Discrete geometric models in problems of automated assembling of objects

L V Markin

Department of Engineering Graphics, Moscow Aviation Institute (National Research University), 4, Volokolamskoe Highway, Moscow 125993, Russia

E-mail: markinl@list.ru

Abstract. The possibilities of geometric modeling of allocation problems, using discrete (receptor) geometric models are shown within the framework of design automation. Their features and examples of practical use in determining the embeddability of placed objects and trace tasks are described. The examples of implementation of the developed algorithms, using the algorithmic language C # and a specially created graphical shell for visualizing design results are shown. The numerical estimation of accuracy and productivity of the developed algorithms shows the possibility of their implementation even on the modern computers of medium power. This allows us to hope for the integration of the developed layout algorithms into modern systems of solid-state geometric modeling in the form of plug-in modules.

1. Introduction

When automating the design of any equipment and building structures, it is necessary to solve the problems of placement (layout). The first publications devoted to the automation of the solution of the problems of placement date back to the 60s of the last century [1-3]. However, the transition from 2D objects to 3D objects and the complication of the form of the placed objects from linear strips to real objects of modern technology caused an avalanche-like complication of the mathematical description of the placement process. Additional difficulties were caused by:

- the need to operate with geometric information, the computer representation of which is a separate, difficult task;
- nonobviousness of the algorithm for solving the optimal allocation problem. The computer does not possess the associative thinking of a person and needs other mechanisms of thinking, which must be transferred to it by a person through special Automatic Data Processing Equipment and Software.

The problem of computer representation of geometric images can now be considered to be sufficiently solved [4-8]. However, other requirements are imposed on models of automated layout, of which the accuracy of the form description is far from the main thing. We have to choose which is better - an exact geometric model, the automatic layout of which is impossible, or a rough geometric model that allows the automatic layout.

Great opportunities in automated design are provided by modern CAD-systems, allowing their means to identify cases of mutual intersection of already assembled objects in the created virtual layout. But in this case it is only a matter of checking the version of the layout already generated taking into account the experience and intuition of the project.

This article discusses the principles of creating and the possibility of automated layout methods based on the use of discretization methods for layout space (receptor geometric models).

2. The receptor method of geometric modeling in problems of automated layout

The receptor method (in the English-language literature known as "voxel") is based on an approximate representation of a geometric object in the form of a receptor space. For a plane case, the receptor field is a homogeneous rectangular $m \times n$ network, each cell of which is considered as a separate receptor, which can have two states - "0" or "1". A mathematically receptor geometric model is described by a set $A=\{a_{i,j}\}$, where $a_{i,j} = \begin{cases} 1, & \textit{if the receptor is disturbed}, \\ 0, & \textit{if the receptor is not disturbed} \end{cases}$

The receptor is considered undisturbed if the boundary of the object does not pass through it and it does not belong to the inner region (Figure 1).

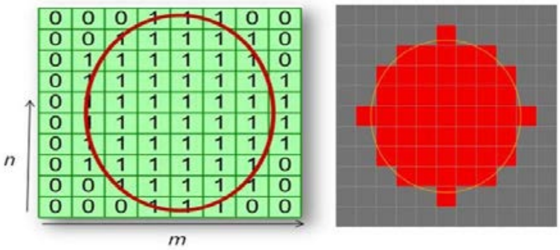

Figure 1. Receptor model of a 2D-object.

Three-dimensional objects are described by a three-dimensional matrix $A=\{a_{i,j,k}\}$ of dimension $m{\times}n{\times}p$ (Figure 2).

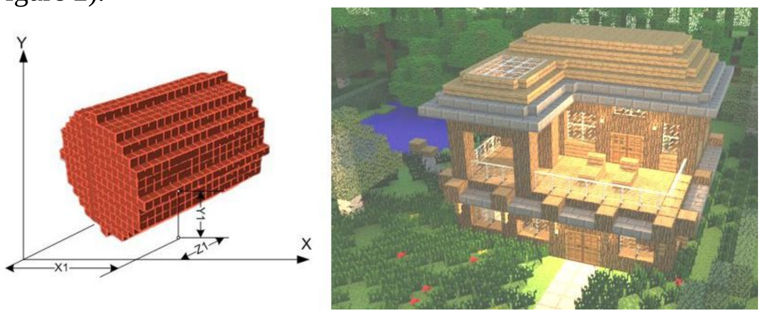

Figure 2. Receptor model of a 3D-object.

