



Comparing methods for merging redundant line segments in maps

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HIGHLIGHTS

- Map building is a basic building block for autonomous mobile robots.
- Some works use maps composed of line segments to represent indoor environments.
- Methods have been proposed for merging together redundant line segments.
- We experimentally compare the most significant of these methods on public data sets.
- We propose some guidelines to choose the appropriate method.

ARTICLE INFO

Article history:

Received 26 July 2016

Received in revised form 1 September 2017

Accepted 20 October 2017

Available online 9 November 2017

Keywords:

Map merging

Line segment maps

ABSTRACT

Map building of indoor environments is considered a basic building block for autonomous mobile robots, enabling, among others, self-localization and efficient path planning. While the mainstream approach stores maps as occupancy grids of regular cells, some works have advocated for the use of maps composed of line segments to represent the boundary of obstacles, leveraging on their more compact size. In order to limit both the growth of the corresponding data structures and the effort in processing these maps, a number of methods have been proposed for merging together redundant line segments that represent the same portion of the environment. In this paper, we experimentally compare some of the most significant methods for merging line segments in maps by applying them to publicly available data sets. At the end, we propose some guidelines to choose the appropriate method.

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1. Introduction

Map building of indoor environments is a fundamental task for autonomous mobile robots in order to effectively localize themselves and efficiently plan paths so that other tasks, like surveillance or cleaning, can be carried out. Several techniques for robot map building have been proposed during the last decades [1]. The mainstream approach stores maps as *grids* of fixed-size cells that represent either obstacles or free space (or some related probability). However, there have been works, such as [2–5], that proposed the use of line segments to represent the contour of obstacles, in order to reduce the size of the data structures storing the maps, compared to those of grid-based maps. Indeed, for structured indoor environments, representing two-dimensional boundaries of obstacles (like walls) with line segments means storing 4 numbers per line segment (e.g., the coordinates of its endpoints), independently of their length.

To efficiently exploit such a representation based on line segments (and to further limit the size of the maps), it is important

to keep the maps “clean” by eliminating redundant line segments that represent the same portion of the environment, as for example shown in Fig. 1. Redundant line segments usually appear because a robot acquires several times data about the same part of the environment (e.g., for localization purposes) and because, in multirobot settings in which a centralized map is maintained, more robots acquire data about the same part of the environment. Due to errors in perception, localization, and registration of perceptions, redundant line segments are not perfectly overlapped. Thus, the problem that arises is that of “merging” the line segments that represent the same obstacle in the environment. Some methods have been proposed to tackle this problem [6], shaping a (narrow, but active) field of research.

In this paper, we aim at providing an experimental comparative evaluation of some methods for merging redundant line segments. The comparison is performed by using publicly available data sets obtained by real robots. This work provides measurable insights on the pros and cons of the methods in different settings in order to provide a mature assessment of their possibilities and performance, which is distilled in some guidelines that can drive the selection of the most appropriate method. This work updates

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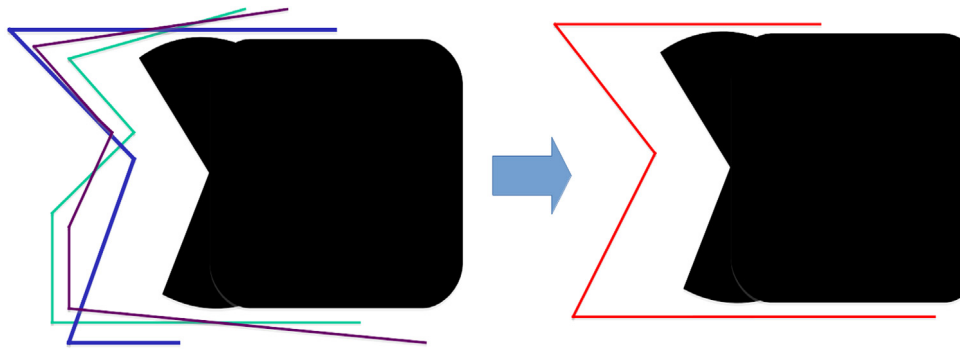


Fig. 1. Redundant line segments derived from multiple scans acquired by a robot representing the boundaries of the same obstacle (in black, left) and the corresponding merged line segments after applying a line segment merging method (right).

and integrates the results of [6] by performing a more complete comparison considering methods recently proposed (that are not included in [6]) and other metrics for assessing their goodness. As such, the original contribution of our study is not in providing a new method, but in presenting a detailed experimental comparison of line segments merging methods and some insights and guidelines that can be derived.

