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ESTIMATING SURFACE AND SPATIAL STRUCTURE FROM WIRE-FRAME MODEL USING GEOMETRICAL & HEURISTICAL RELATION

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ABSTRACT

This paper presents an approach for understanding a spatial structure from a wire-framed environmental model which has been constructed by a mobile robot with a stereo system. We discover the object surfaces using relations of line connection and some geometrical constraints. This method can also infer undetected lines, thus the occluded surfaces can be reconstructed. We present experimental results on some simulated data and a natural scene data.

INTRODUCTION

A number of researchers have investigated vision-based navigation of autonomous mobile robot, using passive sensing systems; stereo camera or motion camera system [1].

In general, by using the passive sensing system, the robot can obtain three-dimensional data of objects. We have presented the mobile robot which has the binocular vision and can build the 3-D model of the robot's environment by using the principle of the trinocular vision [2]. This 3-D data we have been using, come from an edge-based algorithm that yields a wire frame description of the scene, i.e, a set of 3-D coordinates of line segments in 3-D space. For navigation, however, we need the surface-based information to determine free space where the robot can move, and to identify objects or walls. These information may be useful for a mobile robot.

Faugeras et al.[3] proposed an algorithm to generate surfaces based on Delaunay triangulation of the scene but it may produce false surfaces. Furthermore, this method takes a long computational time, and thereby the method is not applicable to real time navigation.

Sugimoto et al.[4] proposed another algorithm which does not produce false surface. However, it assumes a set of 3D loops. It is difficult to obtain 3-D loops because of the noise in the input images.

This paper presents an approach for understanding surfaces and their spatial structures from a wire-framed environmental model. The model has been constructed by a mobile robot with stereo system. We can discover both convex and concave object's surfaces using basic geometrical knowledge of the 3-D world.

The method has three processes as follows; plane extraction, generation of regions and region verification.

First, we find the candidate surfaces from a wire-framed model. Then we detect the surface regions by confirming the neighbor relationships between candidate surfaces. However, it is difficult to discover invisible (occluded) surfaces; e.g., the inside of the caves such as arch and the hidden side of the objects. By using some heuristic relationships between neighboring surfaces and by enlarging the predicted surfaces until the surface contacts with neighboring surfaces, the occluded surfaces can be also reconstructed. We store geometrical constraints as rules and infer the spatial configuration from the wire-frame model. Our system can recognize the surfaces and spatial configuration of the environment even if the obtained location data have noise and lose some boundary edges.

As a result, our system obtains a hierarchical representation of the environment as shown in Fig.1.

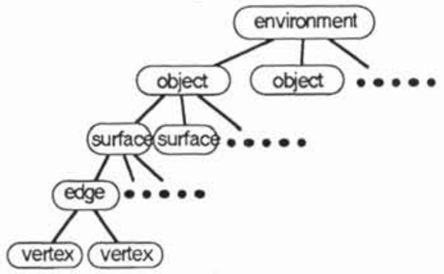


Fig.1

PLANE EXTRACTION

First, we find the candidate surfaces from a wire-framed model. Each line segment in the wire-framed model is caused by one of the edges which surround surfaces of objects. However, the lines detected by the stereo system are usually not perfect and those line segments are disconnected. Then we consider segments which are close to each other belong to a same surface, and compute the candidate surface from those segments.

In Fig.2, p_1q_1 and p_2q_2 are neighboring two line segments. If the distance L between p_1q_1 and p_2q_2, is less than or equal to a threshold, we consider these segments are connected each other at point c, the middle point of L.

The normal vector of the candidate surface is represented by

$$\vec{n}=\overrightarrow{p_1q_1}\cdot\overrightarrow{p_2q_2}.$$

The geometric equation of the candidate surface is determined by the normal vector $\vec{n}$ and the point c. Once the candidate surfaces are found, all the line segments on each candidate surface are extracted. Those segments are stored as components of each candidate surface.

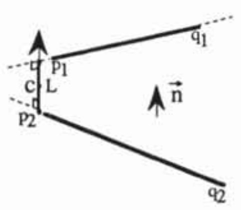
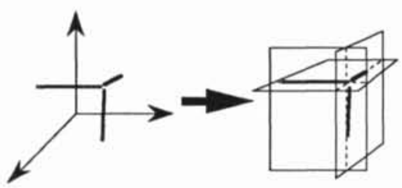


Fig.2

For example, from the wire-framed model composed of three line segments as shown in Fig.3(a), three candidate surfaces are determined as shown in Fig.3(b).



