Methods of formation of receptor (voxel) geometric models for automated layout tasks

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Abstract. In the framework of design automation, the capabilities of receptor (voxel) geometric models in the tasks of automated layout are shown. Being one of the methods of discrete geometric descriptions of composable objects, they make it possible not only to easily determine cases of their mutual intersection, but also to form intelligent composition algorithms (for example, traces). However, the receptor models are inherently in-machine themselves, which significantly complicates their use. At the same time, modeling composable objects by means of CAD systems (AutoCAD, SolidWorks, KOMPAS, Autodesk Inventor, etc.) presents no difficulty. The article shows the possibility of converting a solid-state model made in any of the existing CAD systems into a receptor one. This allows you to continue using this receptor model as the source for the subsequent operations of computer-aided design layout, taking into account additional factors. In our case, this is the definition of the possibility of delivering bulky objects, among others previously placed, which act as areas of prohibition in our case. The practical value of this study is to assess the possibility of moving super-large cargo along the construction site, assessing the ergonomic design of mechanical, electromechanical, air-conditioning and other auxiliary equipment of civil and industrial buildings for ease of installation and subsequent maintenance. An algorithm implemented in the form of a macro CAD-system is described: the formation of a receptor model of a relocatable or assembly equipment based on its solid-state model.

1. Introduction
Layout tasks (placement) are one of the most creative design tasks, since for their solution it is necessary to take into account many factors that are hard to formalize. This makes it extremely difficult to automate the solution of such problems. Therefore, the first automated layout algorithms (and applied only to 2D objects) appeared only in the 60s of the last century [1-3], while the algorithms for describing the shape of 3D objects appeared much earlier [4-7].

In our previous publications [8-11], it was shown that in the tasks of automated layout, the requirement for geometric models of the accuracy of describing a geometric shape is far from being the main one. A much more important property of geometric models is the ability to determine the conditions for the mutual non-intersection of composable objects. The ease of “catching” cases of mutual intersection of composable objects with previously placed (which in our case are areas of prohibition) allows you to create rational places for their installation and the trajectory of moving the object to these installation sites.
In the field of construction, examples of such tasks are the delivery of oversized cargo to industrial construction sites (Figure 1). In this case, we need to decide in advance whether it is possible to move such a load to the installation point, and if possible, on what path. In some cases, to move such an oversized cargo requires not only its movement along a flat path, but also a change in its position in space during movement (Figure 2).

A more complex (from the geometrical point of rhenium) case is the arrangement of objects with regard to ergonomic requirements. By them we mean the possibility of installation and maintenance of the equipment being placed, i.e. the possibility of not only delivering it to a given installation point, but also the convenience of working with the installation tools necessary for its installation / disassembly. Such operations are encountered when installing electrical installations, elevators, air conditioners, etc. in buildings (Figure 3).
Solving these issues is important for improving the quality of design in construction, but it is even more relevant for the automated layout of products with much higher packing density (for example, vehicles).

Having such powerful design tools as modern CAD-systems (AutoCAD, SolidWorks, KOMPAS, Autodesk Inventor, etc.), using them seems to be possible not only solid modeling of assemblies, but also identifying cases of intersection of objects with each other. But such an approach is not a general solution to the ergonomic layout problem - in this case we are talking only about checking the layout variant that has already been generated, taking into account the experience and intuition of the designer. In this case, we determine cases of intersection (or non-intersection) of objects only at certain discrete points without constructing a rational trajectory of moving objects to these points.

2. Using receptor method of geometric modeling in tasks of automated layout, taking into account the ergonomic factor

The basis of the receptor method ("voxel") is an approximate representation of a geometric object in the form of a receptor space. The term "Voxel" is an abbreviation of the words "VOLUMetric" and "piXEL"), i.e. three-dimensional pixel, but in this article we will use the domestic term "receptor".

The essence of receptor models is described in sources [12 - 14]. In spite of the fact that receptor models were proposed as early as the early 70 years of the last century by Belarusian scientist D.M. Zozulevich [15, 16], they receive their practical application today in connection with the development of computing equipment performance [12, 17 - 20].

