Grzegorz Lenda*

Algorithms for Automatic Surface Scanning of any Given Shape for Reflectorless Robotized Tacheometers

1. Introduction

The laser scanning technique has today become one of the standard survey methods that enable precise determination of the shape of a surface area. Specialized laser scanners that can make observations at a high speed and with accuracy comparable to that of reflectorless tacheometers are indispensable for surveying. In the last years, also the range of these instruments has grown so that they can be used for measurement of any engineering structure. The biggest obstacle for this technology to spread is still the price for a single instrument. This results in the need to order works from a company owning such equipment or to hire it for a payment. At the same time, many surveying companies have their own non--mirror robotized tacheometers that can be used as scanning devices. On average, the instruments enable surveying at a speed of ca. 1 point per a few seconds. The most advanced structures, the so called scanning tacheometers can survey up to ca. 20 points per second but their prices, also are too high to make them more accessible. Classic robotized tacheometers can be used for gathering collections of several to between ten and twenty thousand points as it is real to reach such numbers within a surveying day. Scanning with tacheometers seems appropriate in the case of a greater distance from the structure, its greater size or of problems with reflection of the beam of radiation related to the colour, structure or physical properties of the target. As the range of reflectorless stadias is usually twice or three times greater than that of laser scanners coming from the same production period. Practically, all robotized reflectorless instruments have their own algorithms for surface scanning. There is rich software that can be used with scanning

* Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, Krakow

tacheometers. It can, to a wide extent, decide on the range of the area surveyed. However, the most commonly used classic tacheometers are based on methods which are not effective enough and make it impossible for the surveyors to measure more complex or irregular structures.

This article contains proposals for several scanning algorithms for classic robotized tacheometers. They enable fully independent automatic measurement of structures with little complexity of the outlines, or pre-defined automatic measurement of structures with any degree of complexity. Considering the low scanning speed of classic tacheometers, the methods limit the number of unnecessary observations located outside the right structure.

2. Review of Selected Current Methods of Surface Scanning for Robotized Tacheometers

The most commonly used laser scanning method implemented in the majority of robotized tacheometers is, at the same time, the simplest one. Its principle of operation is explained in figure 1. The observer sets a rectangular horizontal area of observation by registration its opposite corners *P* and *K*, and then he sets the horizontal and the vertical intervals for the measuring net (*H* and *V*). This allows on registration points that belongs only to the given structure in the case when the set scanning area includes other elements (e.g. window recesses). The survey is taken at subsequent junctions of grid from the starting point *P* to the end point *K*, according to the direction denoted with arrows. According to the chosen distance *d*, the points denoted with dots will be rejected.

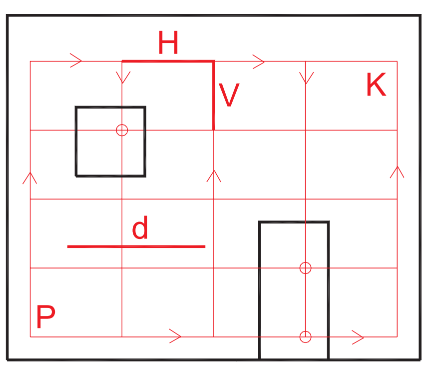

Fig. 1. Standard algorithm for surface scanning

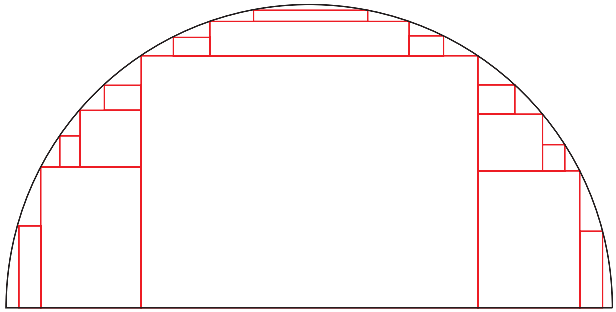

Fig. 2. Repeated use of the rectangular measuring window for spherical surface scanning

The setting of a rectangular area of observation is a considerable limitation that makes it impossible to directly measure many structures, in particular those with nonlinear rounded outlines. Such surface can be scanned only by dividing it repeatedly in rectangular measuring windows (Fig. 2), within which standard scanning from figure 1 will be carried out. Such a process is onerous and time--consuming, all the more so because, for structures with uniform textures and colour schemes it is difficult to remember which areas have been already scanned.

