Fast Method of 3D Map Building Based on Laser Range Data

Received 7th May; accepted 24th May

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Abstract:

In this paper, we consider the problem of 3D maps building based on the 3D laser scanner indications. The map of the environment is represented as a 2D array of cells. Each cell represents rectangular region of the scene and consists of a list of objects. The key idea of the system is lines extraction from the raw laser data and assigning them to the proper cells. Based on the lines, a set of objects (planes) is built and assigned to each cell. Objects represent obstacles in the environment. The main advantages of the system are real-time map building and low memory consumption. We prove that the system works properly in real indoor environment but the system can be extended in order to built the map of unstructured robot's surrounding.

Keywords: *mapping, navigation*

1. Introduction

Localization and mapping are the tasks which must be performed by practically all intelligent, moving robots, independently of their primary task. Only the robot which can make a representation of the environment is capable to perform its task properly. The features of good map are: real-time map building, low memory consumption, fast access to described objects, easy to understand by robots. Mapping methods, usually belong either to grid-map-based [9][10] or landmark-based approach. The former rest on representation the map by a grid of cells. In each cell a value between 0 and 1 is kept. The value represents the possibility that the corresponding region of the environment is occupied by the obstacles. In the later technique the map is represented as a set of features [8] [6]. The stationary landmarks of the environment are the targets which are to be traced. Laser measurement systems are very popular. They are used for obstacle detection [15], localization [1] and map building [16]. Most of the applications concern in 2D world modeling but in many situations the restrictions of the 2D representation have serious limitations. Especially, path planning problem is difficult if all obstacles are described in two-dimensional space. Based on maps 2D, robots can not recognize neither floor accidents, nor obstacles in space. In many practical situations 3D model of the environment is required. For example 3D maps allow to find a path under a table, desk, etc. Many authors described the methods of reconstruction three-dimensional structures from camera images [4]. Such system requires stable light conditions so in many situation it is better to use the active sensors like laser scanners than the passive ones like cameras. In order to build 3D laser range scanner, lasers 2D are mounted on a rotating support. Such systems allow to read scanner data from laser 2D and rotate the whole device vertically up and down. Several authors use 3D laser range scanners for building 3D models of the robot's environment [17][15]. The cloud of points created by 3D range scanner is a valuable, but it is not easily manipulated. Typical mapping programmes require a lot of time in order to interpret a data set that consists of millions of points. One of the fastest method of 3D modeling is 2.5 map of an environment. The map is represented as 2D array of cells, each cell corresponds to a rectangular area of the environment. The value of the cell represents the maximal height of observed obstacle [12][13]. The method of data aggregation is fast but the quality of the map depends on the dimension of the cell and in many situations is not good enough to be used during the localization process. In this approach uncertainty of sensors indications are not taken into account. Figure 1a) represents the picture of an environment and 1b) its 2.5D representation. Another approach uses voxels (volumetric pixel). It is time consuming and the computation cannot be performed in real time.

Fig. 1 Image of an environment(a) and its 2.5D representation (b). Image 1a) is taken from [7].

2. Hardware

The robot Elektron1 presented in Fig. 2, made in Warsaw Technical University has been used in our experiments. The robot is equipped with laser 2D (SICK LMS 200) mounted on a rotating support. Sick LMS 200 reads data every 1° (0°-180°), the rotating support rotates also 1°. The laser was vertically rotated from the -13° to 90°. It gives: 181 x 103 = 18643 points.

