

# Topological Mapping and Navigation Based on Visual Sensor Network

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**Abstract** - In this paper, a novel topological mapping approach applied to the navigation mission is proposed based on visual sensor network. Firstly, the natural objects in the scene monitored by visual sensor network are recognized through the inference model based on structural features. Then, topological nodes are designed according to the recognized objects and their spatial structure information, and topological mapping will be fulfilled. On this basis, global localization for mobile robot in camera view can be implemented with HOG feature based detection and tracking. Finally, the robot can make motion decisions for navigation. Our approach does not rely on artificial landmarks and is tested in large-scale office scene. The effectiveness of the proposed approach is verified.

**Index Terms** - *Visual sensor network, Topological mapping, Navigation, Mobile robot*

## I. INTRODUCTION

Environmental model building is the key problem in the study of mobile robot. Topological map, one of the popular and important environmental models, is widely used in robot localization, path planning, navigation, etc [1-2]. Topological map is composed of nodes and edges, which are used for representing specific locations or regions in the environment and the connection among nodes, respectively. Environment is abstracted to a graph with topological meaning by building topological map. Topology map is suitable for processing large-scale scenes for its low computation complexity and global coherence.

Many algorithms have been proposed on topological mapping, Ranganathan *et al.* [3] present a novel algorithm, called Online Probabilistic Topological Mapping (OPTM), which is theoretically accurate, systematic, and sensor independent. In order to frequently compute and correct the robot's location information, a dense topological map of the robot's workspace is built [4]. Computer vision based methods have also been applied to topological mapping. Shi *et al.* [5] uses the visual scale-invariant features and the beam features of the laser range finder to represent topological nodes for topological mapping, while optical flow is used to detect changes at nodes in a topological mapping and localization framework [6]. Due to the ability of accessing detailed environmental information, omnidirectional vision has gained much focus in building topological map [7-8].

With the rapid development of communication technology, the implementation of the visual sensor network (VSN) shows a trend of diversification and simplification.

Visual sensor network has recently emerged as a new type of sensor-based intelligent system that brings complexity challenges [9]. Undoubtedly, large amount of environmental information will be provided by establishing visual sensor network, which is especially significant in large scale scene. At present, VSN has been applied successfully in some aspects, such as object matching, localization, target surveillance, etc [10-12]. In this paper, a novel topological map, which can be applied to the navigation mission, is built on the basis of natural objects recognized in the scene monitored by visual sensor network.

The remainder of this paper is organized as follows. Section II gives the topological mapping approach. Section III presents the implementation of navigation based on topological map. The experiment results are described in section IV and section V concludes the paper.

## II. TOPOLOGICAL MAPPING

### A. Establishing Visual Sensor Network

The visual sensor network, which consists of six visual nodes, a router, and a visual monitoring platform, is established in our office by using networking protocol of IEEE 802.11n. The video images captured by visual nodes can be transmitted to the visual monitoring platform for processing. One of the advantages of VSN is full-scale and comprehensive monitoring. Even in the large-scale scene, it can be implemented through reasonable layout of VSN with a free posture for each visual node.

### B. Object Recognition Approach

#### a. Line Segment Generating Module

For object recognition, compared with color, texture, image transformation and other features, structural feature can achieve better adaptability in changing environment, and provide more accurate target location as well. Based on structural features of object, the primary task for object recognition is to extract the line segments with high accuracy and reasonable expression.

Line segments are obtained through line segment generating module. In camera view, structural deformation will occur to some degree, so that we adopt Ellipse and Line Segment Detector [13] to obtain line segments and arcs. The arcs with large radius are transformed to line segments as part of the preliminary line segments result. Besides, line segments might be disconnected due to partial occlusions and low image quality. Therefore, it is necessary to identify and repair the

broken line segments. In some cases, a line segment belonging to the object may be extended due to complexity of the environment. In order to better reflect the related structure features, the line segments are further split [14].

