Fast Laser Based Feature Recognition

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I. Introduction

Today the use of mobile robots is accepted as a part of everyday life. Autonomous vaccum cleaners and lawnmowers are examples of products which are available for home use. In industry, large efforts are made to replace manually operated vehicles in dull or hazardous applications with autonomous or teleoperated vehicles. One example of an industry application is the LHD (Load-Haul-Dump) vehicles, which are typically used in mines to transport ore from the stope or muck-pile to a dumping point. The work presented here is a part of an effort to develop algorithms for a control system based on reactive navigation to be used in a LHD vehicle.

The requirements for navigating the tunnels of a mine are basically the same as the requirements for navigating the corridors of an office building. First, the robot has to be able to locate the walls of the corridor that is currently being traversed. Second, intersections or doors have to be identified and their location relative to the robot have to be established. The first requirement has to be fulfilled for the robot to be able to successfully follow a corridor, the second is crucial for the localisation and the ability of the robot to navigate to a particular goal. In this paper we present our methods for feature recognition used for high speed reactive navigation based on a topological map, with none or sparse metric information. Our methods for corridor and intersection detection yields execution times of only a fraction of what we have found previously described in the relevant literature, and have proven robust and reliable in experiments performed both in office environment and in our test mine [Larsson et al., 2005].

A. Related Work

Our Corridor detection algorithm is based on the Hough Transform, a method proposed in 1962 by Paul V.C. Hough [Hough, 1962]. The Hough Transform is a robust and effective method for finding lines in a set of 2D points, and is a commonly used method in image processing [Duda and Hart, 1972]. In mobile robotics the Hough Transform has been widely used both for vision based self localisation, see for instance [Iocchi and Nardi, 1999], and mapping based on laser range data [Giesler et al., 1998]. In [Barber et al., 2001] a complete control system for topological navigation is described. The system uses a Hough Transform to detect lines segments, and from those segments corners and doors are extracted. However, in the experiments described the robot travels at 0.2 m/s, a speed that does not require a fast control loop and thus any high speed feature recognition. The average time to invoke the detection service and get back the detection data in the distributed system running on 400 MHz AMD K6-II processors under Linux are several hundreds of milliseconds, which is far too long to allow high speed navigation.

In [Alempijevic, 2004] a new innovative method to extract lines directly from the range data of the laser scanner is presented. Although this method is fast due to the fact that the line detection is done in sensor coordinates, it has the drawback that to be able to detect a line the laser points on that line have to be consecutive. The execution times of this method is in the order of tens of milliseconds, implemented in Matlab and compiled using the Matlab C compiler.

II. Feature recognition algorithms

Since the intention is to be able to run the feature recognition algorithms on an embedded system controlling a vehicle at high speed, it is most crucial that the algorithms are effective and computationally cheap, but still robust and reliable in all situations. This have been achieved by using a modified Hough Transformation to detect corridors, and by detecting doors or intersections in a combination of sensor space and Cartesian coordinates. To be able to reach the short execution times, both the corridor and the door/intersection detection use the fact that the density of the sensor readings is directly relative to the measured distance, this enables us to exclude a vast amount of data points without losing any information. In our experiments we have achieved execution times for the feature recognition of 1–3 ms on a 1.7 GHz Pentium M running Linux. Figure 1 gives an example of the extraction of the edges and direction of a corridor from laser range data. The green line shows the centre and direction of the corridor while the blue lines indicates the location (dark) and direction (light) of two corridors intersecting the traversed one.