Thus, the layout space is divided into separate areas in the form of cubes or parallelepipeds (receptors), for each of which a value of "0" is assigned to the computer's memory if it is free of placed objects and is accessible for placement and "1 "- if the area is already occupied by the placed object or communication to it. This method, by comparing the values of the receptors, makes it easy to determine the intersection of objects. Obviously, the accuracy of describing the geometric shape of an object depends on the discrete nature of the receptor matrix that we have chosen.

Receptor models were proposed in the early 70s of the last century by the Belarusian scientist Zozulevich D.M. [9,10], but in those years they did not spread from the limited capabilities of computers from memory and speed. Today, in connection with the development of the productivity of computers, they have found their practical application [11-12].

The obvious drawbacks include the discreteness of the model and the need for large amounts of computer memory for its implementation, but now the increase in memory to any volume is not difficult either technical or economic. Another difficulty is that the receptor geometric model is never the original one. Placing and already placed objects are described by the designer, as a rule, by parametric geometric models (that is, giving the form of the object and its parameters - a sphere of radius R, parallelepiped with dimensions $a{\times}b{\times}c$ etc.). Therefore, there is a need for an additional program module "Parametric Model" ↔ "Receptor Model". Thus, the receptor model can be considered as "intramachine".

Although primitives do not exhaust all the richness of the forms of the assembled objects, but according to the literary data [13], the shape of 98% of the assembled instrumentation can be described as a primitive or composition of primitives.

3. The definition of embeddability of a geometric object among previously placed

In the practice of designing, the problem of analyzing the geometric shape of unfilled spaces is often encountered among already placed elements (the "precompact" task).

For a person such a task of "precomponencing" objects will seem quite easy - a person can easily "determine by eye" how several quantities correspond to each other and which object fits into another, and which does not. To do this, he mentally classifies the object in form (almost a sphere, almost a cylinder), and then mentally relates their dimensions. Unfortunately, this operation, so simple for a person, is very difficult even for modern computers.

The advantage of the receptor geometric model is the ability to detect unfilled spaces in the layout for the subsequent placement of objects that have not been placed in them yet. If there is an unfilled space among the aligned objects, then on the corresponding section of the receptor matrix it is relatively easy to identify as "clots" of zero receptors. For this purpose, an algorithm was developed that makes it possible to determine the center of a certain free area (flat) and its dimensions.

Next, scanning lines and columns to identify the largest concentration of inextricably located receptors and identify their centers. For analyzing an individual section of an object we use the transition from the geometric form of the object (in the form of a discrete set of receptors) to the "feature space" adopted in the theory of pattern recognition. the hodograph of the radius vector function from the center of the section (Figure 3) will be such a space of features for us:

$$F = R_i(j_i)$$

where R_i- the current length of the radius vector for i receptor, φ_i- the current length of the radius vector for i receptor.

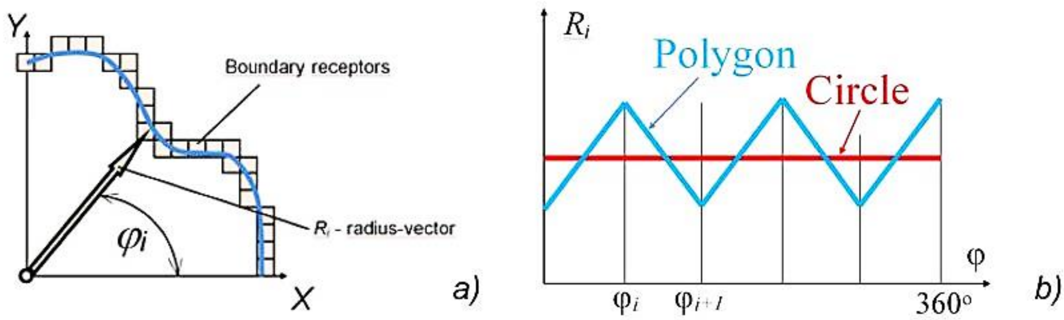

Figure 3. Construction of the hodograph of the radius-vector function (*a*) and analysis of the unfilled space (case - polygon-*b*).