#### b. Inference Based on Structural Features

Under certain scale change of camera view, relative relationship among the line segments is stable. Two categories of structural features are chosen and they are line segment ontology characteristics and relative relationship between the line segments. According to the structural features of each kind of object to be recognized, criterions used for the inference model are made, and the objects are recognized through inference [14].

Fig. 1(a)-(f) give the object recognition results of scenes in camera view corresponding to original images captured by the visual node I to visual node IV, respectively. Cubicle, ground mark, fire hydrant service container and door are the expecting kinds of objects to be recognized.

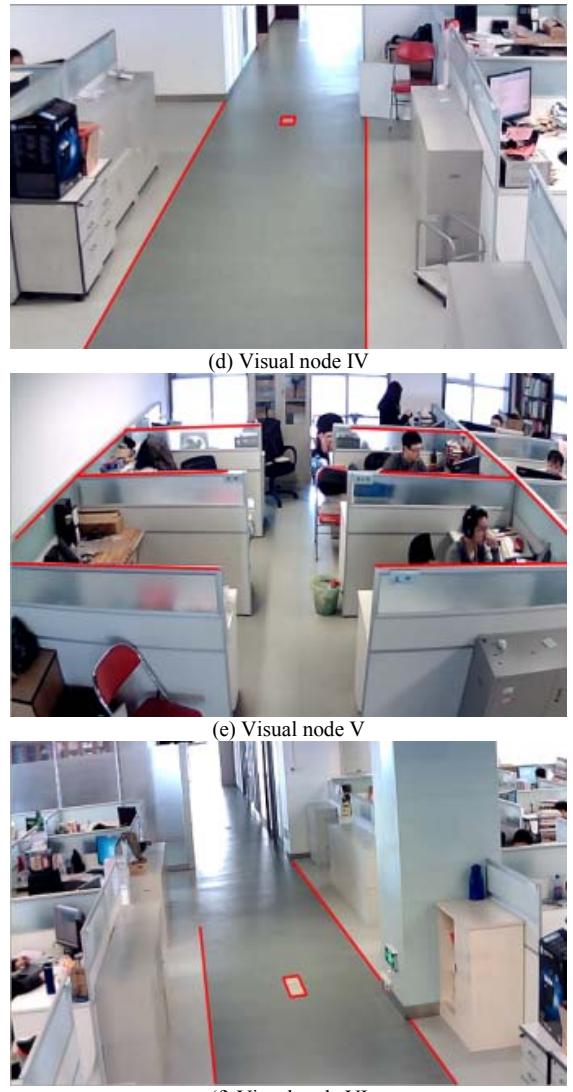


Fig. 1 The object recognition results of scenes in camera view.

#### C. Designing Topological Node

Topological nodes are designed according to the recognized objects and their spatial structure information. On one hand, any a object is mapped to one host node in topological map, and its spatial structure information provides gist for establishing its identification zone in camera view. On the other hand, in order to improve the ability of localization in the areas where the nodes are sparse as well as some key areas, some hidden nodes which are near and subordinate to corresponding host node, are set up manually in the topological map.

Fig. 2 gives an example of the schematic diagram of topological nodes.  $T_1$  and  $T_2$  are corresponding to natural objects recognized in camera view. The identification zones  $D_1$  and  $D_2$ , are established according to  $T_1$  and  $T_2$ , respectively, and they are mapped to the host nodes  $M_1$  and  $M_2$  in topological map. As shown in Fig. 2, the hidden nodes  $N_{11}$  and  $N_{21}$ ,  $N_{22}$  are subordinate to  $M_1$  and  $M_2$ , respectively.

