods of topological skeletonization of objects, when space extractors are used, Wu R.Y. & Tsai W.H. [18] method, ensuring the best result is of special interest.

The extractors, applied in Wu R.Y. & Tsai W.H. method are represented in Table 1. It is characteristic that these extractors contain unused positions with the unidentified beforehand values, hence, allowing variability. The elements of extractors nuclei with alternative colours are marked with "?" sign, whilst unused nuclei elements are marked with «□» sign.

Application of these positions for reconstruction of distorted skeletons allows ensuring their structural correspondence to part's shape, required in the object's zone.

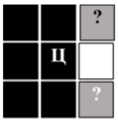
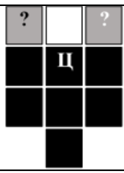
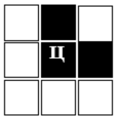
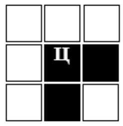
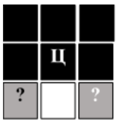
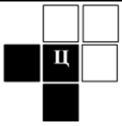
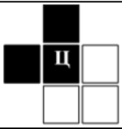
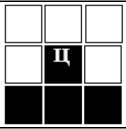
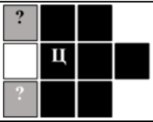
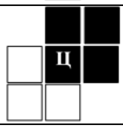
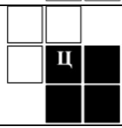
Now, let us consider the proposed methods of restoring homotopic character of the skeleton, generated by the principle method on the example of the method of Wu&Tsai.

THE METHOD OF CORRECTING DISTORTIONS OF THE TOPOLOGY OF SKELETON'S RIGHT ANGLES

The first type of skeleton's distortions is described by iterative violation of the topology of skeleton's right angles (Fig.1).

To explain the essence of the problem of appearance of such a distortion we shall introduce the required definitions:

Table 1. Extractors $\{Z\}_a^k$ for R.Y. Wu, W.H. Tsai [18] method

Index	Extractor	Index	Extractor	Index	Extractor	Index	Extractor
a		*d*		*g*		*j*	
b		*e*		*h*		*k*	
c		*f*		*i*			

- We'll call the point «*a*» the vertex of the convex angle in 4-connected neighbourhood, where adjacent points b_k and b_{k+1} $(k\in[0,3])$ belong to the shape (Fig.2, *a*);

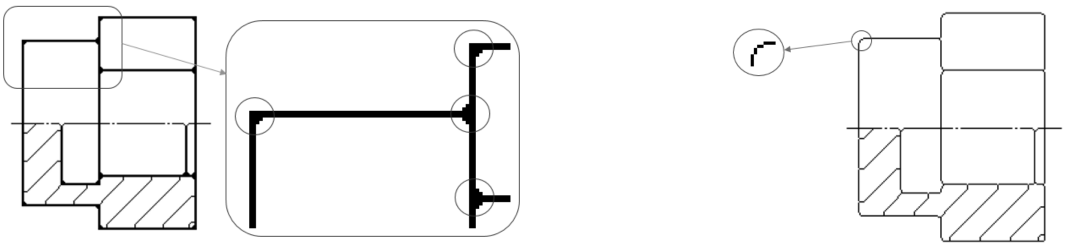
- We'll call the vertex of the concave angle the black "a" in 8-connected neighbourhood, where only one of point of all diagonal points$\{b_1, b_3, b_5, b_7\}$ belongs to the background (Fig.2, *b*).

In the principle method of thinning the convex angles, extractors, using 4-connection "Manhattan" metric are applied, in which distances from the vertex of the convex angle of the shape to the background $\rho_0^M = \rho_6^M = 1$ (see Fig.4, 5, *a*). In accordance with the principle idea of the method, the vertex of the convex angle is considered to be a "simple" point and is removed by $\{Z\}_a^k$ extractors with one pass.

However, vertexes of concave angles in "Manhattan" metric are not boundary points. So, the vertexes of concave angles can't be removed with one pass only with application of $\{Z\}_a^k$, extractors, it leading to distortion of angles topology (see Fig.1), owing to possible application of different set of extractors during two consecutive iterations, it, finally causing violation ion homotopic character of the shape's skeleton.