The most advanced scanning methods are implemented in modern scanning phototacheometers (e.g. Topcon IS). The instrument takes a picture of the structure, and the observer's role is contouring the measurement on the instrument touch screen. Next, similarly as with the method described above, scanning is performed at the junctions of the evenly fixed grid with a range limited to the contours (Fig. 3). In this way, it is possible to survey a surface with any given degree of complexity. Despite of the simplicity and high effectiveness of this method, scanning phototacheometers are high-end products, which, at the presents, makes them inaccessible to a wide range of users.

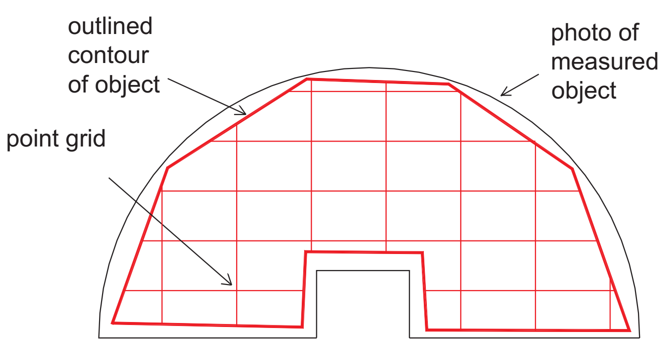

Fig. 3. Surface area measurement with the use of a scanning phototacheometer

3. Concepts of Algorithms for Surface Scanning for Classic Robotized Tacheometers

3.1. Pre-Assisted Scanning of a Surface with any Given Contours

The algorithm for scanning of a surface with any degree of complexity of the contours will be presented as the first. It requires to be initially operated by the user so that the range of observation is specified. The most important task is to measure the selected characteristic external contour points of a structure. They are to be measured according to their order along the contour line, and with the same order they will be then connected so that they make up an external circuit of the area scanned. The structure can have also internal areas, the measurement of which is undesirable. They are to be bordered one by one, with the use of the same method as for the external contour.

The points can be connected in three different ways (Fig. 4). With the first and the simplest one the points are connected directly at the shortest distances (chords) – Fig. 4a. As a result, a part of the structure areas will be left outside the range of observation, and in some other places there will be an extra area of observation, depending on the borderline geometry of the structure. This method is appropriate for establishing the limits of linear structures. Measurement of contour lines with points set thicker will limit this unfavourable effect.

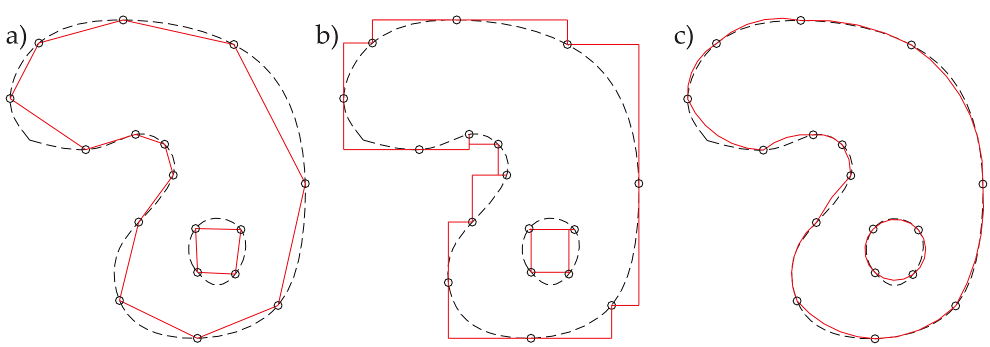

Fig. 4. Establishment of survey contours for pre-assisted surface scanning: a) contours established along the sections between the points; b) contours determined by connection of the legs; c) contours determined by connection of circular arcs (the structure is marked with a dotted line)

With the safe method to connect contour points, a distance between two subsequent points are considered to be as the hypotenuse of a triangle with legs parallel to the coordinate axis (Fig. 4b). The connection of all legs for subsequent pairs of points will result in a polygon, the area of which will be scanned. For the external contour line, legs outside the scanning area are selected, and for internal lines, those inside the area. With this method, scanning limits are made with some extra space which prevents from the risk to lose some observations. The flaws of this method become apparent if outside the scanning area there are no other structures, off which the beam of radiation could reflect. In such a case, the instruments are emitting a beam for a longer time, which also results in increased power consumption. This flaw will appear also with the previously described method but on a considerably lesser extent because excess observations are there usually rarer then the depleteed ones. In this case, too, the "thicker" measurement of contour lines will limit this unfavourable effect.