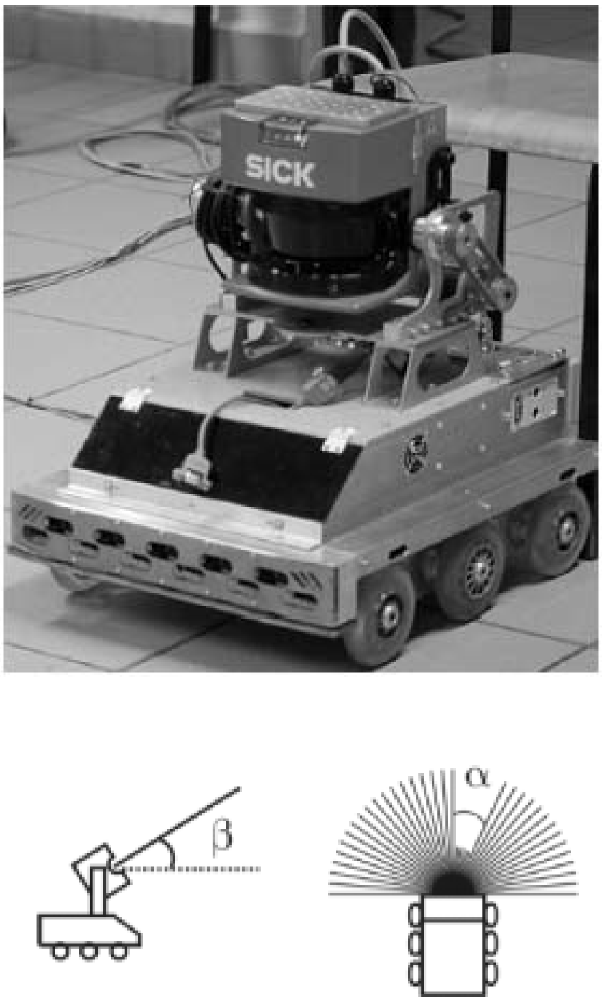


Fig. 2 The mobile robot Elektron 1 used in the experiments. The images are taken from [7].

Data from the laser is obtained in the polar coordinate system (r_r^j, α_i, β_i) where:
r_r^j - distance to an obstacle [meters],
α_i, β_i - respectively the horizontal and vertical angle (fig.5).

They are recalculate to the cartesian one, by the following equations:

$$x_i^j = r_i^j \cos(\beta_i)\cos(\alpha_i)$$
$$y_i^j = r_i^j \sin(\alpha_i) \qquad (1)$$
$$z_i^j = r_i^j \sin(\beta_i)\cos(\alpha_i)$$

where: (x_i^j, y_i^j, z_i^j) - cartesian coordinate of a point.

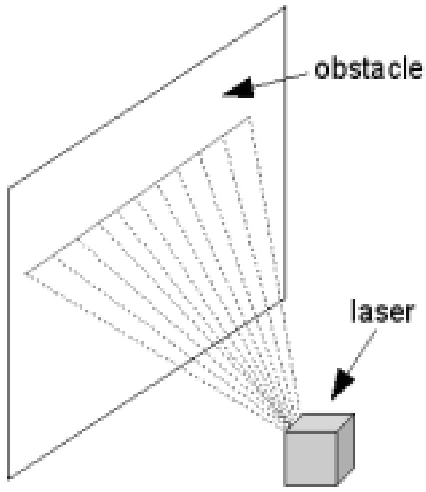


Fig. 3 The concept behind the method

3. Algorithm

The hybrid grid-based and feature map representation is used in our approach. The map of the environment is represented as a 2D array of cells. Each cell corresponds to a rectangular region of the robot's environment and keeps a list of features (planes). In presented approach planar features are recognized but the system can be extended. Figure 4 presents the algorithm of our approach.

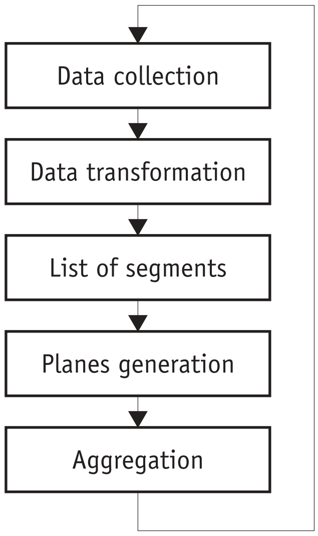


Fig. 4 The algorithm

3.1. Data collection

For each value of the vertical angle b the data is collected. The set {((r_i, α_i, β_i)}$_{i=1,..n}$ is transformed into a set {(x_i, y_i, z_i)}$_{i=1,..n}$ using equation 1.

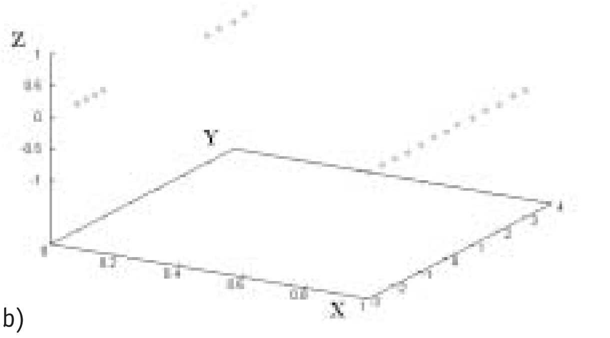
For the given value of parameter β the laser data is a result of intersection of scanning plane and obstacles planes. The split-and-merge algorithm is used to extract line segments. Figure 5 presents the concept behind the method. Then to fit a line to a set of points we use a modification of the method proposed by Lu and Milios [5]. Then based on generated equation of the line the end points of the segment are recomputed.

Segments generated for given vertical angles from β_i to β_{i+n} are stored in a memory of a computer. Each segment is represented as a pair of points $[(x_1, y_1, z_1), (x_2, y_2, z_2)]$.

The value of the parameter n is chosen experimentally.

