A MAP BASED ON LASERSCANS WITHOUT GEOMETRIC INTERPRETATION

G. WEISS and E. v. PUTTKAMER

University of Kaiserslautern, Department for Computer Science, Research Group v. Puttkamer, P.O.-Box 3049, D-67653 Kaiserslautern, Germany

Abstract. A map for an autonomous mobile robot (AMR) in an indoor environment for the purpose of continuous position and orientation estimation is discussed. Unlike many other approaches, this map is not based on geometrical primitives like lines and polygons. An algorithm is shown, where the sensor data of a laser range finder can be used to establish this map without a geometrical interpretation of the data. This is done by converting single laser radar scans to statistical representations of the environment, so that a crosscorrelation of an actual converted scan and this representative results into the actual position and orientation in a global coordinate system. The map itself is build of representative scans for the positions where the AMR has been, so that it is able to find its position and orientation by comparing the actual scan with a scan stored in the map.

Key Words. Autonomous mobile robots; Position- and Orientation Estimation; Map Building; Correlation, Self-Referencing

1. INTRODUCTION

For a determined behaviour of an autonomous mobile robot (AMR) in an indoor environment, a kind of map of the environment is important. A planning algorithm will need either a map in advance to do a off-line planning, or it will need information about already searched regions, that results in a map build on-line. In both cases, this map represents a internal model of the real world. This model may be rather similar to a classical map that a human being may draw, but it does not need to be so.

In many cases these maps are represented by geometrical primitives, like lines or polygons. In literature different approaches for such a map can be found: either the map is given in advance as lines, polygons or other geometrical primitives (Ruß *et al.*, 1992) or the map is established by extracting these geometrical primitives from sensor data (Hinkel *et al.*, 1988). The first case is often impractical, because a CAD model of the operating environment must be available before any action of the AMR can start, the second approach is difficult and sometimes unreliable, since there are only heuristic approaches to extract geometrical primitives from sensor data.

2. MATCHING OF TWO LASER RADAR SCANS FOR POSITION AND ORIENTATION ESTIMATION

We need to explain, how the relative position and orientation displacement between two laser radar scans can be calculated, before we show how a map can be build from these range finder scans. For this purpose we use the approach, that was already shown in (Weiß *et al.*, 1994). The basic idea behind this approach is to find a match of this two laser radar scans, that are taken from different positions and orientations. By computing the matching, the difference in rotation and translation between the two scans are found. The calculation of the matching is divided in two principal steps: the calculation of representations of the scans, that are invariant against rotation respectively translation and the finding of the actual shift between the representations of the scans.

2. 1. Invariants in Laser Radar Scans for Position and Orientation Estimation

In order to match two scans, properties of the scan must be found, that are invariant from the recording place and orientation. First we calculate a representation of the scan, that is invariant from translation. Assuming, that two consecutive scan points in a laser radar scan represent a line, we calculate the angle of this line with respect to a fixed direction. By doing this for all pairs of consecutive scan points, rounding the angle to a discrete value, we establish the discrete distribution of the angles in a scan.

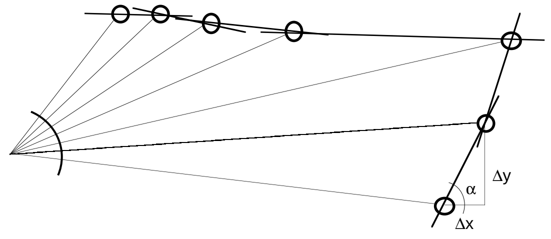

Fig. 1 Calculating angles for angle-histograms.

In an artificial environment, there will be a accumulation at certain angles, where the assumption, that each two points really have represented a line, was true.

These accumulations are representatives of common directions in a room. We call such a distribution “angle-histogram”. It is roughly independent from the position where the scan was taken, but not from the orientation. The independence from position is easy to understand, if we think of a flat surface, that is scanned. If the laser radar is moved closer, more scan points are taken from this flat surface. If the scanner is moved away, the opposite happens. In both cases only the amount of scan points accumulated at a certain angle will change, but not the angle where the accumulation happened.