(a) (b)

Fig.3

GENERATION OF REGIONS

Next, we detect surface regions on each candidate surface. In the preceding section, we describe the scheme to compute the geometrical equation of each candidate surface. However, we haven't determined the boundaries of them. In this section, we will describe a method to decide the boundaries of surfaces.

First, we extract the candidates for edge and vertex. As shown in Fig.4, each candidate vertex can be determined as the intersection of more than three independent candidate surfaces.

Fig.5 illustrates the method to find candidates for edge. If a line segment is found between two candidate vertices, the portion between these two candidate vertices is selected as a candidate for edge.

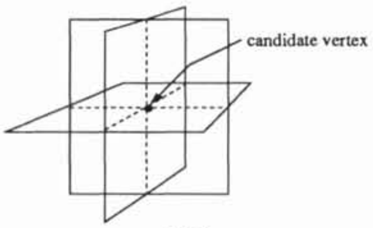


Fig.4

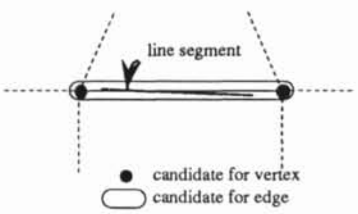


Fig.5

Thus we could find a set of candidates for vertex and edge from candidate surfaces. Next, we detect surface regions on each candidate surface. Each surface region is detected by a closed loop of candidate edges. After this, we call the surface region simply 'region'. As the graph of vertex and edge is already generated, closed loops of edges can be found by searching the graph. For example, on the illustrated candidate surface in Fig.6, there are six candidate edges, and two regions (a and b) are detected as candidate regions. However, sometimes such closed loops can not be found because the obtained data have noise and boundary edges are lost. In this case, we use some heuristic relationships between neighboring surfaces. Its details are described at the section 'Heuristic generation of edge hypothesis'.

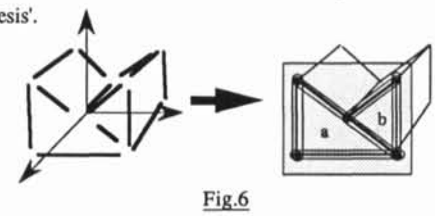
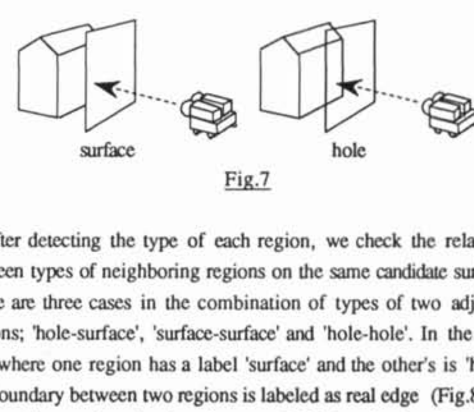


Fig.6

REGION VERIFICATION

In this step, we verify whether each region is hole or real surface by using geometrical relations of line segments. When the region is a real surface, line segments, which are components of other surfaces, do not appear inside the region in the image. On the other hand, when the region is a hole, some other edges can appear on its inside as shown in Fig.7. Thus, by judging whether other line segments appear inside the region or not, we can detect whether each region is hole or real surface.

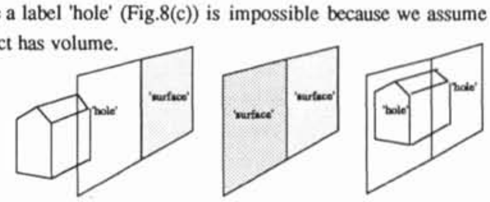
In the region verification process, regions are first classified into two types. If there are some objects behind a region, the region is labeled 'hole'. Otherwise, the region is labeled 'surface'.



surface hole

Fig.7

After detecting the type of each region, we check the relations between types of neighboring regions on the same candidate surface. There are three cases in the combination of types of two adjacent regions; 'hole-surface', 'surface-surface' and 'hole-hole'. In the first case where one region has a label 'surface' and the other's is 'hole', the boundary between two regions is labeled as real edge (Fig.8(a)). In second case where both regions are labeled as 'surface', the edge between two region is thought to be a inner line, we remove the edge between two regions and merge them to one region because it must be texture on the surface(Fig.8(b)). The last case, both regions have a label 'hole' (Fig.8(c)) is impossible because we assume the object has volume.



