Feature Extraction for 2D Laser Rangefinder
Ruiqing Zhuang
School of Shanghai Maritime University, Shanghai 201306, China.
ruiqingzhuang1070739539@qq.com

Abstract
This article presents a feature extraction framework for conventional 2D laser range finder. The framework consists of two main procedures: clustering, feature extraction. Features, such as lines, corners and curves, can be segmented by the curvature function of the range data. For each landmark, the geometrical parameters are provided with statistical information, which are used in the subsequent matching phase, together with a priori map, so as to get an optimal estimate of the robot pose. The method is demonstrated as part of a navigation system for an indoor service robot. Experimental results show that the proposed method is robust in complex environment.

Keywords
2D Laser Range Finder; Feature Extraction; Curvature Function; Robot Navigation.

1. Introduction
It is usually important in mobile robotics that the robot wants to know where it is in a known or unknown environment. Features is the key for autonomous mobile robot navigation systems [1]. It is well known that using solely the data from odometry is not sufficient since the odometry provides unbounded position error [Iyengar & Elfes, 1997]. One of the key problems of feature-based navigation is the reliable acquisition of information from the sensor. Due to many advantages of laser rangefinder, such as good reliability, high sampling rate and precision, it is wildly used in mobile robot navigation. This approach has been studied and employed intensively in recent research on robot navigation [Jensfelt & Christensen, 1998].
Lines are the favorable geometric features extracted from original range data in robot navigation. And there are many methods focused on line extraction [2]. Though many shapes can be approximated by line segments as polygons made up of many short lines, it is unsuitable to cope with round objects like columns or round pieces of walls. Surface curvature has been widely used recently by many researchers to achieve range image analysis [3]. Indeed, local curvature is an excellent tool to characterize a surface, especially because it captures intrinsic properties of the surface. In this work, we employ the local curvature function associated to laser range scan readings to obtain several types of natural landmarks. The main advantages of these approaches are that they can track multiple models, such as line, curve and corner, to describe the measurement process for different parts of the environment. The range data in this article are obtained from a scanning laser rangefinder mounted on a moving vehicle that scans through a 180° arc to give the distance to objects in the environment at angular intervals of 0.5° with a maximum range of 80 m.

In this paper, we describe a feature extraction algorithm, which is composed of two main parts: clustering, feature extraction [4]. For clustering, the adaptive algorithm proposed by Arras et al [Arras, et al 2001] is employed. This algorithm clusters laser scan measurements between two consecutive breakpoints (or rupture points), and it makes the later process fast and robust. And in feature extraction [5], we describe a geometrical feature detection method for use with conventional 2D laser
range finder. The contribution of this paper is that our method employs the curvature function associated to laser range scan readings to segment the original range image to multiple types of natural landmarks, such as line, curve and corner.

2. Laser scan data segmentation

Scan data is clustered by adaptive process. And big noises, such as isolated range readings, are rejected, but it provides an under segmentation of the laser scan. For range data acquired from clustering process, the relationship of adjacent points is, however, totally dependent on the shape of the scanned environment. The difference between neighboring points can be depicted by a function of geometry parameters, such as the direction of the local tangent or curvature of objects in the environment, etc. The curvature of the points belong to the same features is supposed to be same or change regularly. Curvature functions basically describe how much a curve bends at each point. In this work, we employ the curvature function associated to laser range scan images to break the segments into several unique features, and then the segmented curvature function is searched for geometric features. In this paper, the curvature function is calculated according to literature [Knieriemen, et al 1991].

(1) Line segments result from the scan of planar surfaces. Therefore, they are those sets of consecutive range readings with curvature values close to zero which is called zero regions. And they have a certain minimum width ($l_{\text{min}} = 5$ range readings in our experiment).

(2) Curve segments result from the scan of curve surfaces. Contrary to the line segment, the curvature function associated to a curve segment is detected whenever a region of the curvature function has a value larger than a preset value; this value can be found over a certain minimum width and the maximum in the middle of the region differs only by a certain amount from the values at the end.

