Fast Map Segmentation Method Based on Spectral Partition For Robot Semantic Navigation

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Introduction

Background:

- Simultaneous localization and mapping(SLAM) are a fundamental ability for autonomous robot.
- External global map are not available in most of robot's application.
- Divide the global map into some local map can greatly increase the performance in SLAM algorithm
- Map partitioning is a good way to achieve the harmonization between computer and human in the field of environment recognition.

Difficulties:

- Most SLAM algorithm and map partitioning method have a Huge time-complexity
- Hard to present a criteria for map partition progress.
- Establish the relationship (or conditional independency) between different sub-maps.

Introduction

Contents of this paper:

- Presents an adaptive map partitioning method based on spectral clustering and silhouette coefficient.
- Presents different criterion to build similarity matrix:
  - Nearest neighbour criteria
  - Hausdroff distance criteria
  - Feature point criteria
- Presents an online map partitioning method synchronization with robot exploring process.

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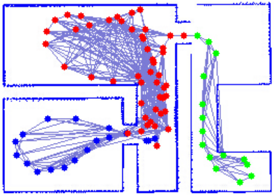

Figure : An Result of map partitioning method

Map Partitioning Algorithm

Spectral Clustering

Spectral clustering is an efficient computational technique based on a generalized eigenvalue problem, and it has been applied successfully in different areas.

The Process of Spectral clustering:

- Construct similarity matrix by the object differences
- Construct normalization Laplacian matrix by similarity matrix
- Calculate the smallest k eigenvalues and eigenvectors
- Cluster the feature vectors

Map Partitioning Algorithm

Problems:

- Why use spectral clustering, but other clustering algorithm. e.g:K-Means, Hierarchical Clustering
- Why the clustering result of Laplacian matrix's eigenvectors can represent the clustering result of samples?
- How to calculate the difference between different samples?

Map Partitioning Algorithm
Calculate similarity matrix and Laplacian matrix

Similarity Matrix:

$$S = \begin{pmatrix} 0 & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{12} & 0 & S_{23} & \cdots & S_{2n} \\ S_{13} & S_{23} & 0 & \cdots & S_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ S_{1n} & S_{2n} & S_{3n} & \cdots & S_{nn} \end{pmatrix} \quad (1)$$

Laplacian Matrix:

$$L_{i,j}^{sym} = \begin{cases} 1 & i = j, deg(v_i) \neq 0 \\ -\frac{1}{\sqrt{deg(v_i)deg(v_j)}} & i \neq j, S_{ij} \neq 0 \\ 0 & otherwise \end{cases} \quad (2)$$

Map Partitioning Algorithm

Nearest neighbour criteria

- Find the optimize match between two observation results
- Calculate the sum of each match's distance
- Don't need to extract features of the map
- Time complexity is acceptable as the size of observation result is small(when use Laser range finder)

$$S(r_a, r_b) = \sum_{r_{bi} \in r_b} \|f(r_{bi}) - r_{bi}\| \quad (3)$$

- r_a, r_b: observation results
- $f(r_{bi})$: The r_{bi}'s match point in r_a

Map Partitioning Algorithm
Hausdroff distance criteria

The main idea of Hausdroff distance is to measure the maximum mismatch of two point sets. This metric is defined as follows:

$$\begin{cases} H(X,Y) = \max(h(X,Y), h(Y,X)) \\ h(X,Y) = \max(xi)\min(yi)\|xi - yi\| \\ h(Y,X) = \max(yi)\min(xi)\|xi - yi\| \end{cases} \quad (4)$$

- The form is simple and easy to implement.
- Time complexity is high, but a designed data structure can greatly decrease the time complexity.

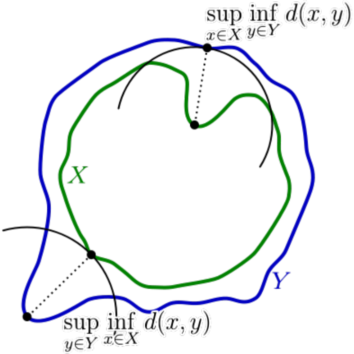

Figure : Hasudroff Distance

Map Partitioning Algorithm

Feature point criteria

- A simple and fast way to measure the similarity of different observation results
- Both time and space complexity is very good
- Generate discrete value

$$S_{ij} = card(\{x| \text{ if } x \in X_i \text{ and } x \in X_j\}) \qquad (5)$$

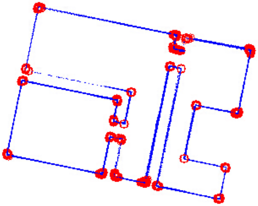

Figure : Feature Point Extraction

Map Partitioning Algorithm

Adaptive clustering method

For each cluster X_i in the above clustering result and each sample $x_j \in X_i$. The cohesion factor a_i is the average distance between every other sample in the cluster X_i. And the separation factor b_i is the minimum average distance between x_j and every other sample not in cluster X_i. Defined as follows:

$$a_i = \frac{\sum_{m=1}^{|X_i|} S(x_j, x_m)}{|X_j|} \quad j \neq i \tag{6}$$

$$b_i = \min\left(\frac{\sum_{m=1}^{|X_i|} S(x_j, x_m)}{|X_j|}\right) \quad j \neq i \tag{7}$$