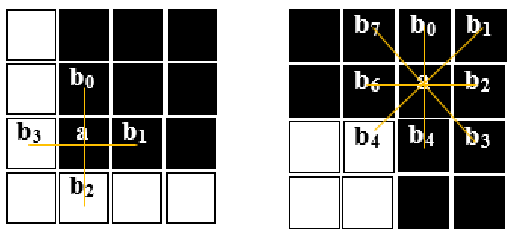
In the proposed method the problem of vertexes' treatment is solved by application of 8-connectoin "chess" metric both for convex and concave angles.

As the distance from vertexes of both convex $(\rho_0^Ш = \rho_6^Ш = \rho_7^Ш = 1)$ and concave $(\rho_7^Ш = 1)$ angles to the background is equal, these vertexes can be removed in one pass. To preserve the shape's topology it is necessary, there, to recognize the vertexes of the concave angles and develop the conditions for preser-



a *b*

Fig.1. Distortion of the skeleton's right angles: *a* – iterative distortion of topology of skeleton's angles; *b* – distorted right angles of the resulting skeleton



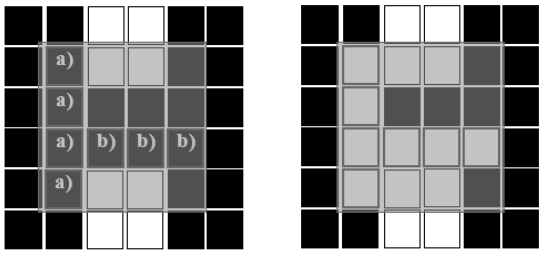
a *b*

Fig.2. Vertexes of the concave and convex angles

vation of skeleton's coherence at their removal. For recognition of the vertexes of the concave angles extractors $\{\tilde{Z}\}_A^I$ (Table 2) were developed.

Elements of the nuclei of basic extractors, unused for the basic method with alternative colours and ignored ones are used there [23]. Here, a candidate to the vortex of the concave angle is marked with «*» symbol. As the vortex of the concave angle has just two neighbouring adjacent points, the shape point may be considered to be the vortex of the concave angle if it is twice marked to be it For realization of this rule for each point of the shape flag $g^{(*)} = 0$ is used.

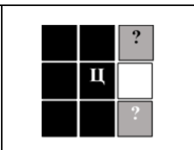
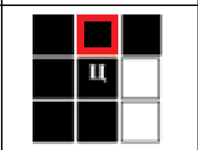
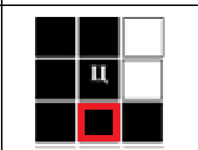
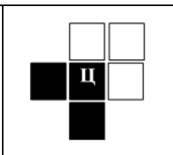
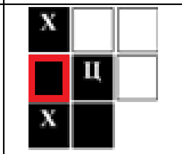
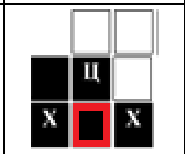
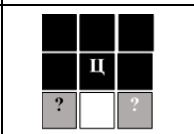
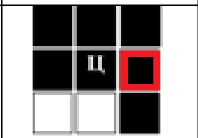
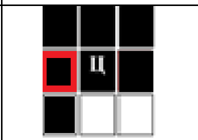
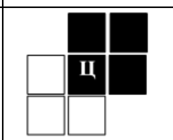
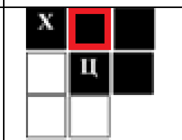
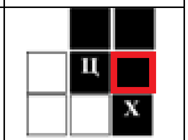
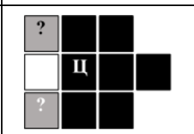
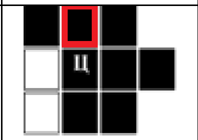
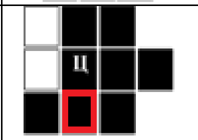
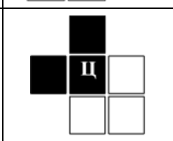
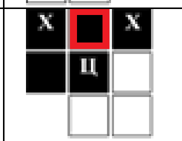
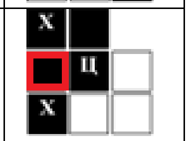
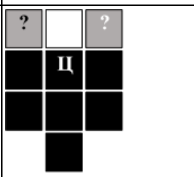
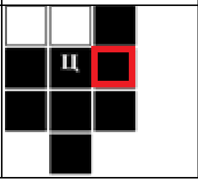
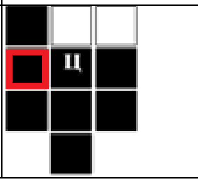
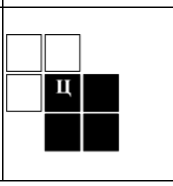
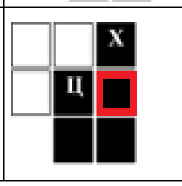
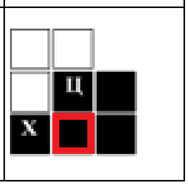
If on any of the correcting extractors a shape point from $\{\tilde{Z}\}_A^I$ is recognized as a vortex of the concave angle it is marked as a corner point and the value of $g^{(*)}$ for this point is increased by 1. Then, if upon completion of checking with $\{\tilde{Z}\}_A^I$ extractors the value of point $g^{(*)} = 2$, then this point is not removed in order to prevent violation of homotopic character of the shape's skeleton.