(3) Corners are due to change of surface being scanned or to change in the orientation of the scanned surface. The corner is always defined by a value associated to a local peak of the curvature function. It is a region with either positive or negative values and a region between two segments which have been marked as line or curve and also has a certain minimum width, which can filter out spurious peak value due to random noise which has a relative low value.

3. Landmark extraction and characterization

As it can be appreciated in Fig.3, the curvature function can directly provide a set of landmarks, which is composed of items associated to real and virtual features of the environment (line segments, curves, corners defined as the intersection of previously detected line segments). In order to provide precise feature estimation, extraction of geometric parameter from segments is needed after segmentation for feature based localization. For each landmark, it is not only necessary to extract the feature parameter vector, but also to determine their covariance matrix which is essential in feature-based SLAM approaches. In this paper, these problems are solved by fitting and estimating the uncertainty associated to corresponding features.

A standard regression method is widely used to find the best line as features. If the fitting error is beyond a predefined threshold, the extracted line will ignored. Then, real and virtual(intersection) corners can be obtained from the intersection of the previously detected line segments. For a circle fitting problem, we use the Levenberg-Marquardt method to solve this nonlinear least-squares problem.

3.1 Line Segments

The line parameters are ($\theta, d$) from the line equation $x \cos \theta_1 + y \sin \theta_1 = d_1$. Given n points $p(r_i, \varphi_i)$, the regression parameters are given by following expressions [Arras, et al 1997]:

$$\theta = \frac{1}{2} \arctan \left( \frac{-2 \sum (\bar{d} - y_i)(\bar{x} - x_i)}{\sum (\bar{y} - y_i)^2 - (\bar{x} - x_i)^2} \right) = \frac{1}{2} \arctan \frac{\sum d_i}{D}$$ (1)

$$d = \bar{x} \cos \theta + \bar{y} \sin \theta$$ (2)
where $\bar{x} = \frac{\sum r_i \cos \varphi_i}{n}$ and $\bar{y} = \frac{\sum r_i \sin \varphi_i}{n}$.

The parameters $\theta$ and $d$ are a function of all the measured points $p_i$, $i=1\cdots n$ belonging to equation (3). Assuming that the individual measurements are independent, the covariance matrix of parameters $(\theta, d)$ can be calculated as

$$C_{\theta, d} = \sum_i J_i C_{xy} J_i^T$$  \hspace{1cm} (3)

where uncertainty of a measured point $p_i$ is represented by a covariance matrix $C_{xy}$, and the terms of Jacobian matrix are obtained as follows

$$\frac{\partial \theta}{\partial x_i} = \frac{(\bar{y} - y_i)D + (\bar{x} - x_i)N}{(N^2 + D^2)}$$

$$\frac{\partial \theta}{\partial y_i} = \frac{(\bar{x} - x_i)D + (\bar{y} - y_i)N}{(N^2 + D^2)}$$

$$\frac{\partial d}{\partial x_i} = \frac{\cos \theta}{n} + (\bar{y} \cos \theta - \bar{x} \sin \theta) \frac{\partial \theta}{\partial x_i}$$

$$\frac{\partial d}{\partial y_i} = \frac{\sin \theta}{n} + (\bar{y} \cos \theta - \bar{x} \sin \theta) \frac{\partial \theta}{\partial y_i}$$  \hspace{1cm} (4)

where $N$ and $D$ are the numerator and denominator of the expression (2).

### 3.2 Curve segments

A circle can be defined by the equation $(x - x_0)^2 + (y - y_0)^2 = r^2$, where $(x_0, y_0)$ and $r$ are the center and the radius of the circle, respectively. For a circle fitting problem, the data set $(x, y)$ is known and the circle parameters need to be estimated.

Assuming that we have obtained $M$ measurements $p(x_i, y_i)$, our objective is to find $p(x_0, y_0, r)$ subjecting to $f_i(x_0, y_0, r) = (x_i - x_0)^2 + (y_i - y_0)^2 - r^2 = 0$ where $i = 1 \cdots M$.