A compromise solution for the establishment of the limits of curvilinear structures is to replace the chord or the complex of legs with an indirect element, that is an arc. A good choice of arcs will reduce both the number of depleted points, characteristic of the first method, and the number of excess points appearing with the second method. Limiting the measuring range with a spline is optimal. Mathematical aspects of determination of spline functions can be found in [1, 2]. Such a method should be recommended for newer instruments, fitted with faster processors and larger operating memory. In case of contour lines made up of numerous points, older instruments can have problems with solving big sets of linear equations, characteristic of determination of splines.

The contour points can be connected, with a good approximation, with the use of circular arcs instead of spline functions (Fig. 4c). The arcs are led through the subsequent threes of points so that they get the right geometry, and then they are used to connect the first two points of a given three. They are lap-formed, that is, the arc outlined based on points i, $i+1$, $i+2$ connecting points i, $i+1$ is followed by an arch outlined based on points $i+1$, $i+2$, $i+3$ connecting points $i+1$, $i+2$. This method is not complex in computational terms, and for nonlinear objects, it enables reaching a sensible compromise between the methods described above.

Depending on the structure geometry, the measurement time and the desired measuring area, each of the presented methods can demonstrate its advantage over the other ones. At the same time, due to the simplicity of the algorithms, it seems sensible to implement them in one program and to give the user an opportunity to make the right choice.

After the establishment of the scanning limits, a regular grid of points measured one by one in rows and columns (Fig. 5a) is put on the structure. The measurement can begin, for example, with the left side of the top row. The beginnings of subsequent rows can be dragged up to the contour line, which is practiced with some of the existent scanning algorithms (Fig. 5b). However, such a procedure worsens the regularity of the distribution of points, which will be unfavourable if the structure shape is approximated with the use of spline functions. It will be much better to leave the regular grid and to add points at the beginning and the end of each row and column resulting from their intersection with the contour line (Fig. 5c). This will, of course, result in irregularities at the edges of the considered area. But it is not as unfavourable as the irregularity over the whole area is. In addition, the boundary points can always be rejected in case of necessity.

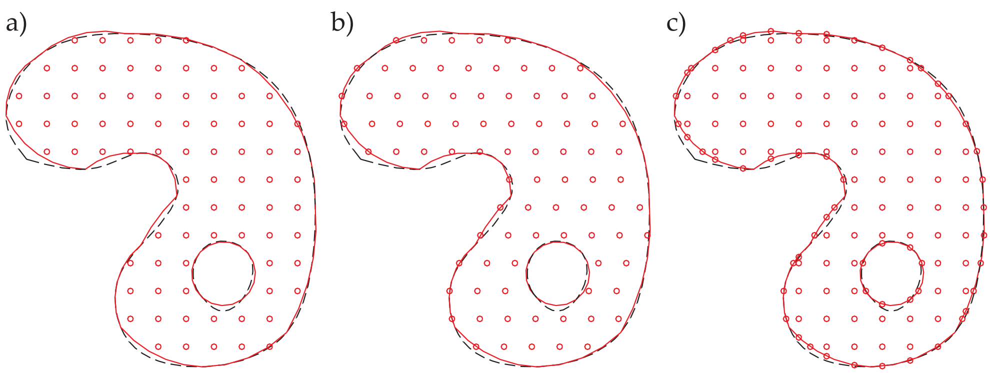

Fig. 5. Establishment of a scanning grid within the limits of the contour line: a) uniform scanning grid; b) scanning grid dragged up to the left edge of the contour line; c) uniform scanning grid with additional points on the limits of the contour line

For measurement of the majority of structures it seems natural to establish a regular vertical grid of points, which is a commonly applied solution. However, projected on a spatial structure, such a grid can bring a quite irregular distribution of the points, which can make the analysis of the results more difficult. The proposals of methods for uniform distribution of observations on the surface area will be described in the next study. It should be noted here that in the case where the scanning is done to horizontal surfaces, the use of a vertical grid will not make it possible to measure them. Observation of elements with slight inclination will be more difficult, too, because very short distances between the vertical grid rows are to be set in order to sensibly cover these elements. So, each algorithm for surface scanning should give the user a possibility to select also horizontal grids of points, created on the very same basis as the one described above.