a *b*

Fig.3. Violation of coherence in the process of thinning of the shape at presence of several concave angles within the boundaries of 4×4 neighbourhood of the point under analysis

Table 2. Extractors $\{\tilde{Z}\}_A^I$

Basic extractor		Developed extractor	Basic extractor	Developed extractor		Basic extractor	Developed extractor
A				E			
B				F			
C				H			
D				I			

THE CORRECTION METHOD FOR IRREGULARITIES IN SKELETON'S COHERENCE

The second type of skeleton's distortion lies in the process of thinning of the shape in case there are some concave angles within the boundaries of 4×4 neighbourhood of the point under analysis (Fig.3).

The points, marked in Fig.3. with the shape, and extractors $\{Z\}_A^B$ will be removed

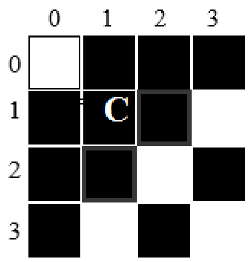


Fig.4. The correcting extractor $\{\tilde{Z}\}_L$

(Indices of extractors removing these points are shown in Fig.3), this is to lead to violation of coherence of the skeleton (see Fig.3, *b*). To solve this problem a correcting extractor $\{\tilde{Z}\}_L$ (Fig.4.) was developed, capable of rotation by angles, divisible by right angle, by application of which the problem of thinning the concave angle at its different orientation is solved.

At that, if the analyzed point of the shape is recognized to be the vortex of the concave angle , it is checked by $\{\tilde{Z}\}_L^{(\angle 0^\circ - \angle 270^\circ)}$ extractor, if the aperture of «C» point coincides with the extractor in one of its four orientations, then the vortex of the concave angle can be removed without violating the skeleton's coherence, the latter being ensured by the extractor's points $\{\tilde{Z}\}_L$ with the coordinated (1, 2) and (2, 1).

THE METHODS OF CORRECTING VIOLATIONS OF THE SKELETON'S TOPOLOGY IN THE POINTS OF INTERSECTION OF GEOMETRICAL PRIMITIVES

The third type of violations lies in violation of homotopic character of the skeleton in points of primitives intersection, as the character of the analyzed object's zone requires affiliation of these points (e.g. vortexes of the skeleton's right angles) with the shape (Fig.5) [23, 24].

The methods of topological skeletonization are sensitive to local properties of the shape, changing after each iteration of its thinning. Thus, for a thickness of the primitive in several points ($W \geq 1$) even during the first iteration with $\{Z\}_A$ extractor a "forepart" artifact turns up, increasing its dimensions from iteration after iteration, greatly distorting the skeleton (Fig.6).

