Three Dimensional Segmentation of Object and Its Characteristic Points Definition

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Abstract. Reconstructing three dimensions (3D) of object is a big challenge for researchers in many years. To solve these problems, it is necessary to identify objects and obstacles on the 3D description of the working stage, to determine their real dimensions and spatial coordinates. In this paper, algorithms for image segmentation are examined and a way of describing spatial objects is proposed. The algorithm for segmentation was developed by us and was presented in details in this study. The aim of segmentation is to partition the original set of points into disjoint subsets. Examination of complex shape body showed that the algorithm can be extract detailed geometry of the model. Accuracy of the algorithm in analyzing geometry structure was presented detailed in this study.

Keywords: 3D segmentation, image segmentation, working stage

1 Introduction

At present, the urgency of creating robots to replace a person in extreme and life-threatening conditions is very high. To solve these problems in automatic mode, it is necessary to identify objects and obstacles on the 3D description of the working stage, to determine their real dimensions and spatial coordinates. To obtain a 3D description of the working stage, different systems of technical vision are commonly used: multi-camera, stereo systems, laser illuminated systems, etc. In this case, the system of vision with a structural illumination is considered, at the output of which three coordinates of each point of the working stage are formed [1-2].

3D image processing was conducted before by Jennanea et al. [3], Wang and Deng [4] and many others. However, the results are still questionable. An efficiency technique should be developed for highly accurate results.

In this paper, algorithms for image segmentation are examined and a way of describing spatial objects is proposed. The aim of segmentation is to partition the original set of points into disjoint subsets. In this case, the scene is divided into flat segments with their subsequent division into smaller ones, which is acceptable, since most real objects have flat faces within the selected range of deviations. As a result, the working stage is represented as separate segments, which, within the tolerance, can be approximated by planes.

2 3D Image segmentation of object

2.1 Algorithms of scene segmentation

The system of technical vision with structural illumination provides obtaining 3D coordinates of each point of the working area of the robot [1,4,5]. Input data of the algorithm are: the number of points and their spatial coordinates. Each point is the vertex of an elementary triangle, with which all objects of the working scene are described. As a result, a file containing the following is generated at the output of the vision systems:

- number of points and number of triangles;
- coordinates of all points of the field of view (x_i, y_i, z_i);
- the number of vertices of each elementary triangle.

Using this information of the 3D vision system, we analyze the spatial orientation of each elementary triangle and divide them into separate arrays - segment the original image of the working stage. First, for each triangle we compose the equation of the plane in the form

$$Ax + By + Cz + D = 0, \qquad (1)$$

or in vector form $(r, N) + D = 0,$

Where r – radius vector of a point (x , y, z), $N = (A, B, C)$ – vector perpendicular to the plane of the triangle. In Fig. 1a shows an example of a triangle that has vertices V_i , V_j, V_k and the normal N_f . The angles between the normal and the coordinate axes are shown in Fig. 1b.

The coefficients of the equation of the plane by three points $V_i(x_i, y_i, z_i)$, $V_j(x_j, y_j, z_j)$ and $V_k(x_k, y_k, z_k)$ can be obtained from the following determinants:

$$A_f = \begin{vmatrix} 1 & y_i & z_i \\ 1 & y_j & z_j \\ 1 & y_k & z_k \end{vmatrix}; \quad B_f = \begin{vmatrix} x_i & 1 & z_i \\ x_j & 1 & z_j \\ x_k & 1 & z_k \end{vmatrix}; \quad C_f = \begin{vmatrix} x_i & y_i & 1 \\ x_j & y_j & 1 \\ x_k & z_k & 1 \end{vmatrix}; \quad D_f = -\begin{vmatrix} x_i & y_i & z_i \\ x_j & y_j & z_j \\ x_k & y_k & z_k \end{vmatrix} \qquad (2)$$

Solving (2), we obtain:

$A_f = y_i(z_j - z_k) + y_j(z_k - z_i) + y_k(z_i - z_j)$; $B_f = z_i(x_j - x_k) + z_j(x_k - x_i) + z_k(x_i - x_j)$;

$C_f = x_i(y_j - y_k) + x_j(y_k - y_i) + x_k(y_i - y_j)$; $D_f = x_i(y_k z_j – y_j z_k) + x_j(y_i z_k – y_k z_i) + x_k(y_j z_i – y_i z_j)$.