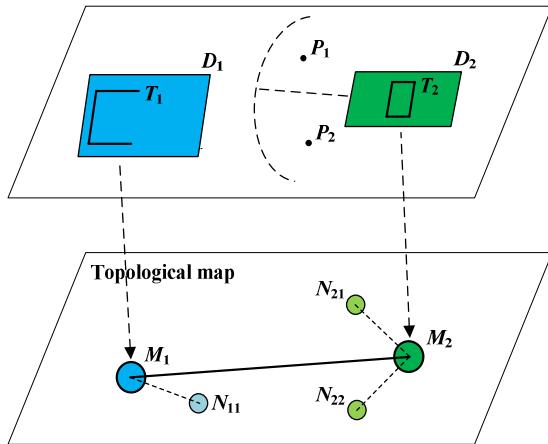


Fig. 2 An example of the schematic diagram of designing topological node.

When the robot is close to  $T_i$ , the specific criterion of judgment used for localization is as follows:

$$P_T = \begin{cases} M_i, P_C \subset D_i \\ N_{ij}, P_C \not\subset D_i, j = \arg \max \left( \vec{e}^{i(\alpha_{ic}-\theta_{kd})} \cdot \vec{e}^{i\beta_{ij}} \right) \end{cases} \quad (1)$$

where  $P_C$  and  $P_T$  are robot locations in camera view and topological map, respectively,  $\theta_{kd}$  is the angle difference caused by scene change from camera view to topological map,  $\alpha_{ic}$  and  $\beta_{ij}$  are the orientation angles from center point of  $D_i$  to  $P_C$  and from  $M_i$  to  $N_{ij}$ , respectively.

#### D. Building Topological Map

Based on the extracted host nodes, their hidden nodes as well as their connections from multiple camera views, topological map is built. Fig. 3 gives the result of topological mapping on the basis of natural objects recognized shown in Fig. 1, where partial hidden nodes are shared by multiple host nodes.

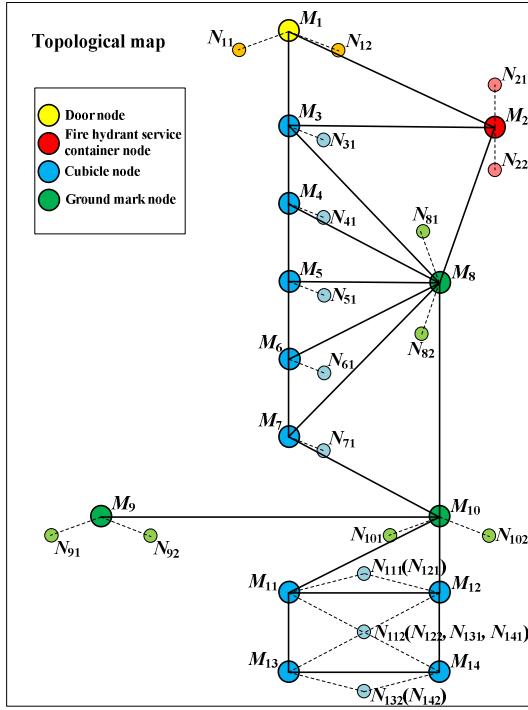


Fig. 3 Topological map corresponding to Fig. 1.

### III. NAVIGATION BASED ON TOPOLOGICAL MAP

#### A. HOG Feature Based Detection and Tracking

We combine detection and tracking to locate the robot. HOG feature [15] is extracted to detect the robot, and particle filter [16] is then employed to track the robot based on HOG feature.

Since the robot has distinctive shape and gradient, we use HOG feature to represent the robot. HOG is an effective descriptor for capturing the intensity gradient information of the object. The detail of the method is as follows: 1) Samples of size  $64 \times 64$  are taken from images of the robot in slightly different angles and illumination. 2) Blocks of  $16 \times 16$  with stride size of  $8 \times 8$  are extracted from the samples, and each block is divided to 4 cells of size  $8 \times 8$ . In each cell, angles of gradients are evenly divided into 9 bins of  $0^\circ \sim 180^\circ$ . So the overall feature vector is 1764 dimensions. 3) Linear SVM is used to train the classifier.