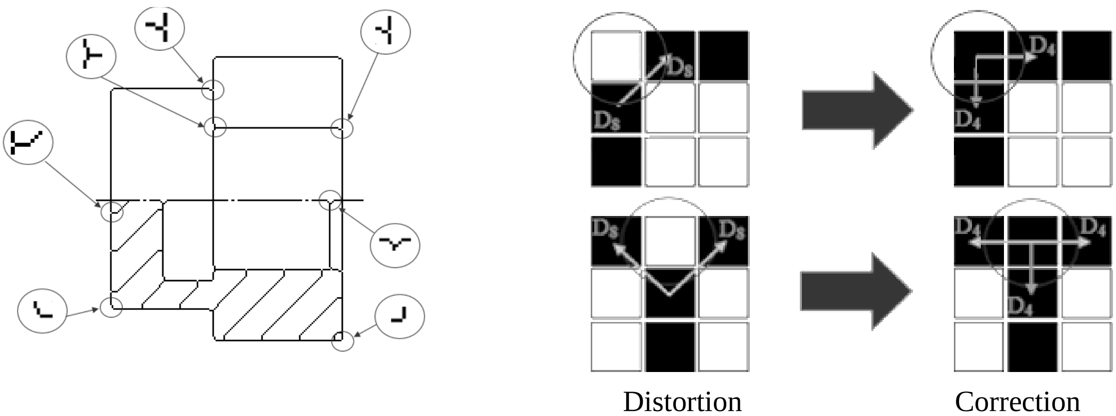


Fig.5. The method of correcting of skeleton's distortions in the points of intersection of the primitives

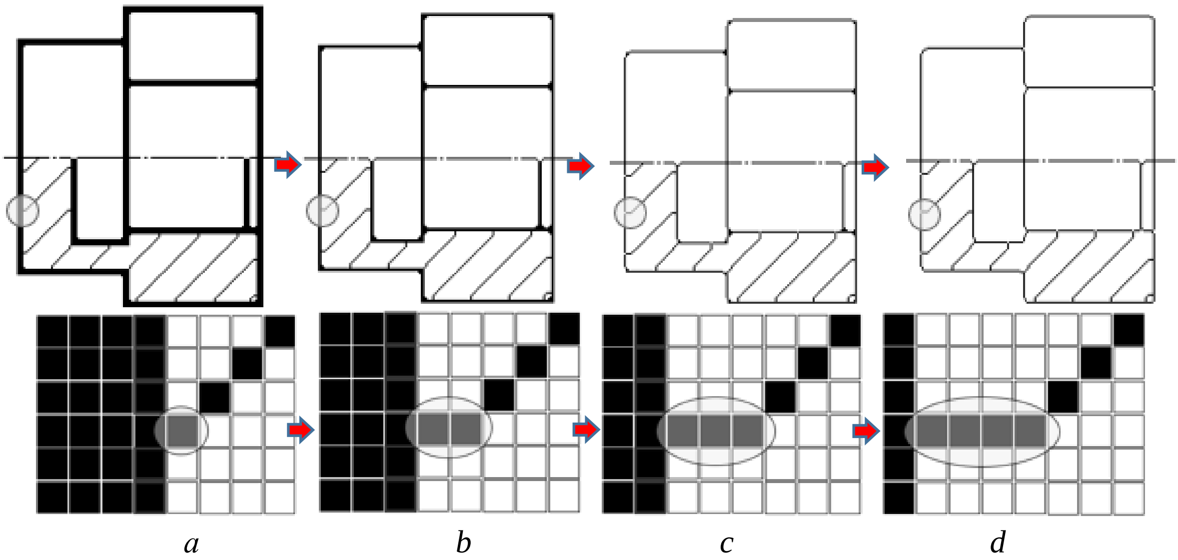


Fig.6. The result of iteration thinning of coupling of the thin and thick primitives of the shape

Elimination of these drawbacks requires regeneration of the resulting skeleton by correction of the artifacts, distorting its topology. Restoring extractors $\{\tilde{Z}\}_{(0)-(18)}^{(\angle 0^\circ-\angle 270^\circ)}$ 5 x[5 in size (Table 3) were developed for this, with possibility of turning by angles 90°, 180°, 270°, and a possibility of their balancing with regard to ordinate axis. $\{\tilde{Z}\}_{(0)-(9)}^{(\angle 0^\circ-\angle 270^\circ)}$ extractors are applied for skeletons at the end of each iteration and after completion of the shape's thinning extractors $\{\tilde{Z}\}_{(10)-(18)}^{(\angle 0^\circ-\angle 270^\circ)}$ are applied just once.