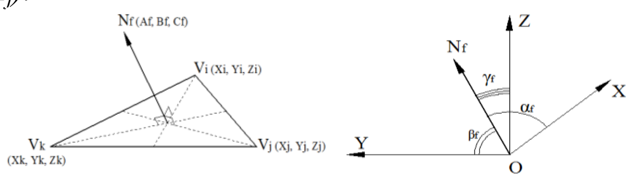

Fig. 1. Position of the vector $N_f(A_f, B_f, C_f)$ (a); the angles of the direction cosines of the vector N_f (б)

Then the direction cosines of the vector N_f: $cos(\alpha_f)$, $cos(\beta_f)$, $cos(\gamma_f)$ for each triangle can be determined from the following expressions:

$$\cos\left(\alpha_f\right)=\frac{A_f}{\sqrt{A_f^2+B_f^2+C_f^2}};\quad \cos\left(\beta_f\right)=\frac{B_f}{\sqrt{A_f^2+B_f^2+C_f^2}};\quad \cos\left(\gamma_f\right)=\frac{C_f}{\sqrt{A_f^2+B_f^2+C_f^2}} \tag{3}$$

The first way is to use the direction cosines [1,2]. In this approach, we divide all data into several classes (for example, by eight) by analyzing the cosine angles α_f, β_f and γ_f (3) vector N_f each triangle. As a result of segmentation, we can get up to eight separate arrays (triangles and their vertices). Each array can include several parallel areas of the original image.

The second method is to analyze the parallelism of triangles. In this trek, the location of the planes of the triangles of the original image is analyzed. All triangles that have the same orientation in the workspace belong to the same class. A graphic illustration of this approach is shown in Fig. 2.

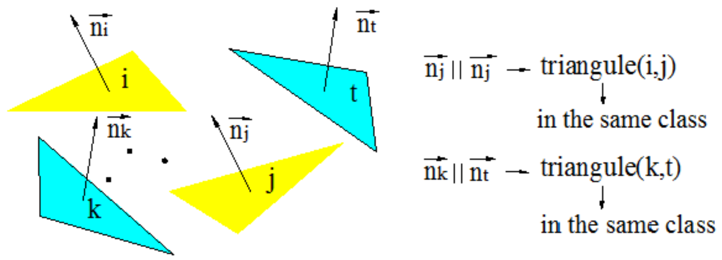

Fig. 2. Arrangement of triangles

Using expression (2), we find the equation of the plane of the i-th triangle in the form: $A_ix + B_iy + C_iz + D_i = 0$, and the normal vector to this plane: $N_i(A_i, B_i, C_i)$.
Similarly, the equation of the plane of the j-th triangle and the normal vector to it have the form:

$$A_jx + B_jy + C_jz + D_j = 0, \qquad N_j(A_j, B_j, C_j).$$

In the segmentation process, the condition of parallelism of the planes i and j is checked. Note that when working with real images, the condition of approximate parallelism was used: $\frac{A_i}{A_j} \approx \frac{B_i}{B_j} \approx \frac{C_i}{C_j}$.