Particle filtering is a general Monte Carlo method for performing inference in state-space models. Let  $X_t$  denote state variable of the target at time  $t$ . With a set of observations  $Z_{1:t} = \{Z_1, Z_2, \dots, Z_t\}$ , the posterior probability by Bayesian theorem is:

$$p(X_t | Z_{1:t}) \propto p(Z_{1:t} | X_t) \int p(X_t | X_{t-1}) p(X_{t-1} | Z_{1:t-1}) dX_{t-1} \quad (2)$$

#### B. Global Localization for Robot

When the mobile robot carries out tasks in the scene under monitoring by visual sensor network, the visual monitoring platform will detect the robot in real time by processing the video images and make global localization for robot in topological map. Robot can obtain its location at any time by communicating with platform. The detailed algorithm of global localization is shown in Algorithm 1, where for visual node related scene  $C_k \in \Phi_C$ , object  $T_i \in \Phi_T$ , identification zone  $D_i \in \Phi_D$ , host node  $M_i \in \Phi_M$ , hidden node  $N_{ij} \in \Phi_N$ , respectively,  $W(P_C, T_i)$  is the distance value of  $P_C$  and  $T_i$  in camera view.

#### Algorithm 1. Global Localization for Robot

**input:** scene set  $\Phi_C$ , number  $A$  of visual nodes in VSN, object set  $\Phi_T$ , identification zone set  $\Phi_D$ , host node set  $\Phi_M$ , number  $B$  of host nodes in topological map, hidden node set  $\Phi_N$ , robot location  $P_C$  in camera view.

**output:** robot location  $P_T$  in topological map.

```

1  $P_T \leftarrow 0;$ 
2 for each  $k$  in  $[1, A]$  do
3   if  $(P_C \subset C_k \text{ and } P_T = 0)$  then
4     for each  $i$  in  $[1, B]$  do
5       if  $(T_i \subset C_k)$  then
6         if  $P_C \subset D_i$  then
7            $P_T \leftarrow P_{M_i};$ 
8         else
9            $Q_i \leftarrow W(P_C, T_i);$ 
10        end
11      else
12         $Q_i \leftarrow \infty;$ 
13      end
14    end
15  if  $(P_T = 0)$  then
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16    $t^* \leftarrow \arg \min_{t \in [1, B]} Q_t;$ 
17    $s^* \leftarrow \arg \max_{N_{t^*s} \in \Phi_N} \left( \bar{e}^{i(\alpha_{t^*s} - \theta_{kd})} \cdot \bar{e}^{i\beta_{t^*s}} \right);$ 
18    $P_T \leftarrow P_{N_{t^*s^*}};$ 
19 end
20 end
21 end

```

### C. Navigation through Visual Guidance

Any node in topological map can be set as the target location. It is easy for robot to calculate the current target orientation by combining its location and target location in topological map.

The local environment around robot is divided into multiple sub-regions based on the sensing information provided by laser range finder [17]. Each sub-region is then evaluated by considering the distance influence factor and visual guidance. Finally, the optimal sub-region adapted to current environment will be used for motion decision of robot.

The robot can make motion decisions for navigation and stop moving when the target location is accord with the result of global localization.

## IV. EXPERIMENTAL RESULTS

In order to verify the effectiveness of the proposed approach, experiments for topological mapping and navigation are conducted in the office scene monitoring by VSN, whose size is 10m\*18m. The corresponding scenes in camera view are shown in Fig. 1. The robotic platform AIM is equipped with laser range finder to obtain range information. AIM gets an average speed of 30 cm/s in the experiments.