In the Table 3 the following designations are assumed:

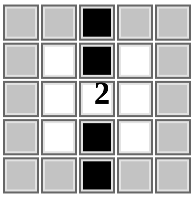
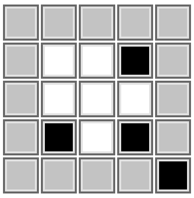
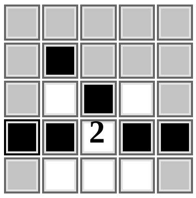
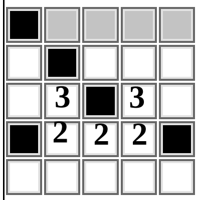
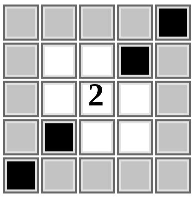
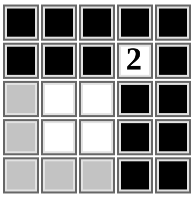
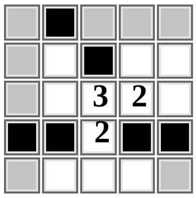
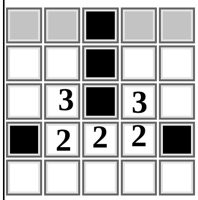
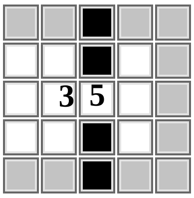
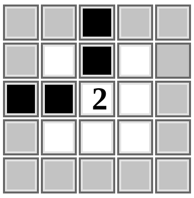
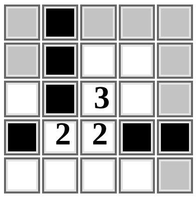
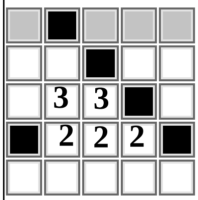
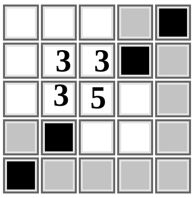
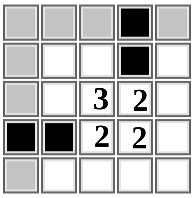
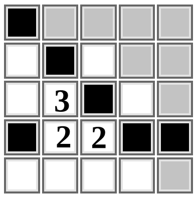
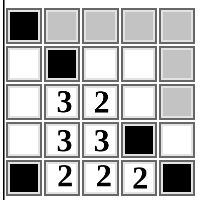
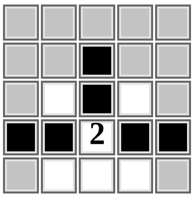
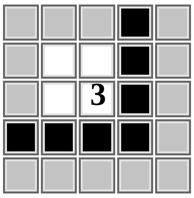
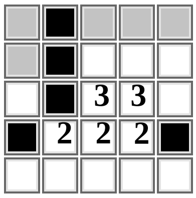
The following main principles were observed or development of $\{\tilde{Z}\}_{(0)-(18)}^{(\angle 0^\circ-\angle 270^\circ)}$ extractors:

- the extractors embrace all possible variants of distortions of the skeleton by the basic method and are classified, according to the groups of distortions as;
- $\{\tilde{Z}\}_{(0)-(1)}$ extractors, correcting points omissions, the extractors of this group are corrected filling the isolated points of the background with shape's points;
- $\{\tilde{Z}\}_{(2)-(3)}$ extractors, for corrections of the lines bends, the extractors of this group

□	the background
▒	the shape
■	makes no difference whether shape or background

2	the background, it becomes a shape in case of coincidence with the extractor
3	the shape, but it becomes a background in case of coincidence with the extractor
4	makes no difference whether shape or background, however it becomes background in case of coincidence with the extractor
5	makes no difference whether shape or background, however it becomes background in case of coincidence with the extractor

Table 3. Restoring extractors

Index	Extractor	Index	Extractor	Index	Extractor	Index	Extractor
0		5		10		15	
1		6		11		16	
2		7		12		17	
3		8		13		18	
4		9		14		–	–

straighten distortions of angular type, appearing due to the peculiarities of the primitives of the shape with half-tones, in accordance with Brazenham's algorithms.