As a result, we get several separate arrays. Each array can include several parallel areas of the original image.
The third method is a sequential analysis of neighboring triangles. In this method, the values of the inclination angles between the normal of the i-th and adjacent triangles are checked sequentially. If the angles between normal are less than a given threshold, then these triangles are assembled in one array.
For example, the i-th triangle has three adjacent triangles (j, k, m), as shown in Fig. 3. If the angles $\alpha_{ij,}$ $\alpha_{ik,}$ α_{im} between the normal of neighboring triangles with triangle i is less than a given threshold, then it is assumed that they are parallel and belong to the same array (triangles i and j). Otherwise, for each triangle (m and k), an array is formed.
To calculate the angles α¬ij, α¬ik, α¬im we use the equation of the plane. So for the i-th triangle it has the form: Aix + Biy + Ciz + Di = 0 and the normal vector Ni(Ai, Bi, Ci). Similarly for the plane of the j-th triangle: Ajx + Bjy + Cjz + Dj = 0 and the

normal vector Nj(Aj, Bj, Cj). Then the angle between two normal vectors of the planes (Ni, and Nj) can be calculated from the formula:

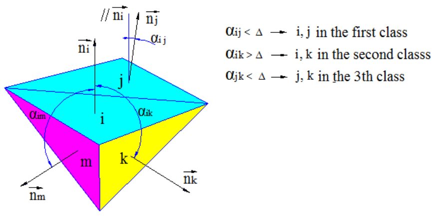

Fig. 3. Four adjacent triangles (i, j, k, m)

As a result of using the third approach, we get many arrays; and each contains the coordinates of points of only one area of the image.

2.2 Investigation of segmentation algorithms for the scene

For experimental studies of the proposed segmentation algorithms, we used a real scene, the image of which is shown in Fig. 4a. As you can see from the figure on the scene, there are several objects limited by 16 planes.

The results of applying segmentation algorithms are shown in Fig. 4b, 4c and 4d. When using the first approach, 7 arrays of points (segments) of possible 16 were obtained. Each segment consists of several independent regions having the same orientation in the workspace.

Using the second approach, 25 point arrays (segments) were obtained for possible 16. This is because the scene has a complex underlying surface and shadows in the objects.

Using the third approach, we got 17 arrays of points (segments) with 16 possible. Here, each segment consists of points of only one independent area of the image.

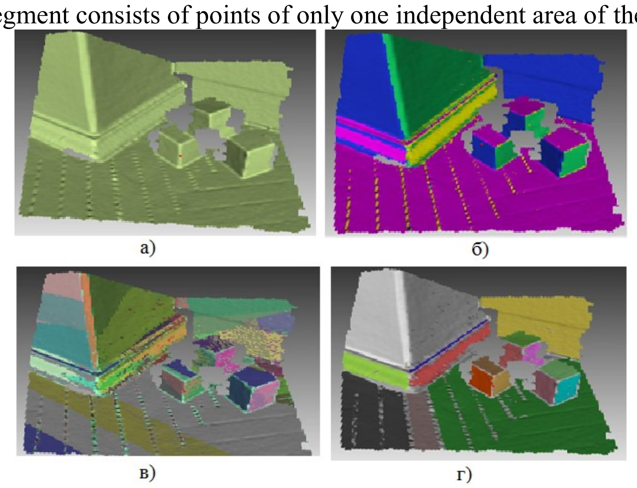

Fig. 4. The results of stage segmentation (a): b) - the method of directing cosines; c) - by analyzing the parallelism of triangles; d) by the method of sequential analysis of triangles.

The conducted experiments showed that all the segmentation methods give good results when working with simple scenes, and for the complex scenes the third method shows the best results. The obtained numerical values are given in Table 1.

Table 1. Numerical results comparison

Scene	The number of plate of the real scene	Experimental results					
		The first way		The second way		The 3th way	
		Mumber of plate	Time of processing	Mumber of plate	Time of processing	Mumber of plate	Time of process ing
Simple	4	4	200ms	4	500ms	4	450ms
Medium difficulty	8	7	300ms	11	800ms	8	750ms
High difficulty	16	7	450ms	25	1200ms	17	1100ms