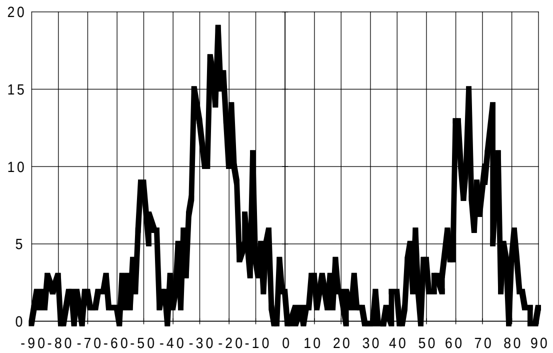

Fig. 2 Angle-histogram of a single scan

If the changes in position are small with regard to the size of the scan, the angle-histogram does only change in amplitude, but a phase-shift in the angle--histogram appears, if the orientation changes.

The phase-shift between two angle-histograms can be found by calculation of the crosscorrelation of the two histograms h_1 and h_2, since the histogram can be assumed to be a discrete periodic function.

$$c(j) = \sum_{i=1}^{n} h_1(i)\, h_2(i+j) \qquad (1)$$

This crosscorrelation function shows a local maximum at the phase-shift between the two angle-histograms. Together with a rough estimation of the orientation, e.g. by dead–reckoning, the correct local maximum can be found. Although this crosscorrelation function has discrete arguments, the exact angle can be found by calculation of the mean value for the values of the crosscorrelation function around the maximum.

After the orientation displacement is found, the translation must be calculated. For this purpose, the so called x- and y- histograms are calculated. A x- (or y-) histogram shows the distribution of scan-points in x- (or y-) direction with respect to a coordinate system, in which the x- (or y-) axis is in parallel with the most common direction. The most common direction is the direction in which the highest peak in the angle-histogram shows up, i. e. the direction in which the most lines are headed. Because the y- (or x-) axis is perpendicular to this most common direction, all the scan points, that represent lines in this common direction accumulate in the same y- (or x-) distances. As in artificial environments rectangular structures are very common, the accumulations will also appear on the x- (or y-) axis. These two histograms, calculated for both scans, differ roughly only in a phase-shift, like the angle-histograms do. Therefore the x- (and y-) displacement can also be found by crosscorrelation.

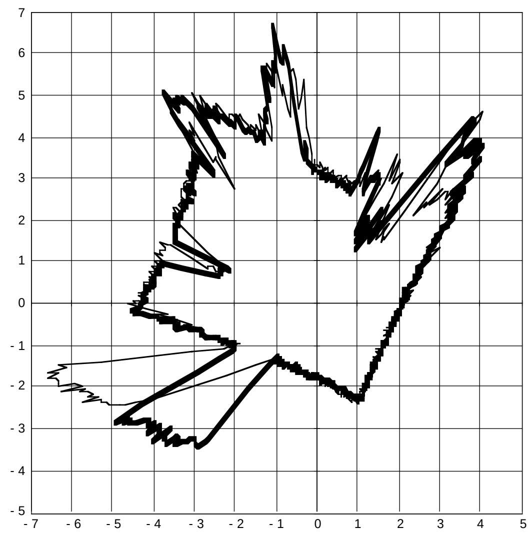

Fig. 3 Two scans after a correction of 43° rotation, 0.14 and 0.96 m translation

2. 2. Normalized Crosscorrelation Functions as a Measure of Reliability

Taken the crosscorrelation function in the above form, we can only find the maximum of correlation, but have not a statement of the quality of this correlation. If we alter the crosscorrelation to a form, there $\bar{s}_1$ and $\bar{s}_2$ are the mean values of the histograms, it is now called the normalized crosscorrelation function and its value is in the range from -1 to 1:

$$c(j) = \frac{\sum_{i=1}^{n} (s_1(i) - \bar{s}_1)(s_2(i+j) - \bar{s}_2)}{\sqrt{\sum_{i=1}^{n} (s_1(i) - \bar{s}_1)^2 \cdot \sum_{i=1}^{n} (s_2(i+j) - \bar{s}_2)^2}} \qquad (2)$$