We use the Levenberg-Marquardt [Nash, 1979] method to solve this nonlinear least-squares problem

$$\begin{pmatrix} A_k \lambda_k \end{pmatrix} \Delta p_k = -A_k \hat{f}_k$$  \hspace{1cm} (5)

where $A = [\nabla f_1, \nabla f_2, \cdots, \nabla f_M]^T$ is the Jacobian matrix, and $\Delta p_k = p_{k+1} - p_k$ and $p_k$ is the estimate of $p(x_0, y_0, r)$ at the $k$-th iteration. The initial value of $(x_0, y_0, r)$ is got by using the first, last and middle points. According to [Nunez, et al 2007], an estimation of the curve segment uncertainty can be approximated by three points of the curve segment.

### 3.3 Corners

Then, real and virtual corners can be obtained from the intersection of the previously detected line segments. Once a corner is detected, its position $(x_c, y_c)$ is estimated as the intersection of the two lines which generate it. Given two lines $xc \cos \theta_1 + y \sin \theta_1 = d_1$ and $xc \cos \theta_2 + y \sin \theta_2 = d_2$, the equations to calculate corner $(x_c, y_c)$ is:

$$\begin{align*}
x_c &= \frac{(d_1 \sin \theta_2 - d_2 \sin \theta_1)}{(\sin(\theta_2 - \theta_1))} \\
y_c &= \frac{(d_2 \cos \theta_2 - d_1 \cos \theta_1)}{(\sin(\theta_2 - \theta_1))}
\end{align*}$$  \hspace{1cm} (6)

where $(d_1, \theta_1)$ and $(d_2, \theta_2)$ can be get from previous line extraction process. And the variance of $(x_c, y_c)$ is

$$C_{x_c,y_c} = J C_{\theta_1 \theta_2} J^T$$  \hspace{1cm} (7)

Where $J$ is the Jacobian matrix of equation (7) to $(d_1, \theta_1, d_2, \theta_2)$. And $C_{\theta_1 \theta_2}$ is the covariance matrix of line parameters $(d_1, \theta_1, d_2, \theta_2)$. For convenience, the line parameters $(d_1, \theta_1)$ and $(d_2, \theta_2)$ for two different tangent lines are supposed to be independent. Then $C_{\theta_1 \theta_2}$ is simplified to be $\text{diag}(C_{\theta_1}, C_{\theta_2})$. 

89
4. Experimental results

In this section, we use the mobile robot which is equipped with a laser rangefinder LMS200 as exteroceptive sensor to test the localization capability of our method. The robot is running under windows system in a 1.8 GHz PC and can be controlled by a remote control module via wireless network. All Algorithms are programmed in C++. The SLAM experiment is carried out in a laboratory environment (see Fig.4).

Fig. 1 A range image for an indoor environment

Fig. 2 Curvature function w.r.t. Fig.1

Fig. 2 is the cuvature function, which is searched for geometric feature, with respect to Fig.1: Fig. 3 shows the detected line segments( signs), corners( signs) and curve segments( signs) associated to Fig.1.

Fig. 3 Features extracted from range scan data in Fig.1

Fig. 4 Localization experiment: odometry, estimated trajectory.
Fig. 4 represents the map trajectory estimation obtained using the UKF [Julie, et al 1995] based navigation algorithm in an indoor environment. The accuracy of the estimated trajectory, which starts in a laboratory and continues through a corridor and finally returns to the laboratory, is shown. The uncertainty of landmarks (only corners) and robot pose are also shown in this figure. It can be noted that the extracted and characterized features has been used in this navigation system providing stable landmarks to the robot localisation and map building process.

5. Summary

This paper describes the implementation and obtained results of an feature extraction framework using a 2D laser rangefinder. A segmentation based on the curvature function of the range image is introduced. This algorithm can provide line segments, corners and curve segments for mobile robot localization. Landmarks extracted from these segments are not only characterized by their parameters but also uncertainties. The total time necessary to process the scan data is very reduced, which is suitable for real time applications. Compared to other feature extraction algorithms, the proposed method permits to extract and characterize several features with very low computational requirements. The accuracy and robustness of the proposed method was demonstrated in an indoor robot navigation experiment. Future work is to develop an algorithm for feature extraction in dynamics environments.

References