The block scheme of algorithm of pre-assisted scanning of a surface with any given contours is shown at figure 6.

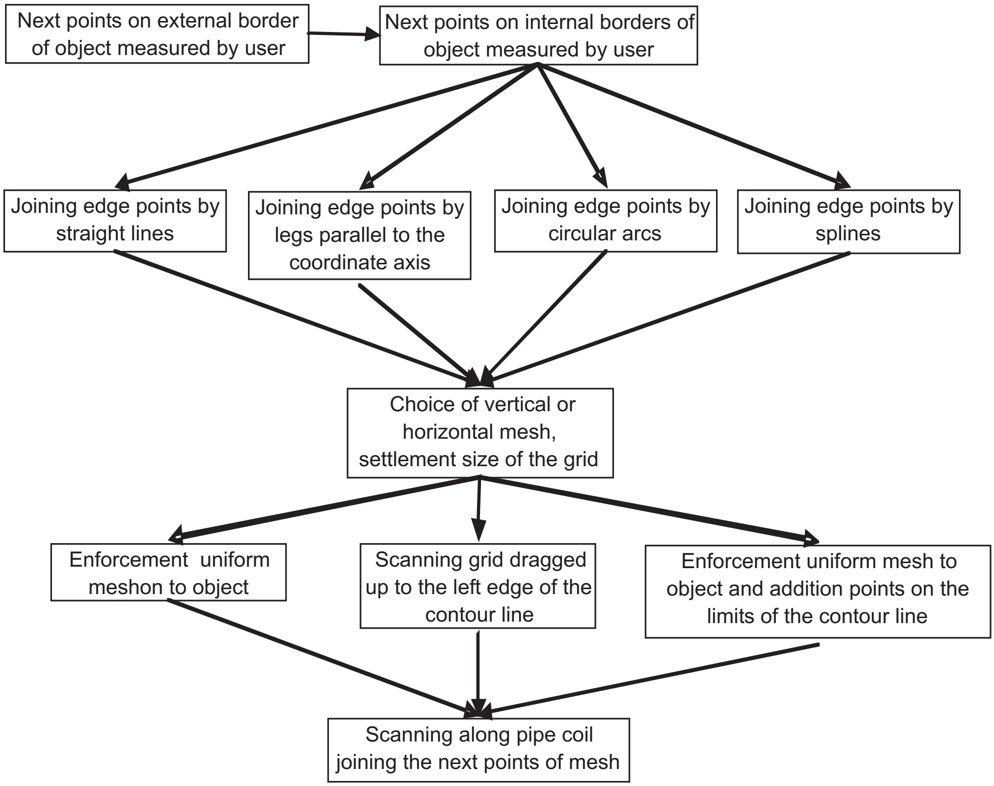

Fig. 6. Block scheme of algorithm of pre-assisted scanning of a surface with any given contours

3.2. Automatic Scanning of Surfaces with Uncomplicated Contours

Algorithm (I) of the fully automatic scanning of structures with little complexity of the contour line is presented in figure 7. The user has a task to make two observations on the surface: near the centre and on the point most distant from the centre. They will establish the maximum distance *d* that will be used for rejection of the points outside the structure. The instrument starts the measurement at the central point and continues it over the junctions along the rows and columns of a rectangular volute. The vertical and horizontal spacing for the junctions is predefined by the user. At the moment when the instrument points at a target outside the limits of the structure, the background will be measured and then the *d* distance will be exceeded. If there is no background, the measurement will not take place. In both the cases the instrument will abandon further observations at the direction of the line perpendicular to the current row/column of the volute at a given point.