(a) (b) (c)

Fig.8

ESTIMATION OF OCCLUDED SURFACES

It is difficult to discover invisible (occluded) surfaces; e.g., the inside of the cave, the hidden side of the object. Using some heuristic relationships between neighboring surfaces, we can reconstruct the occluded surfaces.

When we could obtain more than two line segments on each occluded surface, we can estimate candidate surfaces in the same way as unoccluded surfaces (Fig.9).

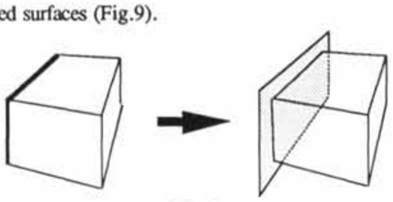
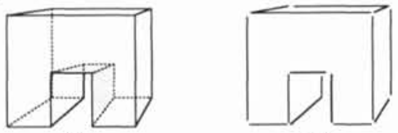


Fig.9

However, when only one line segment is obtained on a occluded surface, this process does not work. Let us consider two occluded surfaces in Fig.10(a) (shaded in the figure). It gives a wire-framed model like Fig.10(b). The line segment on each occluded surface is only one in wire-framed model. Then each geometric equation of those candidate surfaces can not be determined by the plane extraction process.

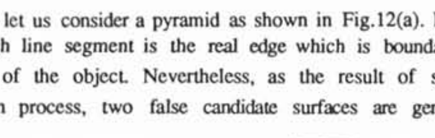


(a) (b)

Fig.10

For this reason, another method has to be applied to these surfaces, as follows.

In this case, each candidate surface is estimated as the plane which include both a line segment and the view point where a wire-framed model is built. After estimating the candidate surface, we use the region generation process described in the preceding section (Fig.11). As the result, we can estimate minimum size of free space. Information about free space is thought to be useful for navigation of mobile robot, etc.

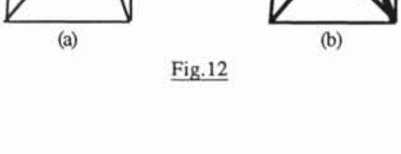


● visual point

Fig.11

ELIMINATION OF FALSE PLANES

Now, let us consider a pyramid as shown in Fig.12(a). In this case, each line segment is the real edge which is boundary of surfaces of the object. Nevertheless, as the result of surface extraction process, two false candidate surfaces are generated



(a) (b)

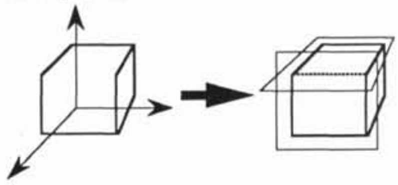
Fig.12

(Fig.12(b)). We would like to discriminate real surfaces from false ones. False ones have a common feature that all line segments on the candidate surface belong to more than three candidate surfaces. This is heuristic which work on worst cases; however, we believe these are some exceptions. At present, we identify false candidates with this feature and remove them.

HEURISTIC GENERATION OF EDGE HYPOTHESIS

When input data is perfect, our system works well. However, in real scene, the obtained data have noise and the lacks of boundary edges are occurred in the data of line segments. In this case, using some heuristic relationships between neighboring surfaces, we predict the lost edges and estimate the regions.

For example, in Fig.13(a), one of line segments is lost in input wire-frame model. As shown in Fig.13(b), let us consider two surface candidates detected in the plane extraction process. On these surface candidates, no region can be detected because the lack of a boundary edge is occurred and closed loops can not be obtained. In this case, we predict the lost edge (a broken line in Fig.13(b)) with some heuristic relationships; the candidate vertices exist at each end of the portion, the portion is at the intersection of two unclosed candidate surfaces. Finally, a candidate for edge is inserted at the portion, and two regions are detected. These regions are also checked in the verification process.



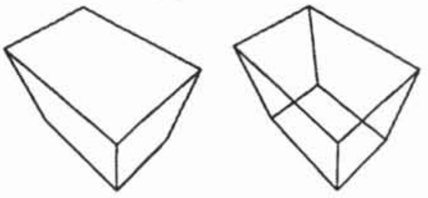
(a) (b)

Fig.13

EXPERIMENTAL RESULTS AND DISCUSSION

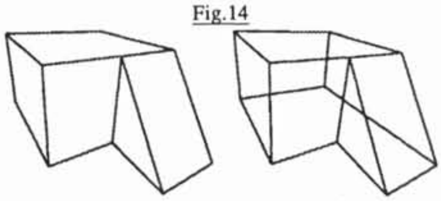
The experiments are performed to both some simulated data and a real world (toy houses) data which has been constructed by a mobile robot with stereo system.