As can be seen from the obtained results, it is expedient to use the first segmentation method, which has a minimum operating time, for analyzing fairly simple scenes with a limited operating time. If the working stage consists of several overlapping objects that are located on a complex background, you need to use the third way to extract characteristic points. In this study, numerical and experimental methods were applied for analyzing boundary layer profile around an axisymmetric model under low-speed conditions. The numerical methods show high advantage in determining all parameters of the flow. On the other hand, data processing technique on images allow to capture velocity fields around the model. Although the experimental data allowed to capture only velocity profile, the resolution of the boundary layer near the model is very high. Both experimental and numerical methods showed a large wake structure behind the base surface. Additionally, the boundary layer profile did not change much before the base edge. Experimental and numerical results are highly consistent for velocity profile far from the model surface. However, near the surface of the model, both of them show some limitation. However, the k-ω turbulent model and single-pixel ensemble correlation can be used for further study of boundary layer and the large wake structure.

3 Algorithm for isolating characteristic points of objects

Allocation of characteristic features of an object is the most important stage of image processing, since recognition algorithms work effectively with objects that easily detect any characteristic features (corners, peaks, holes, etc.). In this case, we use the characteristic points of the object as points of intersection of three planes (three segments) for which certain conditions are fulfilled.

3.1 Descriptions of the segment plane

For each segment, we write the equation of the plane, using the mean values of the coefficients A_m, B_m, C_m, D_m. For example, for a segment i that consists of n triangles, you can compose your equation of the plane using expression (1) in the form:

$$A_{im}x + B_{im}y + C_{im}z + D_{im} = 0, \tag{5}$$

Where: $A_{im} = \frac{\sum_{j=1}^{n} A_j}{n}$; $B_{im} = \frac{\sum_{j=1}^{n} B_j}{n}$; $C_{im} = \frac{\sum_{j=1}^{n} C_j}{n}$; $D_{im} = \frac{\sum_{j=1}^{n} D_j}{n}$.

In this paper, the problem of isolating characteristic points of spatial objects is considered. Therefore, the quality of segmentation and the accuracy of the description of the plane of the segment (face) on the 3D image of the object determine the result of the selection in considerable accuracy. To estimate the accuracy of the description of the segments of one object, consider the image of the object (Fig. 5), which is obtained from the 3D camera and consists of three segments 4, 5 and 6. Using the expressions (1), (2) and (5), one can find the equation of the plane for each segment.

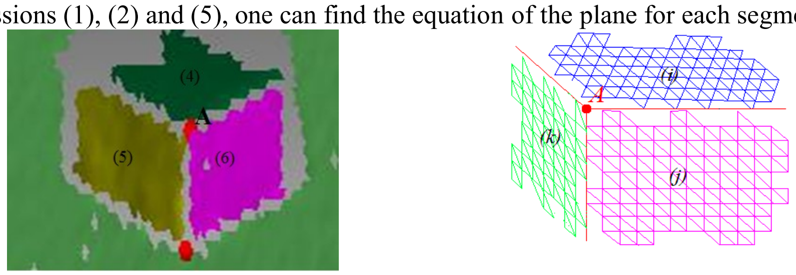

Fig. 5. The real image received from the 3D camera

For example, the fourth segment (Fig. 5) consists of 214 triangles and includes 140 points, the fifth segment consists of 242 triangles and 149 points, the sixth segment consists of 218 triangles and 135 points. As a result, we obtain the equations:
The deviation ε is determined for each point of the segments to the plane of such a segment. An illustration of the deviation of ε is shown in Fig. 6.

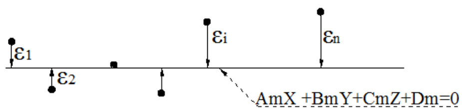

Fig. 6. Deviation of the point on the segment to the plane of this segment

Distances from the point $M(x_M, y_M, z_M)$ to the plane $AmX + BmY + CmZ + Dm = 0$ can be found using the following formula:

$$\varepsilon = \frac{\left| Am \cdot x_M + Dm \cdot y_M + Cm \cdot z_M + Dm \right|}{\sqrt{Am^2 + Bm^2 + Cm^2}}, \tag{6}$$

With the help of expression (6), we determine the distance of deviation from all points that are on its segment, up to the plane of the segment and the results are shown in Fig.7.