A value of 0 will appear for arguments, if the histograms are uncorrelated, a value of 1 if they are correlated (Ball 1968). Any measure in between is normally meaningless, but because we know, that the histograms are calculated from scans taken in roughly the same environment, the value of the maximum of this normalized crosscorrelation is a measure how "good" the two histograms correlate. As long as the maximum of this crosscorrelation function is near to 1, a good correlation of the two histograms can be assumed. This does not necessarily mean, that this correlation is highly reliable, since e.g. two angle-histograms of a circular room will show nearly a cross-correlation of 1 for any angle. Therefore a second thing need to be checked: a significant crosscorrelation can only be calculated, if the underlying histogram shows also significance. Therefore it needs to be checked, that high enough peaks are present in the histograms.

3. FROM POSITION AND ORIENTATION ESTIMATION TO A MAP

If we use our knowledge now, the approach for establishing a map during a task of the AMR is rather straight forward. Since the histograms taken at certain places will not alter very much over time, at least not over the time a mission takes, we could not only use them once for an incremental position and orientation update, we could store them and use them at a later time again. At this later time we can then reorientate the AMR by the scan taken previously, if the vehicle is back in the vicinity of the former position.

3. 1. The Organization of the Map

In order to organize the storing of the scans, the environment is divided into a grid with a cell size of about the vehicles size. If the vehicle is moving around, each and every new scan is used to calculate a matching with one of the earlier taken reference scans, so that drift errors can be corrected. In addition, the corrected scans are stored in the nearest grid-cell, in order that they can be used in future as reference points.

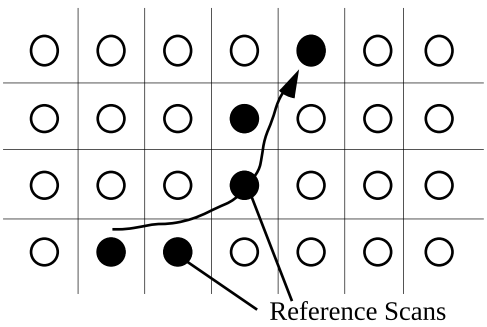

Fig. 4 The assignment of scans to grid-cells

The advantage of using a grid is, that it is rather simple to implement and the neighbours are easy to find. There are of course more (memory-) efficient solutions, but even a 100 x 100 grid needs only space for 10,000 pointers (which mostly refer to NIL) and 40 kByte is not very much nowadays.

3. 2. The Basics of the Algorithm

We will first show our approach in principle and then by an example. After the first scan is taken at the starting point, we go towards our goal, guided by a planner and a local obstacle avoidance system integrated into the pilot which is all not discussed here. While the AMR drives toward its goal, it takes as fast as it can new scans of its environment, in order to have a reliable position and orientation estimation and to establish the map. To establishing the map, for each new corrected scan it is checked, if there is already a representative scan stored in the map at the grid cell that represents the scans position. If this is the case, a second check is done: maybe the new scan has a higher significance than the stored one. The stored one will then be replaced. A still empty grid cell will be filled by the new scan.