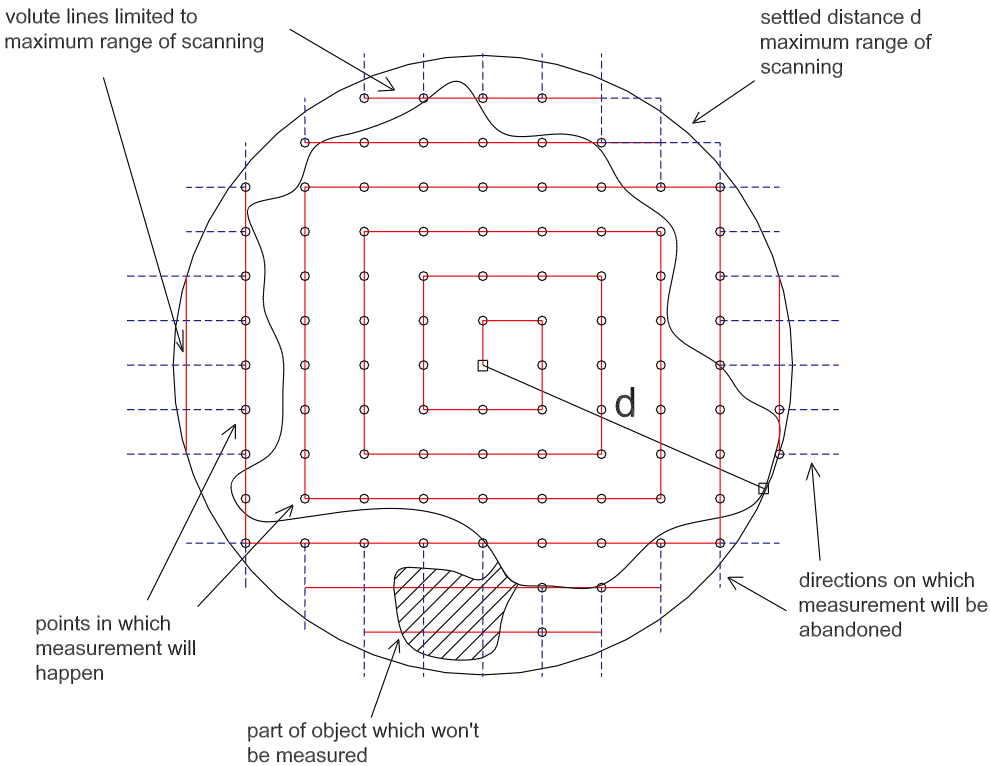

Fig. 7. Algorithm (I) for automatic surface scanning

The additional parts in the figure are hatched. It is visible that, with the use of the method described they would not be measured. So, the algorithm is well fit for measurement of structures with not very complicated contours like spheres, cylinders, ellipsoids and other, best convex surfaces (Fig. 8a). Its greatest merits are the operation speed (the algorithm stops measuring at a given direction immediately after detecting the edge of a structure) and the maximum reduction of the participation of the user who is to measure two points only. If some background elements appear so close to the measured structure that the distance between them and the central point of the volute is shorter than the set *d*, the instrument will include these elements in the measuring process. Since the structure is always related to the area in a way, a part of the background (area) elements will me measured before the *d* distance conditions starts working. In an extreme case, if the contour line was only a symbolic boundary of two parts with the same surface area, it would not be detected and the round area with a radius of *d*, located around the central point would be subject to measurement. In such a case it is better to use the previously described, pre-assisted method.

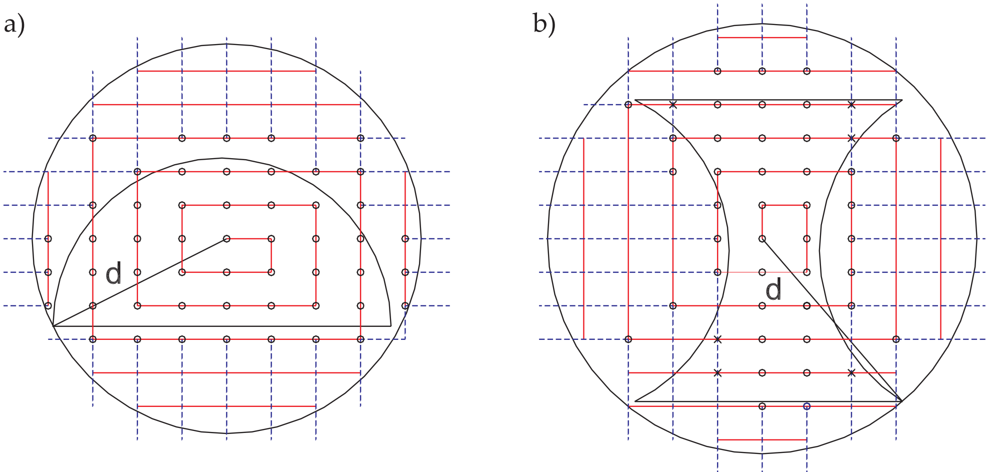

Fig. 8. Correct scanning of convex surface (a). Scanning of concave surface. The crosses stands for the places in the area where observations were lost (b)