After the construction of the function R_i (φ_i) its analysis begins. If the shape of this space was a circle, then the function would be an ideal straight line, the height of which would show us the radius of this circle (Figure 3*b*), if the regular polygon is a "saw" with the number of vertices equal to the number of sides. The coordinates of the vertices by φ will allow us to determine the aspect ratios of the rectangle. To do this, we use a well-known test of statistical hypotheses, implemented as a calculation program module.

The real results of the analysis of the hodograph function are naturally superimposed "noise" caused by the discreteness of the description of the assembled objects. An example of such real-time hodographs of a flat section of composite objects, statistically identified as slices of a "polygon", "cylinder", and "sphere" are shown in Figure 4 *a*, *b* and *c* respectively.

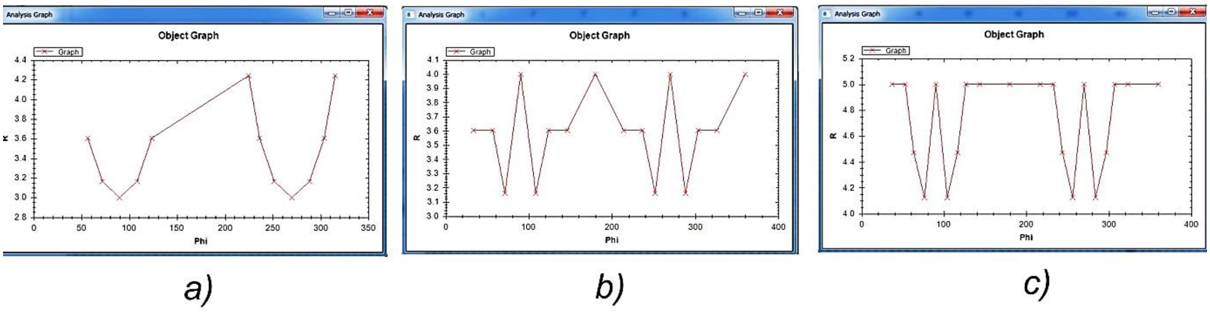

Figure 4. View of the hodograph of the slice function R of φ for the polygon (*a*), the sphere (*b*), and the cylinder (*c*).

An illustration of the software implementation of this method is shown in Figure 5 [14]. The results obtained are implemented within a graphical shell written in C #. If we don't want to place in this area a parallelepiped of the maximum size, but, for example, a sphere of a certain radius, it becomes after that a full-right participant of the scene and after pressing the "Analysis" button a new definition of the configuration of unfilled spaces occurs.

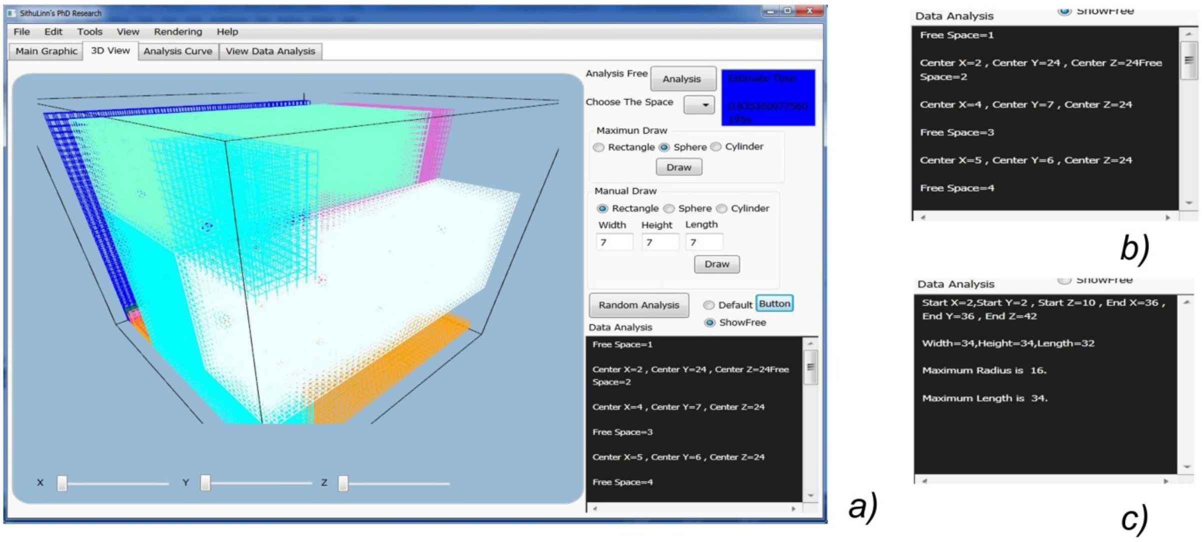

Figure 5. Defining the configuration of unfilled spaces: *a* - visualization of space; *b* - output of data on the size and position of the free region; *c* - evaluation of the possibility of writing different figures.