While the vehicle is moving, it may happen, that the correlation between the reference scan at the starting point gets poor. In this case a new reference scan needs to be chosen. Our heuristic approach for choosing this new reference point is as follows: first we test if there is already a reference point in the direction that the vehicle is headed for. Since in this case we are moving into a already visited area, it is a good choice to use this scan as reference. If there is no scan in the direct front, we will check in addition, if there is one left or right to the front. If this all fails, it is likely, that the vehicle is moving into a not jet known area: in this case we take the scan out from the grid cell where we came from. In this manner a sequence of scans is generated, during the way from a starting point to a goal, which are representatives of their environments. These representatives are aligned to each other within some small error range, that depends on the accuracy of the position and orientation estimation algorithm. Although this small error may sum up over a longer way, the local position and orientation estimation has a high precision, since it is always relative to a local representative. As far as the path that the robot had taken was free of loops, even a slight error in absolute position and orientation does not harm in finding the starting point on the way back precisely. But even if a loop in the path of the robot occurs, slight errors during consecutive correlations do not necessarily harm. The error between the actual and former scans leads only to a small "drift" whenever the vehicle crosses the boarder between a nearly correct representative scan and a representative with a accumulated drift error.

The whole scheme is illustrated in Fig. 5. The AMR starts at grid-point 1 and goes its way to the goal in the near vicinity of grid-point 10. On this way it takes first the starting point 1 as a reference scan and enters for each new grid point that it passes a scan into the map. Assuming at grid point 4 the correlation gets to poor with the starting point as reference, it will take point 3 as the new reference, since there are no scan points in the map in front of the vehicle at this time. This happens consecutively until the goal is reached. We show two cases for the way back: direct and with a loop. In the first case (drawn with the black arrow backward), the vehicle will choose the reference points that are already there, whenever it loses the correlation with the former used reference point. This happens although the vehicle is nearer to other points as it passes points 7 to 10, but these are empty and the chosen points are direct neighbours of those that are directly on its path. While the vehicle is passing this empty points, it also stores scans into them.

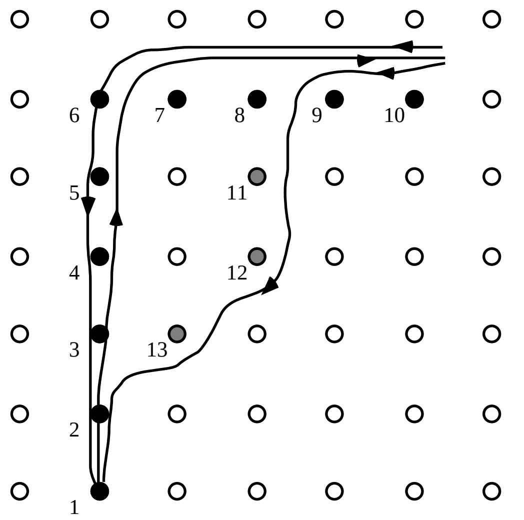

Fig. 5 An example for establishing and using the map

In the second case (drawn in grey), the vehicle chooses a different way back to the starting point after passing point 9. It therefore adds scan 11 to 13 into the map on its way. Assuming, that at point 12 the correlation gets lost, it will use point 11 as a reference. If the correlation gets lost again in the near of point 13, point 2 will be chosen since this point is in the direct heading of the vehicle. By taking now the (relatively) old point 2 as a new reference, a bigger deviation might be found, since the map might be somewhat distorted on the path back from point 10 to 13. On the other hand, this does not harm in finding exactly the starting point, since this was given relatively to point 1.

4. EXPERIMENTAL RESULTS

In Fig. 6, a environment is shown that was used for test purposes. It consists of our test lab, a door and the corridor in front of the lab. Our vehicle with one driven and steered front wheel and two free-running back wheels has the size of 110 x 62 cm. The test room we used is approx. 5 x 4 m. The grid cell size was 80 cm. The vehicle started as marked in the figure, made a turn left and back right, went through a door of the size of 98 cm, went down the corridor (width 2,50 m), turned round with a back-and-forth manoeuvre and went through the door again.