This paper is structured as follows. The next section surveys related work on the use of line segments in robotic mapping. Section 3 describes our experimental setting and Section 4 illustrates the methods we selected for comparison. Section 5 shows the experimental results. Finally, Section 6 concludes the paper by discussing the outcomes of the experiments and some guidelines.

2. Related work

Line segments have been used in different ways in robotic mapping. On one side, they have been used as a mean to register successive point scans (e.g., taken by a laser range scanner) in a consistent way. For example, Censi [7] designs a variant of the Iterative Closest Point (ICP) method [8] in which the distance is defined between points and line segments (representing sets of points). Mazuran and Amigoni [5] improve the matching accuracy of traditional scan matching algorithms by introducing mutual compatibility constraints, namely registering line segments extracted from scans in order to “induce” the correct roto-translation.

On the other side, line segments are used for creating compact maps of the environment. For example, Lakaemper [9] proposes a method to convert scans into line segments and to merge similar line segments using mean shift clustering. Amigoni et al. [3] show an incremental approach to successively merge scans with the current partial map without using odometry, but only exploiting their geometric features.

To have a compact and efficient line segment based map representation, it is fundamental to reduce the number of line segments by merging those that represent the contour of the same obstacle, e.g., a wall. Some methods have been proposed (e.g., [9–13]) relying on different clustering techniques and on different ways to define a distance (or similarity metric) between line segments. These methods are described in detail in Section 4.

3. The experimental setting

In the experimental evaluation performed in this paper, we consider a mobile robot that moves in an environment and acquires two-dimensional data with a laser range scanner. The sensor is characterized by a field of view (angle) f and a range R and returns a set of points, representing the distance (up to R) between the sensor and the closest obstacle along evenly-spaced directions (within f).

The two-dimensional map of the environment known by the robot is represented by a set of line segments. A line segment $s = (a_s, b_s)$ is represented by its endpoints $a_s = (x_a, y_a)$ and $b_s = (x_b, y_b)$ in the Cartesian two-dimensional space with respect to a global coordinate system. The map is iteratively built with the data collected by the mobile robot. Specifically, given a scan acquired by the sensor at step i , the raw points returned by the laser range scanner are approximated by a set of line segments S_i (e.g., using the split-and-merge method presented in [14], the method of [10], or a least-square fitting method, see Section 5.3). The line segments of S_i are aligned with those of M_{i-1} (e.g., with the registration method of [3], with that of [15], or according to the ground truth, see Section 5.3) and then the map M_i is updated by adding the aligned line segments S_i to the old map M_{i-1} . Probabilistic approaches that account for the uncertainty of perceptions and alignments [16] could be also employed. The final result of the mapping process is thus a set of line segments M in the global coordinate system.

A line segment merging method can be applied either to M at the end of the merging process (*batch*) or to the aligned scan S_i and the partial map M_{i-1} at each step i (*iterative*). Batch methods work on a single set of line segments, while iterative methods work on two sets of line segments. (Note that batch methods can also be applied to each M_i .) The result of the application of a merging method to M (respectively, M_{i-1} and S_i) is a new map $\hat{M}$ (respectively, $\hat{M}_i$) whose size, in terms of number of line segments, is usually reduced. Note that the line segments merging methods are largely independent of how the line segments have been acquired.

4. The compared methods

In this section, we present the representative line segments merging methods we experimentally compare; please refer to the original papers for more information. Note that, in the following, some notation overload occurs as we try to keep the notation used in the original papers. Our sample covers well the spectrum of the current merging methods *explicitly* devoted to reduce the number of redundant line segments in maps (see Table 1). In this sense, we do not consider merging methods that have been presented as part of more general mapping systems. The selection of methods includes representatives of batch and iterative methods, methods that merge pairs or sets of line segments, and methods that need to set more or less parameters. To the best of our knowledge, no significant method is left out from our analysis. For each method, we present the *fusion conditions* under which two or more line segments in M (respectively, M_{i-1} and S_i) are merged (or the clustering method) and the *fusion procedure* that determines the approximating line segments in $\hat{M}$ (respectively, $\hat{M}_i$).

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