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 volumes does not represent a technical or economic complexity. The advantages of receptor models include the possibility of a solid-state description (albeit discrete) of geometric shapes of any complexity.

The essence of our approach is geometric modeling of the service area of already arranged objects. In our approach, geometric models of assembled objects (a prohibition zone), the working tool itself, its working movements and the trajectory of its movement to the point of delivery are formed. The working movements of the tool and the trajectory of its movement are formed as a sequence of instantaneous movements of the working tool in a selected direction (Figure 4).

Figure 4. Movement to the working area and working movements of the hand tool (wrench).

Thus, we must form two most complex geometrical objects in their form - a set of instantaneous positions of the tool delivery to the working area and a set of instantaneous positions of the working movements of the tool. If we manage to create an aggregate geometric model of the approach of the tool to the working area and its movement in the working area itself, then we will consider this geometric model (a set of instantaneous movements) as a composable object, which we will try to “fit” among already placed objects. This is the essence of our approach to solving the task, which we consider to be original.

If the solid-state model of the tool-moving path formed by us fits among the equipment, this means that everything is in order, the delivery of the tool to the work area and the working movements in it are possible and our layout meets the ergonomic requirements. If there are any intersection cases, then it is necessary first of all to figure out what is wrong - either the delivery of the tool to the work area is
impossible, or there is not enough space for the work of the tool in the work area itself. In this case, we
have to identify the intersection of the placed objects and try to change the trajectory (or the position
of the tool during its movement along the trajectory) so that it could still be “carried” into the working
area, or cut in the working area itself, or search another tool to perform the required operations.

3. Formation of receptor models of the working tool and its trajectories
By its geometric essence, the receptor method, which in our approach was adopted to solve the prob-
lem, is a special case of the method of analytical approximation of objects, which is used to describe
three-dimensional objects, including complex surfaces of second and higher orders [23]. Since the
computational processing of such surfaces is difficult, they are approximated by portions of surfaces
of a lower order (planes, cylinders, etc.).

As already noted, the receptor method has both its advantages and disadvantages. The principal
disadvantage of the receptor model is the impossibility of studying the engineering-differential charac-
teristics of the object surface (Figure 5 a). However, this does not prevent the creation of completely
recognizable objects of complex technical forms and even scenes from cubes (Figure 5 b).

The main difficulty in the implementation of receptor geometrical models is that the receptor geo-
metrical model is never the initial one. Placed and already placed products are described by the de-
signer, as a rule, by parametric geometric models (that is, they define the type of object and its param-
eters — a sphere of radius R, a parallelepiped with dimensions $a \times b \times c$, etc.). Therefore, there is a need
for an additional software module "Parametric Model" $\leftrightarrow$ "Receptor Model". Thus, the receptor model
can be considered as an “in-machine” model, created on the basis of the original parametric one.
Therefore, when working with receptor models, various researchers create their own software modules
for transforming a parametric model into a receptor model, taking into account the research objectives
set for themselves [24].

If the working tool is not a very complex form (for example, as in Figure 6), then this approach is
quite acceptable. For hand tools of more complex shape, shown in Figure 7, the implementation of
these operations will require much more effort and a significant simplification of the original shape of
the working tool. For this case, we need to approximate all the elements of the form of the working
tool with primitives.

Figure 5. Receptor models of simple (a) and rather complex in shape geometric ob-
jects (b).

Figure 6. Formation of the receptor matrix of a simple tool.
Unfortunately, the shape of the working tool needed for the installation and maintenance of the assembled objects can be quite complex and diverse (Figure 8). Therefore, an extremely urgent task is to simplify the preparation of the original receptor matrix. It is easiest to get all the source information from a solid-state geometric model, which is easy to form into any of the modern CAD systems (AutoCAD, SolidWorks, KOMPAS, Autodesk Inventor, etc.). The sequence of the chain of such operations is shown in Figure 9.