Figure 5b) presents the list of segments created based on the data given by LMS in the scene presented in the image 5a).

a)



b)

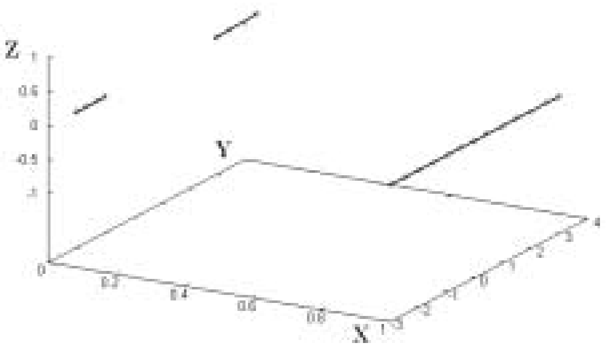
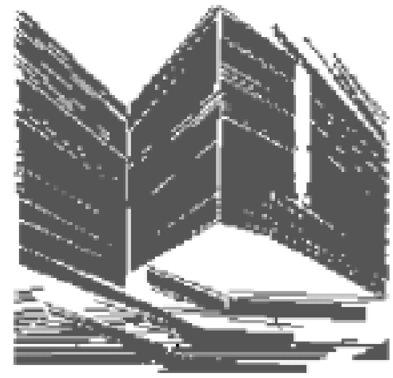


Fig. 5 Scanner readings for given b (a) and extracted lines (b)

a)



b)

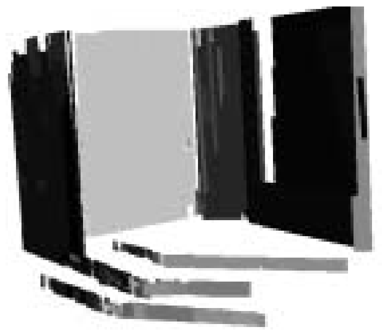


Fig. 6 List of segments a) and list of planes b)

3.2. List of planes extraction

A list of segments $s_{i\{i=1,...n\}}$ is assigned to each cell of the grid-based map. It is assumed that the segment s_k is assigned to the cell ij if the projection of s_k onto XY plane intersects the corresponding region of the environment. Then the list is analyzed and a set of planes is extracted. Our approach is similar to the split-and-merge algorithm.

If it is possible, the equation of a plane p which includes segments s_1 and s_n is generated according to formulae 3.

$$p : A \cdot x + B \cdot y + C \cdot z + D \quad (2)$$

$$\begin{aligned} A&=(y_1^1-y_0^1)(z_0^1-z_0^1)-(y_0^n-y_0^1)(z_1^1-z_0^1)\\ B&=(z_1^1-z_0^1)(x_0^1-x_0^1)-(z_0^n-z_0^1)(x_1^1-x_0^1)\\ C&=(x_1^1-x_0^1)(y_0^1-y_0^1)-(x_0^n-x_0^1)(y_1^1-y_0^1)\\ D&=-x_0^1-A-y_0^1B-z_0^1C \end{aligned} \quad (3)$$

where:

$$\begin{aligned} s_1&=[(x_0^1,y_0^1,z_0^1),(x_1^1,y_1^1,z_1^1)]\\ s_n&=[(x_0^n,y_0^n,z_0^n),(x_1^n,y_1^n,z_1^n)] \end{aligned} \quad (4)$$

If $s_1 \subset p \wedge s_n \subset p$ then:

$$d=\sqrt{\frac{Ax_1^n+By_1^n+Cz_1^n+D}{A^2+B^2+C^2}} \leq \varepsilon \quad (5)$$

d is the distance from the found plane to the point (x^n,y^n,z^n).

If $d > \varepsilon$ we are looking for the minimal value m such that the plane which includes s_1 and s_{n-m} exists.

For each segment s_k, where $k \in (1, ..n)$ a value d_k is computed

$$\begin{aligned} d_k&= \max\,(d_k^0,d_k^1)\\ d_k^0&=\sqrt{\frac{Ax_0^1+By_0^1+Cz_0^1}{A^2+B^2+C^2}}\\ d_k^1&=\sqrt{\frac{Ax_1^k+By_1^k+Cz_1^k}{A^2+B^2+C^2}} \end{aligned} \quad (6)$$

If $\forall_{i=1,...,n} d_i < \varepsilon$ the equation of the plane is calculated according to the formulae 9.

In other cases we are looking for a value m such that:

$$d_m=\max(d_1,.., d_n) \quad (7)$$

The set of segments is divided into to subsets $\{s_i\}_{i=1,..,m}$ and $\{s_i\}_{i=m,...,n}$. The algorithm is repeated until the set of planes is generated.

Figure 6b) presents the set of planes generated for segments which are presented in figure 6a). Each cell represents to 20cm × 20cm region of the environment. The plane which are parallel to the floor are not presented.