○ $\{\tilde{Z}\}_{(4)-(5)}$ extractors for correction of distortions of primitives intersections, isolated background points of intersections of vertical, horizontal and diagonal primitives are filled with shape's points;

○ $\{\tilde{Z}\}_{(6)-(9)}$ extractors for correction of angles distortions, extractors belonging to this group eliminate thickenings of concave angles and regenerate cuttings off of vortexes of convex angles of the shape's skeleton;

○ $\{\tilde{Z}\}_{(10)-(18)}$ extractors for correction of stepwise distortions, emerging, due to application of asymmetric thinning extractors of the basic skeletonization method;

○ extractors' configuration must not infringe the local regularities of topology of the shape and the skeleton, for examples, extractors 14 and 15, describing similar stepwise skeleton's distortions produce various structural corrected fragments of the skeleton (Fig.7), corresponding to topological orientation of the primitives in the images' aperture;

○ the zone of points (with codes 2…5), of the aperture 5 × 5, changed by the extractor must be surrounded with neighboring background points, or with unchanged shape's points, it allowing to avoid violations of skeleton's coherence at its modification with extractors.

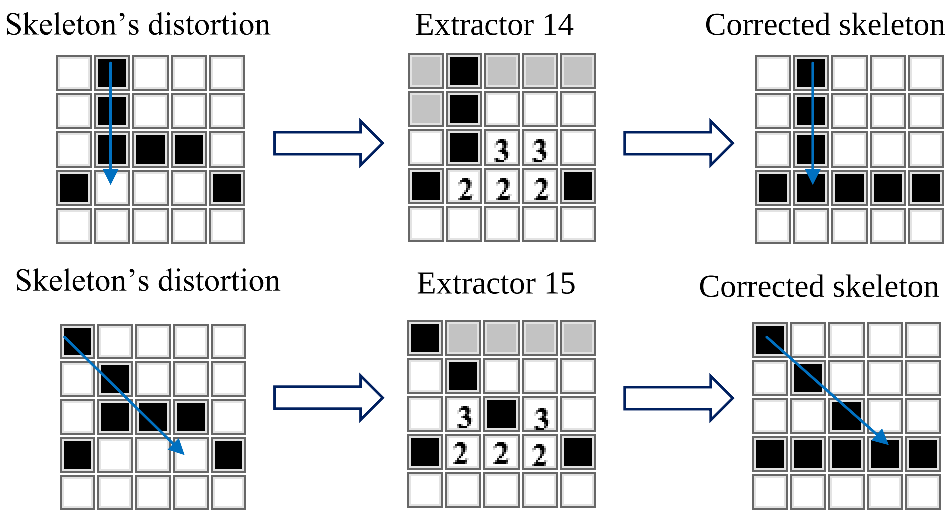


Fig.7. An example of dependence of skeleton's topology upon extractor's configuration

An example of shape's skeletonization of a part of a "Nut" type (Fig.9, *a*) is shown in Fig.8 and 9 with performed according to the basic method, with heavy distortion of the skeleton (Fig.9, *b*) and with application of the improved method, where these distortions have been removed (Fig.9, *c*).

CONCLUSIONS AND RECOMMENDATIONS

Improvement of structural distortions of skeletons is reached by applying of the developed method, the complex of method, consisting of:

- the method of correction of distortions of the topology of skeleton's right angles, based upon application of the "chess" metric, instead of "Manhattan" metric and extractors of recognition of shape's angles;
- the method of correction of violations of the skeleton's coherence, based upon application of the developed correcting extractor;
- the method of correction of violations of topology in the points of intersection of geometrical primitives, based upon application the developed regenerating extractors.