A. Corridor detection

In our experiments the Hough space of the corridor detection is discretized with the angular resolution $1\,^\circ$, and the radius in 100 steps, i.e. radius resolution is the desired detection-range/100. Since all the angles of the laser data and Hough Transform are known in advance, the sine and cosine functions of these angles are all precomputed and stored, and thus can be accessed by a single indexing operation. The Hough Transform is by far the most time consuming operation of our algorithm. To reduce its computation time, we have implemented a simple function to exclude redundant information: any laser point that is closer to its predecessor than the radius resolution is excluded. In indoor environments where we have used the detection range 10 m, this reduces the laser data points in the typical situation of Figure 1 to one third, giving a significant reduction of the computation time. The elimination of redundant information also gives

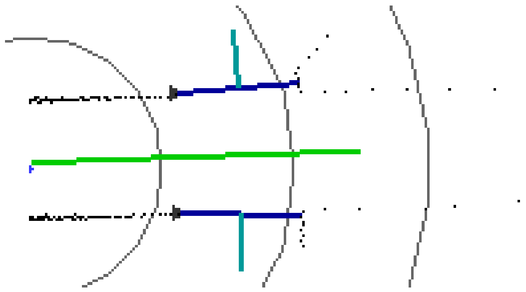

Fig. 1. Detected corridor line (green) and intersecting corridors (blue), robot (small blue triangle) on the left of the figure, heading right. Distances between scalelines (grey arcs) are 2.5 m.

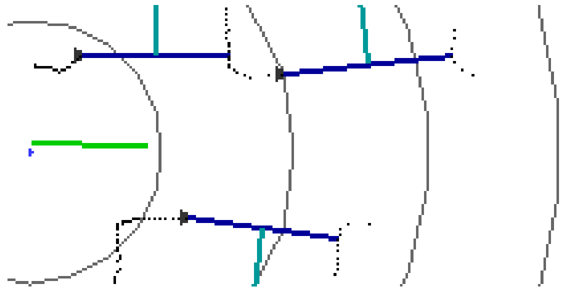

Fig. 2. Example of feature extraction in mine, the distances between scale lines (grey arcs) are 10 m. Tunnel width approximately 11 m.

another benefit, it eases up the identification of distant lines. By excluding laser points in close proximity to each other, the data point density is more evenly distributed and distant lines can be detected as well as lines close to the sensor.

The extraction of lines from the Hough space is implemented straight on as a search for the most intense candidates. These lines are then evaluated to find a line pair for which the directions differ approximately $180\,^{\circ}$ and the distance between the lines is within the boundaries of the specified corridor width. The centre and direction of the corridor, relative the robot, are then easily calculated from the selected lines.

B. Intersection detection

In our application we use the opening detection to detect the presence and location of intersecting corridors/tunnels, but the algorithm can just as well be used to detect open doors. The algorithm is based on the fact that the presence of an intersecting corridor will result in a discontinuity in the laser range array, and that such an event therefore can be detected directly in sensor coordinates. By evaluating the difference in range of consecutive laser points (R_n, R_{n+1}) we have a sufficient condition to locate all potential intersection event candidates, but we can also get a large number of false positives. These are eliminated in two steps. First, the distance from the first point of the event is compared to all following points. If the distance in any case is shorter than our specified minimum opening the event can be dismissed. Second, the laser point (R_{n+x}) closest in euclidian space to the first point (R_n) of the event is located. If this point is identical to the initial second laser point (R_{n+1}) of the event (i.e. $x = 1$)), the event can be dismissed. If not, the two laser points R_n and R_{n+x} unambiguously reveal the presence and location of a corridor intersection.

For the algorithm to be robust there are a few other conditions that have to be considered as well, such as splitting the laser points in a left and right side. However, the detection of one or several intersections or doors can be performed fast with high reliability, and the execution time of the intersection detection is only fractions of a millisecond, well below 0.1 ms on our test system.

III. Experiments

The algorithms have been verified using our ATRV-Jr robot equipped with a SICK LMS 200 laser scanner. During the experiments the robot have successfully navigated at its full speed 1.7 m/s, both in the basement of the university building, and in our test mine. The only parameters that have to be changed between the different locations are the min and max width of expected corridors, and the detection range of the Hough Transform. Figure 2 shows tunnel and intersection detection in our test mine, note that the tunnel is correctly identified even though its walls are interupted by many side tunnels.

IV. Conclusion

The algorithms presented here have shown promising results to provide a robust and fast way to extract features from laser data for topological navigation of mobile robots. The functions have also proven to be flexible and easy to adapt to different environments such as mines tunnels and office corridors. For the future, we intend to evaluate the algorithms on a real LHD vehicle in the test mine.

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