The block scheme of algorithm (I) of automatic scanning of surfaces with uncomplicated contours is shown at figure 9.

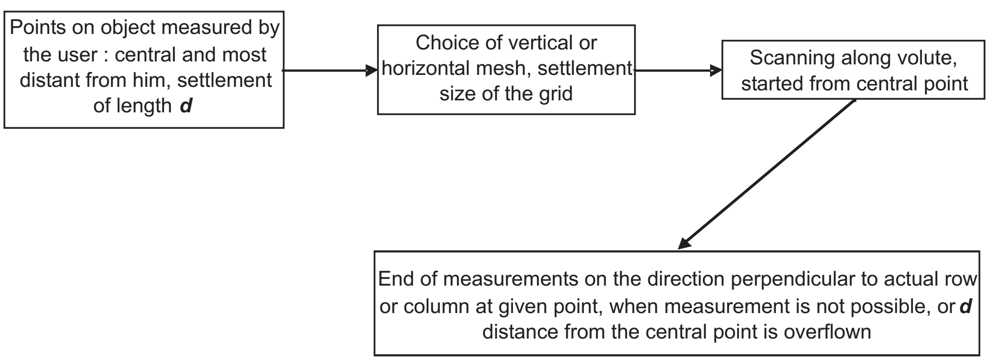

Fig. 9. Block scheme of algorithm (I) of automatic scanning of surfaces with uncomplicated contours

Figure 10 presents an alternative algorithm (II). It enables measurement of more sophisticated (particularly concave) contours than the algorithm presented above. On the same basis, it runs the risk of not identifying the edges of a structure (for background elements close to the surface). The first step for this algorithm is identical to that described above. The observer measures one point on the surface near its centre another one most distant to that. As with the previous algorithm, the points will establish the maximum distance *d* that will be used for rejection of the points outside the structure.