First we show some simple examples in Fig.14,15 and 16. (a) shows a simulated data and (b) shows the result of surface in these figures.



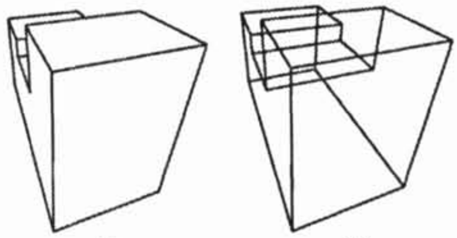
(a) (b)

Fig.14



(a) (b)

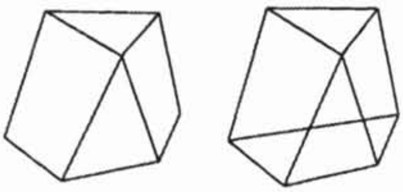
Fig.15



(a) (b)

Fig.16

Next simulated data is shown in Fig.17(a). The supposed object in it has an vertex on which four planes placed. This is an example of objects which cause false surfaces. The result of surface recognition is given in Fig.17(b). There is no false surface in the result and the occluded surfaces are also reconstructed .



(a) (b)

Fig.17

Fig.18 shows simulated data which has cave. It is the case that we can observe only one line segment on the occluded surfaces. As mentioned preceding section, temporary surfaces are inserted to estimate minimum free space in this case. As shown in Fig.19,20, the candidate surfaces can be estimated by assuming the surface which include both a line segment and the view point. (In Fig.19, viewer's position is same as Fig.18. Fig.20 shifts viewer's position from Fig.19 to show inserted surfaces).

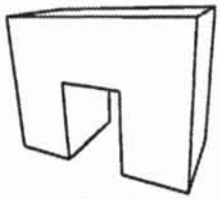


Fig.18

Fig.19

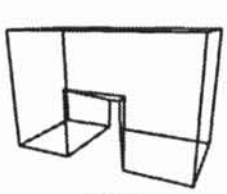


Fig.20

We also applied our system to a real scene. Input image is shown in Fig.21. Fig.22 shows detected 3D line segments from Fig.21. Detail of acquiring 3D wire-framed model can be found in [2]. The result of surface recognition is given in Fig.23. Though some segments has been lost in Fig.22, they are recognized correctly as shown in Fig.23.

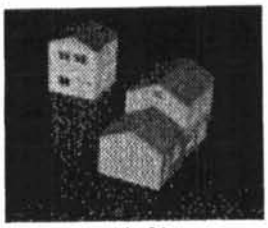


Fig.21

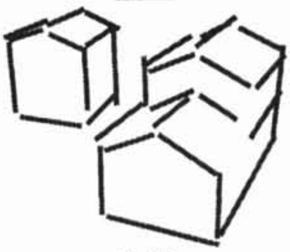


Fig.22

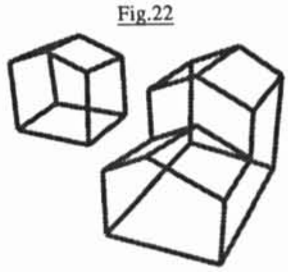


Fig.23

CONCULUSIONS

We mentioned a method for recognizing surfaces from the wire-framed model of the environment. The proposed system provides an explicit volume representation of free space and a hierarchical representation of objects. We have shown that the representation could be efficiently computed by using some geometric & heuristic constraints and simple visibility constraints.

REFERENCES

[1] A.M.Waxman, J.J.Lemoigne, and L.S.Davis "A Visual Navigation System for autonomous Land Vehicles", IEEE J. Robotics and Automation, vol.RA-3,No.2,pp.124-141,1987

[2] Masahiko Yachida, Akihiro Tsudo, "Understanding Spatial Configuration of Robot's Environment from Stereo Motion Images", IEEE/RSJ IROS'91,November 3-5,1991

[3] O.D. Faugeras, E.Le Bras-Mehlman and J.D.Boissonnat, "Representing Stereo Data with the Delaunay Triangulation", Artificial Intelligence 44, 41-87, 1990

[4] Kazuhide Sugimoto, Hironobu Takahashi, Fumiaki Tomita, "Geometric Modeling of Environment by Stereo Vision for Mobile Robot" , Technical Report, Computer Vision Group,Information Processing Society of Japan, 68-5, 1990