To implement this operation, we have developed a special algorithm, designed in the form of a macro CAD-system (in our case for SolidWorks). We believe that we already have a 3D model of a working tool formed in a CAD system. The stages of the formation of the receptor model on the basis of a solid-state model are shown in Figure 10. In the CAD-system, a scene is formed in the form of a parallelepiped with the overall dimensions of the simulated instrument. Both the previously prepared 3D model of the working tool and a single parallelogram with the dimensions of a single receptor (voxel) are placed in this scene. It is placed in the initial point with 0 coordinates along all three coordinate axes (Figure 10 a). In this figure, for ease of understanding of the principle of operation, it is not a real working tool, but a more elementary in form test object. Next, a CAD system macro is launched that determines whether the intersection of this test receptor has occurred with our solid state object. If it does not, then the code of the test receptor in the corresponding receptor matrix remains
unchanged, that is, "0". If an intersection has occurred, the code "0" of the receptor matrix is replaced with the code "1". This means that the object described by the receptor matrix is present at this point in space. Then the position of the test receptor is changed by one position along one of the coordinate axes. Thus, this test receptor passes all points of the scene space, each of which checks its intersection with the layout object. If it occurs (Figure 10 b, c), then in the receptor matrix being formed, the code of its corresponding components is replaced with “0” by “1”. In Figure 10 b, such receptors for illustration are highlighted in red. Having performed such a test by running the macro as many times as there are single receptors in the receptor matrix, we will automatically form the receptor matrix of the working tool necessary for further analysis of the layout for ergonomics and maintainability.

Figure 10. Stages of formation of the receptor digital model of the working tool 3D model formed in the CAD system (b), a formed receptor model (c).

The operation of forming a digital receptor model described above is the most difficult and time-consuming when using receptor-based geometric models. Thus the receptor matrix obtained, is placed in the general layout scene, where the trajectory of its rational displacement will be formed. The formation of such a trajectory is beyond the scope of this article.

4. Evaluation of the accuracy and efficiency of receptor geometric models
The most important issue in the use of receptor geometry models is the accuracy of this model. According to our estimates, a single receptor size of 1 cm × 1 cm × 1 cm is a reasonable compromise between reasonable modeling accuracy and time spent on computer modeling. A previous study of test examples showed that with an increase in the size of the receptor d, the error in describing the form increases in an approximately linear relationship and its expectation is approximately 0.9 d ± 0.28 d with a confidence interval of ± 3σ. Simulation allowed us to estimate the CPU time costs, which are also expected to increase when the size of the receptor is reduced by a parabolic dependence from several seconds to almost 1.5 minutes (depending on the size of the scene) when using a personal computer with a power slightly higher than the average for the modern level. For example, this means that with a receptor size of 1.0 cm, the error in form presentation is 0.9 ± 0.28 cm, which is quite enough for practical use in construction design tasks. At the same time, there are considerable reserves for reducing the required computing power (for example, by using adaptive receptor sizes). The rapid growth of computer productivity makes discrete receptor models more and more attractive and increasingly in demand in the practice of computer-aided design.

5. Conclusion
Using receptor geometric models opens the way to the creation of automated layout methods using elements of artificial intelligence. With moderate expenditures of computational power and small losses in the accuracy of describing the geometric shape of composable objects, they allow us to solve many practical problems.
1. The urgency of solving the problem of ergonomic layout of mechanical, electromechanical, climate and other civil and industrial buildings for the convenience of its installation and subsequent maintenance is shown.
2. The possibility of extending the methods of solving the ergonomic layout problem for estimating the movement of super large-scale cargo in cramped conditions of a construction site is shown.
3. The use of the receptor method of geometric modeling for solving the problem is substantiated.
4. In our approach, the set of instantaneous movements of the assembly tool along the path of movement and when performing assembly operations, as well as the movement of an oversized cargo, is considered as a composable object that needs to be rationally placed among already placed objects that are areas of prohibition.
5. The ways of formation of receptor matrices are shown on the basis of solid-state models of the placed equipment and servicing tools from the system of geometric modeling (in our case SolidWorks).

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