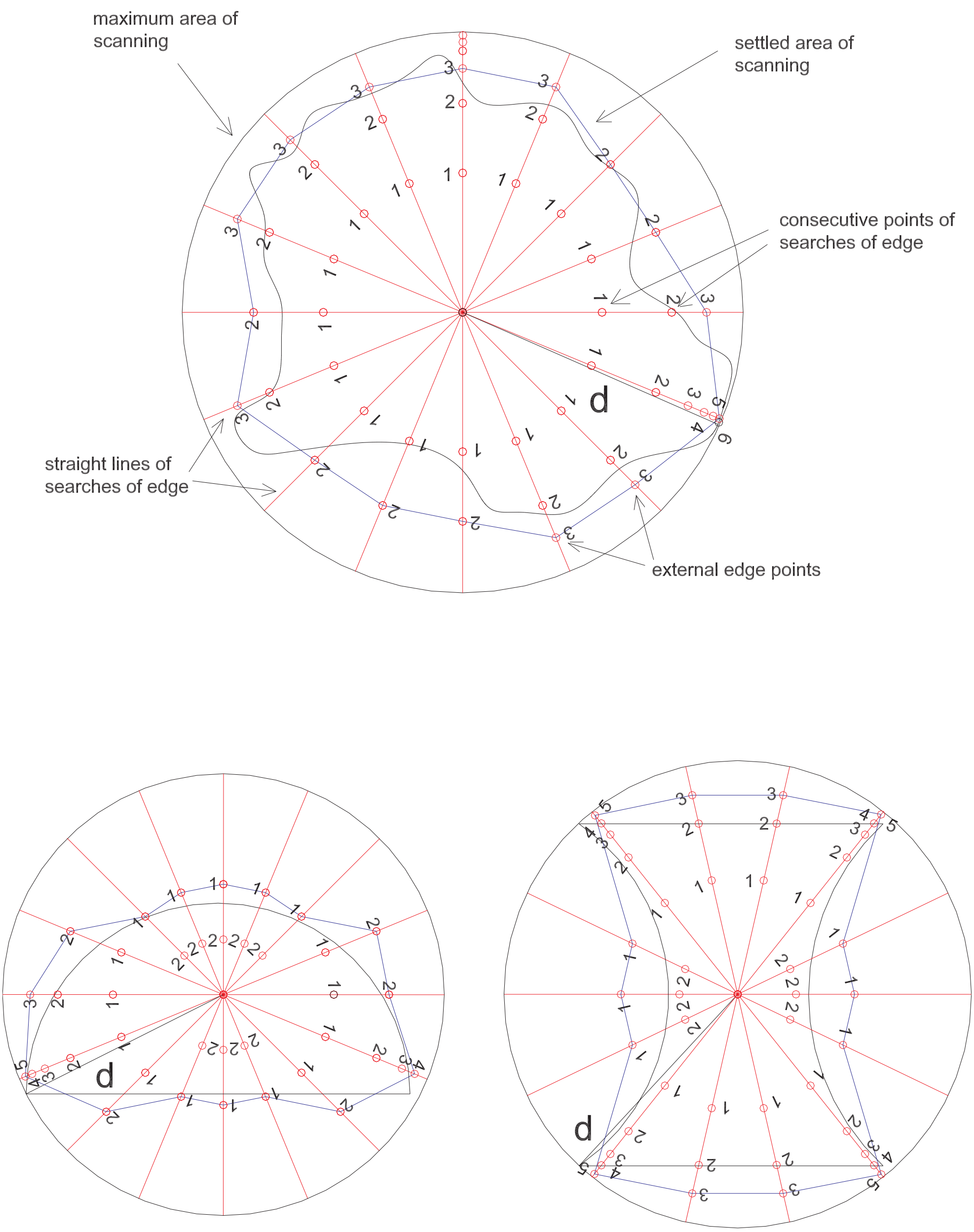

Fig. 10. Algorithm (II) for automatic surface scanning.
Contours established along the sections between external points.
The numbers refer to subsequent points set at the search for the contour

Next, the inbuilt computer constructs uniformly distributed straight lines radiating from the central point. External edges of the structure will be then searched for at the directions determined by the lines. The number of straight lines is defined by the user. The higher the number, the more precisely will the contour of the structure be outlined but the algorithm runtime will be longer. Along each straight line, at distance $d/2$ from the central point, a point is measured. If the measurement is not possible (there is no background) or the obtained distance from the central points exceeds d (measurement up to the background elements), the algorithm will recognize that the point is outside the structure. The subsequent point will be measured at the middle of the $d/2$ distance, at the same direction. If this one, too, is not identified as a point outside the structure, the next measurement will be performed in the middle of the previous distance from the central point, and so forth until a point on the right structure is identified. If the measurement of the first point at the set direction at the distance of $d/2$ is identified as an observation on the structure, the algorithm will perform other measurement, lengthening the previous distance by half. Subsequent measurements will be taken at distances lengthened by smaller and smaller division of the $d/2$ distance, until a point outside the structure is identified.

A simpler method can also be proposed. Observations of the points along the straight lines will be made from the central point every interval set by the user until external edges of the structure is identified. This will allow to identify the limits of the structure more accurately, but at the expense of a longer measuring time.

As a result, the instrument will determine two groups of points: the extreme points of the structure and the points situated directly behind them, outside the structure. The scanning area limits can be outlined based on one of these groups. The connection of the points on the structure will shorten the measuring time but it will form limits cutting away a part of the structure area. Connection of external points will bring opposite results. The connection of points can be made in one of the ways described in paragraph 3.1.

The algorithm discussed here is dedicated to determine the external limits of a structure without possibility to exclude potential internal areas which are not belong to surface. After the establishment of the scanning area, a grid of points measured one by one in rows and columns as in paragraph 3.1 is put on the structure.

The block scheme of algorithm (II) of automatic scanning of surfaces with uncomplicated contours is shown at figure 11.

Both the algorithms described cannot offer so many possibilities to select scanning areas as the pre-assisted method, yet they require only little operation by the user.