In the first experiment, topological nodes  $M_{10}$  and  $M_5$  are set to goals for AIM in sequence, where  $M_{10}$  and  $M_5$  are corresponding to the ground mark located at  $G_{R1}$  and cubicle located at  $G_{R2}$ , respectively. The robot's trajectory is shown in Fig. 4. AIM starts from  $S_R$  in Fig. 4, avoids the obstacle  $obs1$  and goes towards to  $G_{R1}$  under visual guidance. When entering the identification zone of ground mark located at  $G_{R1}$ , the result of global localization for AIM is  $M_{10}$  in topological map, and then the target location is updated to  $M_5$  immediately and the visual guidance for AIM is changed as well. After AIM reaches the identification zone of cubicle located at  $G_{R2}$ , the navigation mission is accomplished.

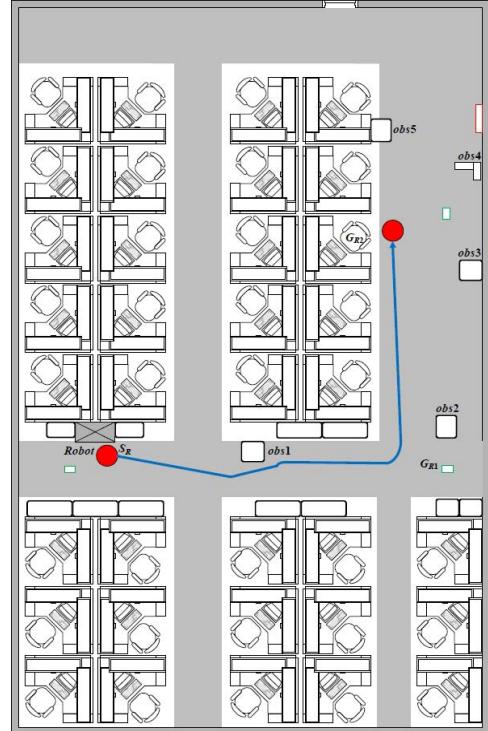


Fig. 4 The robot's trajectory in the first experiment.

In the second experiment, topological node  $M_5$  is set to goal for AIM. The robot's trajectory is shown in Fig. 5. It is seen that AIM starts from  $S_R$ , firstly moves out of the narrow aisle under visual guidance, then moves to the optimal sub-region selected between obstacle  $obs2$  and cubicle and avoids the obstacle  $obs2$ , finally goes straight to the identification zone of cubicle located at  $G_R$ .

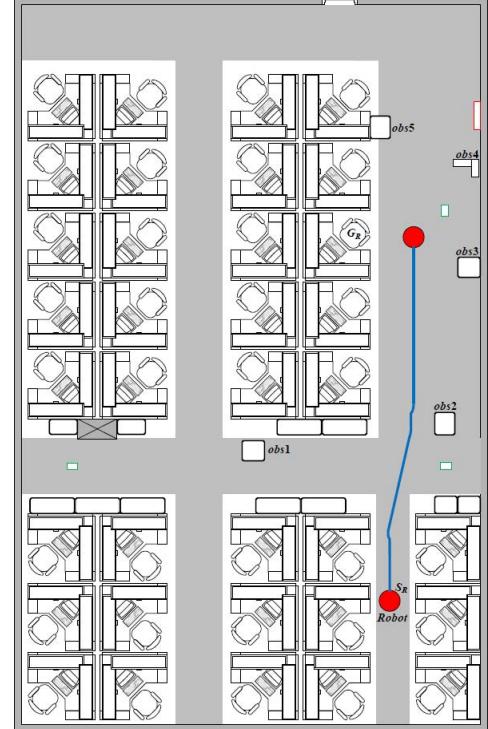


Fig. 5 The robot's trajectory in the second experiment.

## V. CONCLUSION

Based on visual sensor network, we propose a novel topological mapping approach applied to the navigation mission. Our approach does not rely on artificial landmarks and is tested in large-scale office scene. From the experiments we have conducted, this topological map is not only easy to build and maintain, but also capable of implementing navigation through visual guidance. In the future, we plan to improve the performance of topological map. In addition, the identification zones of natural objects recognized will be further optimized.

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