4. Data aggregation

A list of planes is generated based on a list of segments. Equation 3 can be described by:

$$n_x x + n_y y + n_z z + 1 = 0 \qquad (8)$$

It is assumed that $D \neq 0$.

If (x_i, y_i, z_i) is a set of end points of segments $\{s_k\}$ and p such that for all i $s_i \subset p$ exists then using regression method [3] parameters n_x, n_y, n_z are a solution of an equation 9.

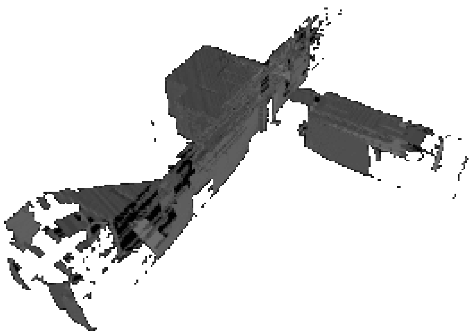
$$\begin{bmatrix} \Sigma x_i^2 & \Sigma x_i y_i & \Sigma x_i z_i \\ \Sigma x_i y_i & \Sigma y_i^2 & \Sigma y_i z_i \\ \Sigma x_i z_i & \Sigma y_i z_i & \Sigma z_i^2 \end{bmatrix} \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} = \begin{bmatrix} -\Sigma x_i \\ -\Sigma y_i \\ -\Sigma z_i \end{bmatrix} \qquad (9)$$

The uncertainty of a plane equation is described by parameter σ

$$\sigma = \frac{1}{N} \sum_{i=1}^{N} \frac{|n_x x_i + n_y y_i + n_z z_i|}{\sqrt{n_x^2 + n_y^2 + n_z^2}} \qquad (10)$$

If new data is obtained, new values of $(\Sigma x_i^2, \Sigma y_i^2, \ldots\ldots)$ are calculated based on stored and new information and new values of parameters (n_x, n_y, n_z) are computed again.

a)



b)

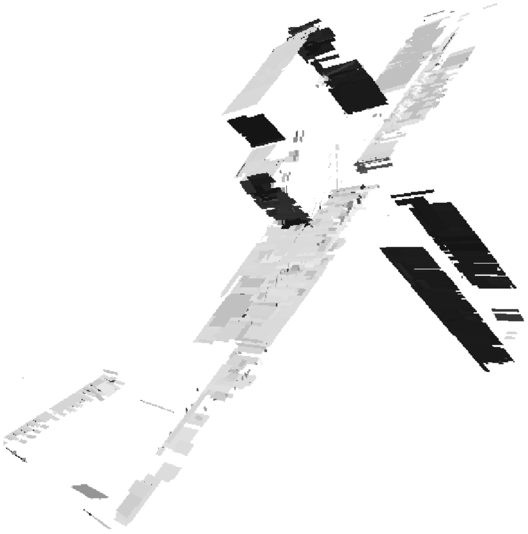


Fig. 7 The image of the environment

5. Experiments

The experiments where performed in a real office environment on the scene 21m × 19m. The data was collected by a Sick LMS200 laser mounted on a robot Elektron1 (fig. 2). The whole scene is presented in fig.7. The robot Elektron1 works under well known Player/Stage environment. Player is a server which allows to control real mobile robots as well as perform simulations. Localization of the robot was supervised by "lodo" module which is a part of the Player server.

Data is taken from 6 different places. Two of the places are presented in fig. 1a and fig. 8a. Data from the places was used to create a set of planes. The former experiment shows a place with stairs. The results (fig. 6b) show that the stairs are easy to be recognized. The later experiment shows a long corridor and a hall in front of it (fig.8a). There are 3 main planes in the picture: the left wall of the corridor, the right wall of the hall and small left hall plane. The results in fig.8b, show the planes. The right wall of the corridor is not visible, because from the place where data was taken it is not seen very well. In the experiments the size of cells are 20cm × 20cm.

a)

b)

Fig. 8 The image of the environment a) and its plane representation b)

6. Conclusions

In the article a hybrid grid-based system of 3D map building based on laser 3D data is presented. All obstacles are presented as planes. The raw laser data is transformed to segments, which are stored in cells. The main difference from other approaches is a new hybrid 2D grid-based and object-based representation. The method consumes less memory than for example typical mesh and voxel methods. Planes are generated based on a list of segments that why it is not necessary to remember the cloud of points. Another advantage is that a single scan is sufficient to start data analysis. In this paper a new method of data segmentation is presented.

ACKNOWLEDGMENTS

We would like to thank R. Chojecki, P. Trojanek and M. Majchrowski for helping us in performing the experiments.

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