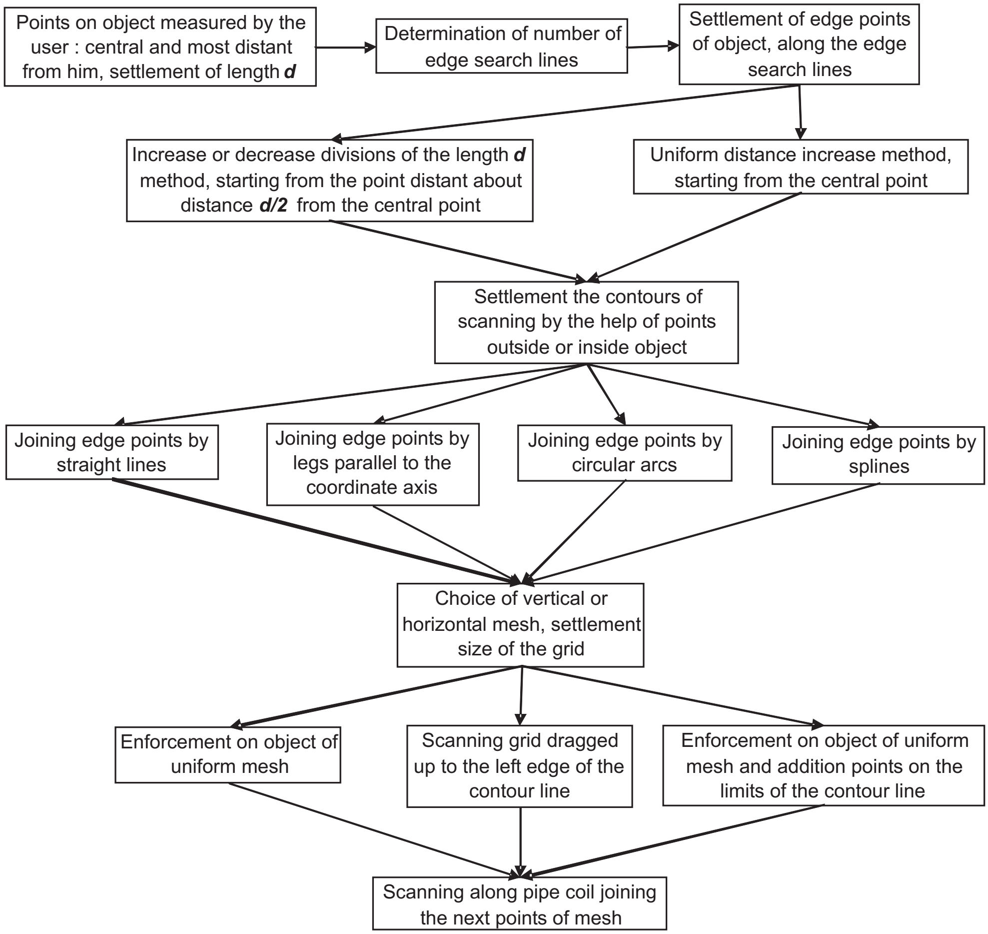

Fig. 11. Block scheme of algorithm (II) of automatic scanning of surfaces with uncomplicated contours

4. Summary

All the algorithms presented have been programmed by the author on a PC with the purpose to check their effectiveness. Tests made on representative structures have proved the effectiveness of the algorithms, so they can be adapted for any robotized reflectorless tacheometer. The right algorithm can be chosen depending on the degree of complexity of the structure contour, the required participation of the user, the measuring time and the power consumption.

References

[1] Lenda G.: *Zastosowanie funkcji sklejanych w zautomatyzowanym procesie geodezyjnej kontroli kształtu powierzchni obiektów budowlanych*. Rozprawa doktorska, AGH, Kraków 2005 (Ph. D. thesis).

[2] Lenda G.: *Metody tworzenia i modyfikacji funkcji sklejanych dla potrzeb opisu kształtu obiektów obserwowanych punktowo*. Geodezja (semiannual of AGH), t. 12, z. 2, 2006

[3] Advertising Materials of Companies: Leica, Topcon, Trimble [Materiały reklamowe dotyczące bezzwierciadlanych tachimetrów zrobotyzowanych firm Leica, Topcon, Trimble]. 2008.