For the sample x_j, silhouette coefficient is:

$$s_i = \frac{(b_i - a_i)}{max(a_i, b_i)} \tag{8}$$

Map Partitioning Algorithm

Adaptive clustering method

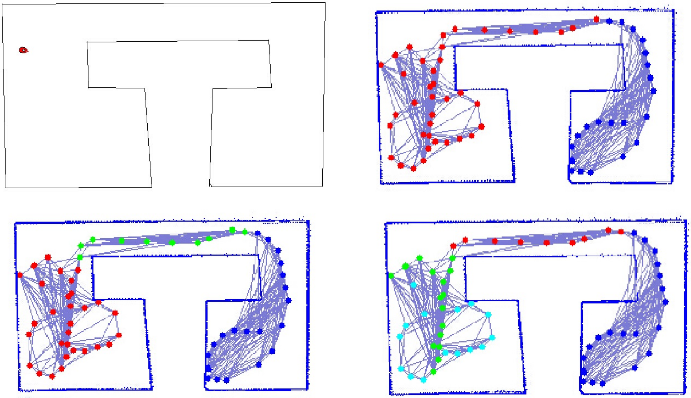

Figure : Silhouette coefficient in different cluster numbers

Online Map Partitioning

1. Autonomous mobile robot wanders in the room and explores part of the global map.
2. Archive separation threshold T with offline map partitioning method. T is the maximum similarity between each cluster.
3. For a new scanning result Xi, calculate the similarity S_{ij} between X_i and every other cluster center Z_j. Determine the category of that result with S_{ij} as follow:
    - If $S_{ij} \leq \theta T$ $(0 \leq \theta \leq 1$ is a pre given parameter determined by the complexity of map). Then X_i and Z_j belongs to same category.
    - If $S_{ij} \geq \theta T$, Then X_i and Z_j do not belongs to the same category.
    - If $\theta T \leq S_{ij} \leq T$ t, Then do not consider the belonging of X_i.
4. If for each center Z_j, $S_{ij} \geq T$, Then such scanning result belongs to a new cluster and take that result as a cluster center.
5. If X_i and Z_i belongs to the same category and the amount of scanner result in Z_i is t, then set cluster center with the equation below:

$$Z_i(t+1) = \frac{1}{t+1}[tZ_i(t) + X_i] \tag{9}$$

Online Map Partitioning

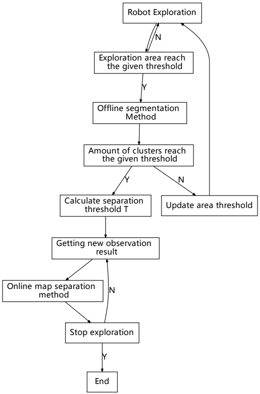

Figure : Digram of online map partitioning method

Experimental Result

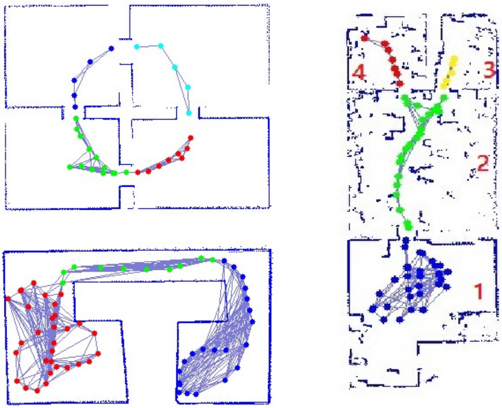

Figure : Experimental Result In Simulation Platform

Experimental Result

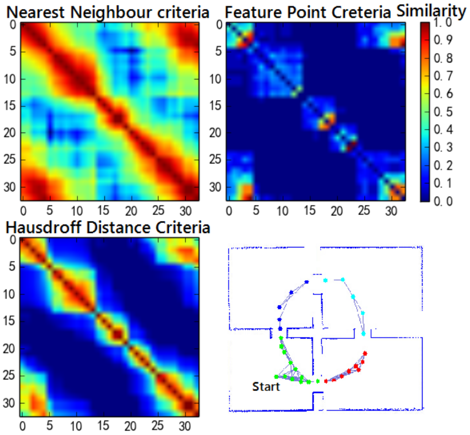

Figure : Similariy Matrix Generated By Different Similarity Measurement Creteria

Experimental Result

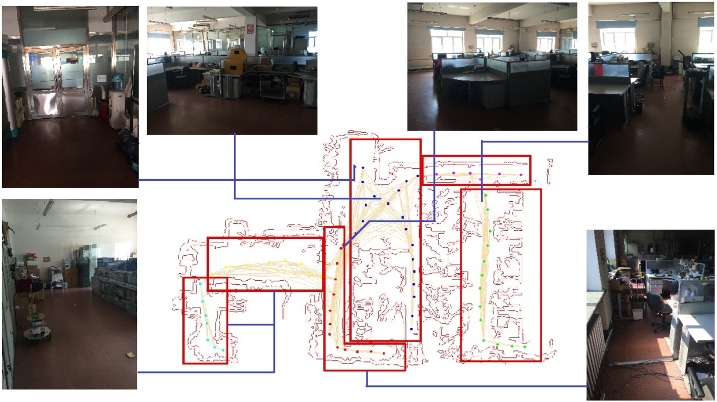

Figure : Map Partitioning Result In Real World

Conclusions And Future Work

Conclusions:

- Presents an adaptive map partitioning method based on spectral clustering and silhouette coefficient.
- Presents different criterion to build similarity matrix:
  - Nearest neighbour criteria
  - Hausdroff distance criteria
  - Feature point criteria
- Presents an online map partitioning method synchronization with robot exploring process.

Future Work:

- Building an human-computer harmonize system with map partitioning and object recognition.
- Optimize the online partitioning method.
- Parallel Processing of map partitioning algorithms.

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Q&A