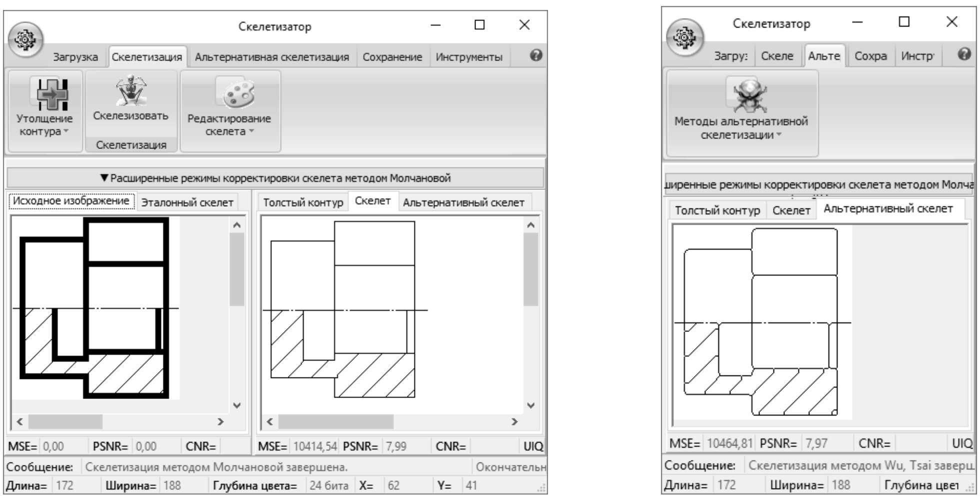


Fig.8. The result of correction of skeleton's topology

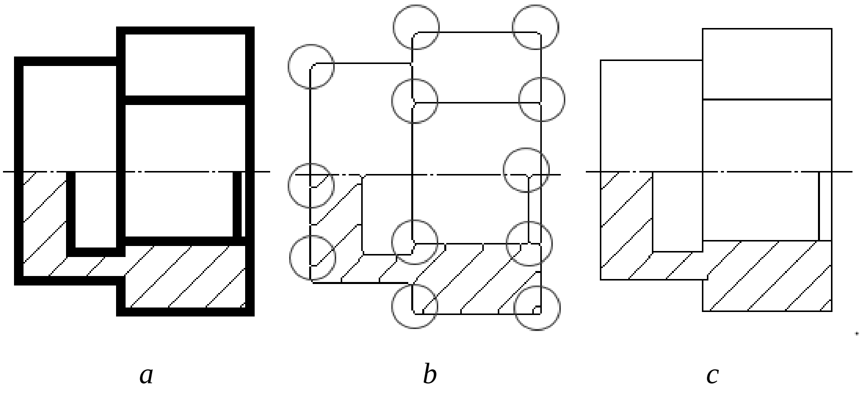


Fig.9. The result of correction of skeleton's topology: *a* – part's reducible shape; *b* – the skeleton, obtained by application of the basic method, *c*– the skeleton, obtained by the improved method

A substantial reduction in skeleton's distortions is reached by two-staged correction of the skeleton of the part's shape:

- at the first shape during iterative thinning of the part's shape iterative distortions of the skeleton are corrected;

- at the second stage, after the entire skeleton has been formed, reconstruction of distorted zones of intersections of geometrical primitives of the skeleton is done.

The skeleton of shapes of sea transport parts confirmed a substantial improvement of the quality of the produced skeletons with preservation of their topological similarity to the original shapes in the number of geometrical primitives, their shapes and coherence.

The proposed methods of iterative topological skeletonization of drawings of sea transport parts can be used for skeletonization of diagrams of road junctions, engineering drawings, functions graphs and the like.

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Методика гомотопной скелетизации растровых чертежей деталей морского транспорта

Вера Молчанова

Аннотация. Решение задачи распознавания и векторизации чертежей деталей морского транспорта требует формирования скелетных изображений, топологически эквивалентных по формам геометрических примитивов и их связности контурам деталей.

Автором выполнен сравнительный анализ лучших методов параллельной топологической скелетизации площадных объектов, основанных на применении пространственных масок. Анализ показал, что в рассматриваемой предметной области существующие методы имеют типовые недостатки, выражающиеся в итеративных искажениях топологии примитивов и их композиций.

Цель статьи – освещение разработанной методики улучшения топологической эквивалентности результирующих скелетов контурам деталей морского транспорта за счёт поэтапной коррекции типичных искажений скелетов. Разработанная методика предполагает корректировку итеративных искажений скелета модифицированными масками базового метода скелетизации и реконструкцию результирующего скелета масками восстановления гомотопности скелета на основе разработанных правил его реконструкции. Реализация предложенного метода выполнена на примере базового метода Wu R.Y. & Tsai W.H. Показаны примеры результатов скелетизации чертежей деталей, подтверждающие эффективность предложенной методики. Методика может быть адаптирована к методам топологической скелетизации площадных объектов, основанных на использовании пространственных масок.

Ключевые слова: рисунок, форма, скелет, экстрактор, когерентность преобразований, гомотопный характер.