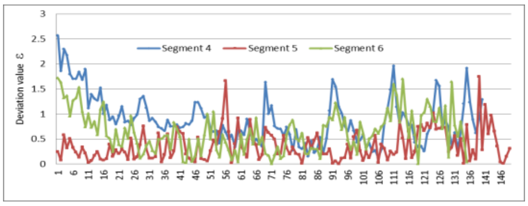

Fig. 7. Distance deviation from point to plane of its segments

To estimate the accuracy of the description of segments, we use the normal distribution-the Gaussian distribution, which in the one-dimensional case is given by a probability density function that coincides with the Gaussian function. The results of the error distribution by the Gauss method are shown in Fig. 8. As seen from the results, the plane approximates the segment of the object with high accuracy.

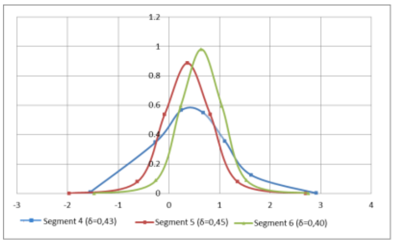

Fig. 8. Results of the estimation of the accuracy of segment (4), (5) and (6) of a parallelepiped by the method of Gauss

3.3 Results of experimental studies

To confirm the efficiency of the proposed method, a program was developed and testing of the proposed algorithms was performed on real 3D scenes of various complexity. In the course of experiments, the operability of the proposed algorithms for image segmentation of spatial objects and the possibility of their subsequent description with the help of characteristic points was checked.

Experiment with a simple scene, on which there is only one object (Fig. 9). As a result of the operation of the algorithms, two characteristic points A and B and vectors coinciding with the lines of intersection of two planes are found, which are shown in Fig. 10 on the left and on the right, respectively.

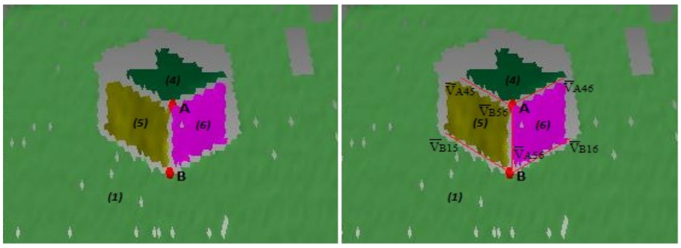

Fig.9. Experiments with a simple scene

Experiment with a medium-complexity scene, on which there are several separate objects (Fig. 10-left). As a result of the work, 12 segments, 8 characteristic points and their parameters were found. And with a complex scene on which there are several overlapping objects (Fig. 10b), the program has found 13 segments and 9 characteristic points: two points 1, 2 on the first object; five points 3, 4, 5, 6, 7 on the second object and two points 8, 9 on the third object.

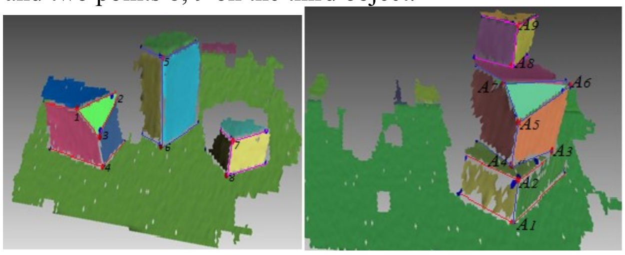

Fig.10. Experiments with a medium-complexity scene (a) and a complex scene (b)

4 Conclusion

The proposed methods of segmentation and selection of characteristic points make it possible to obtain a fairly complete description of objects by their image. This makes it possible to use effective algorithms for recognizing and analyzing the current situation in the working space of the robot.

The presence of information about the 3D coordinates of characteristic points and their mutual arrangement allows us to determine the position and orientation of objects in the working space of the robot and, accordingly, to perform the necessary actions on them.

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