4. The use of receptor geometric models in the design of channel surfaces

The purpose of channel surface design is to deliver a certain material carrier (fluid, gas, electric energy from one point of a technical product to another (Figure 6*a*) along a certain trajectory, one of the design tasks is the design of communications between already placed objects. Such problems are quite difficult to formalize and difficult to solve because of their inherent multi-extremal nature [15].

A special and much more complicated type of trace is the so-called "solid" trace, i.e. such a case, when the dimensions (of connecting elements) of the traces are comparable with the sizes of the elements to be assembled (Figure 6 *b*).

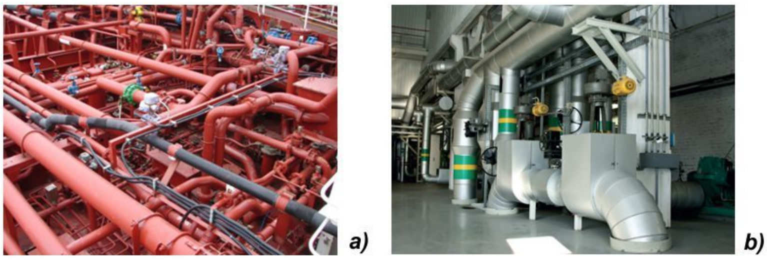

Figure 6. An example of the arrangement of pipelines (*a*) and a channel "solid" trace (*b*)

The common in the design of any channel surfaces is the requirement to ensure smoothness. To do this, it is necessary to simulate a route that takes into account not only the previously assembled objects, but also provides a given smooth current [16,17]. The complexity lies in the fact that for sufficiently complex geometric forms of placed objects the geometric form of communications will prove even more complicated.

An additional problem is the ambiguity of the solution of the task. Figure 8 shows that it is possible to draw a path between the given initial and final points A and B in different ways. It can be assumed that of all the traces in Figure 7, it is better to have one that is shorter, but more often it is necessary to provide a given smoothness. The difference of our approach is that if before the channel was designed according to the given characteristics, and then it was already placed, then we have the opposite - we are trying to design a channel with the specified characteristics, "inscribed" in an already existing layout.

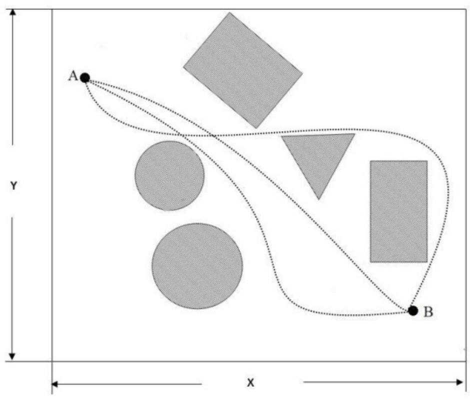

Figure 7. Finding a rational path between two endpoints A and B in a 2D statement.

The main problem is to bypass obstacles, which are already assembled objects or communications between them (Figure 8 *a*). The simplest solution is to ignore obstacles before they collide with them. This principle of circumventing obstacles is the basis of the well-known Dijkstra's algorithm [18]. It can be seen from Figure 8 *b* that although it allowed to go from the initial to the final points, it did it irrationally, having made many unnecessary movements.

The most perfect algorithm for spatial tracing is represented by the algorithm A*, proposed by Masatomo Kanehara [19]. created for robot movement in 2D space, this algorithm uses the clothoid to smooth out the trajectory (Figure 8 *c*). Our study showed that it works better than the rest of the search strategies, so we chose it as the base.

The disadvantages of the algorithm A * in its existing form include:

1. As a rule, the path laid with its help contains sharp changes in the direction of movement and, in principle, does not satisfy any requirements of smoothness.

2. There are no ways to build a path at a given distance from the forbidden areas (that is, observing the δ-neighborhood).

3. In the present form the algorithm A * is not able to take into account the given changes in the area or volume of the path as it moves along it.

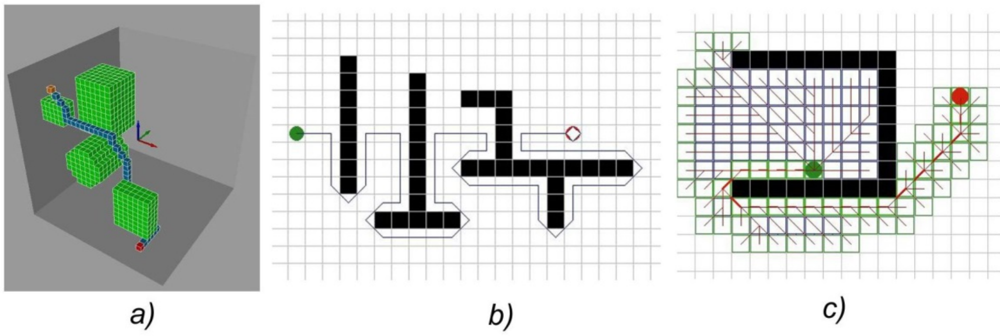

Figure 8. The principle of circumvention of obstacles in the construction of the route by the receptor method (*a*), by the Dijkstra's algorithm (in the 2D statement - *b*), by the algorithm A * (in the 2D statement - *c*).

These shortcomings were eliminated by the addition of new heuristics, which contain elements of artificial intelligence, since the solution is chosen according to the predicative principle "If" - "Then". In the algorithm developed by us, a heuristic is used that involves a multi-directional search in 8 directions if the channel is built in the plane and along 26 adjacent vertices in the design of the spatial channel (Figure 9).

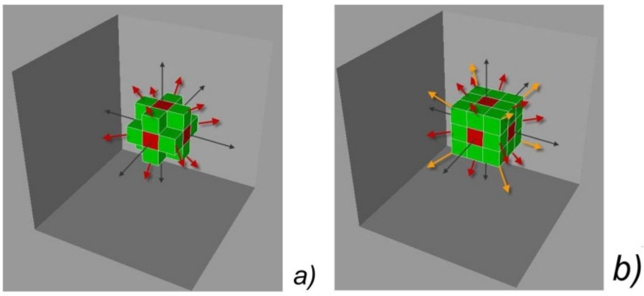

Figure 9. Path search in the receptor field in the 3D image: *a* - along 8 adjacent vertices; *b* - along 26 adjacent vertices.

To implement the proposed algorithm, the Advanced Pathfinder System (APS) was written using the C # programming language. In reality, our bypass algorithm turned out to be much more complicated than algorithm A *, since we have to refer to subroutines that describe various heuristics of avoiding obstacles and smoothing the path. However, the use of these heuristics increases the speed of our algorithm in 3..5 times compared with the algorithm A * [20].

5. Evaluation of accuracy and efficiency of receptor geometric models

The most important issue of the use of receptor geometric models is the accuracy of this model. Our study on test examples showed that with the increase in the size of the receptor d, the error in describing the shape grows along an approximately linear curve and its mathematical expectation is approximately 0.9d ± 0.28d with a confidence interval of ± 3σ. Simulation modeling allowed to estimate the CPU time costs, which also increase with the decrease in the size of the receptor for parabolic dependence from a few seconds to almost 3 minutes when using a personal computer power, slightly higher than the average for the current level. This means that with a receptor size of, for example, 0.2 mm, the error in representing the shape is 0.18 ± 0.06 mm, which is quite sufficient for practical use. At the same time, there are considerable reserves for reducing and the required processing power (for example, by using adaptive receptor sizes. The rapid growth of computer technology makes discrete receptor models more attractive and more and more popular in the practice of computer-aided design.

6. Conclusion

The use of receptor geometric models opens the way to creating methods of automated layout using elements of artificial intelligence. With moderate costs of processing power and small losses in accuracy of the description of the geometric shape of the assembled objects, they allow solving many practical problems.

Unsolved while the problem of using receptor geometric models in problems of automated layout is the lack of their integration into modern systems of solid-state geometric modeling, that limits their wide adoption in the practice of computer-aided design.

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