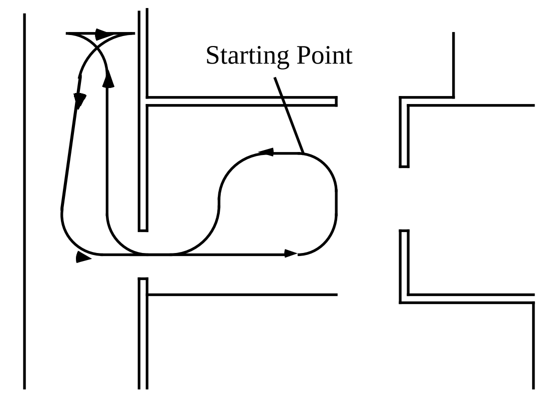

Fig. 6 Test Environment

The path was totally preplanned and programmed into the vehicle, so that it was able to repeat it infinitely. While the vehicle moved the first time the full path, it established the map as described earlier. The responding placement of the grid points can be seen in Fig. 7. Their positions originate from the position of the starting point. The path needed to be driven very exactly because of the lack of space. In some positions, especially while passing the door, only a few centimetres space was left. The test has been done without the collision avoidance activated in the pilot function, because the pilot was in most case to anxious in narrow passages.

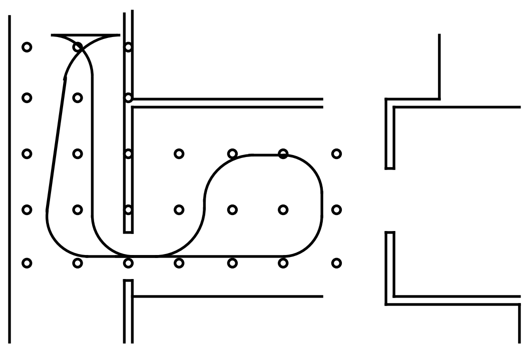

Fig. 7 The placement of the representative scans in the grid

Without the map building and continuous position and orientation correction, the vehicle managed to pass the door once, but was not able to pass the door on the way back again, since the error in orientation of approx. 3-5° led in hitting the doorframe. With the map building enabled and continuous orientation and position correction, the vehicle was able to drive continuously for a long time, we stopped after about 20 rounds. In addition I tried to cheat the vehicle and simulated some slippery just by picking the vehicle up at the front, where the driven wheel is mounted and put it back onto the floor with a turn of about 5-15°. The vehicle was able to correct this error after a new scan and managed to keep the path as long as the disturbances were made at parts of the path, on which was enough space left to correct the position and orientation before some obstacle was hit.

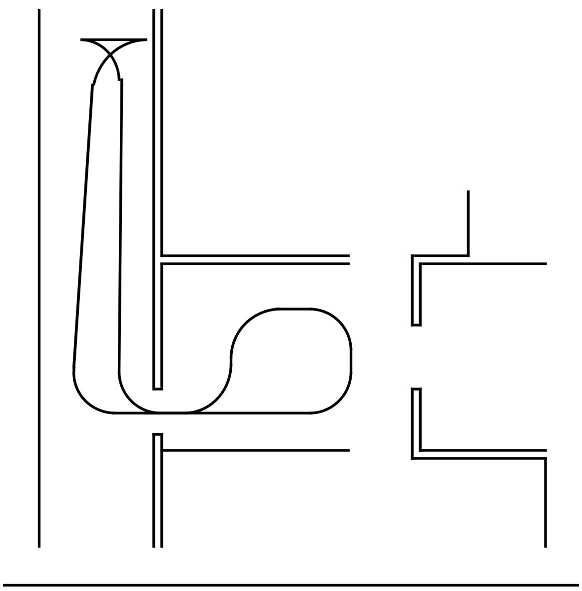

Fig. 8 An environment that fails

In Fig. 8 the same environment can be seen with a slightly modified path. The difference is the length of the path in the corridor. This lengthen has led to a failure. Since the corridor has no significant obstacles in the long direction, it was not possible for the position and orientation estimation to correct the drift in the long direction of the corridor. The result was a drift error of about 20 cm and, while turning into the door, a hit into the doorframe. After we manually (by pushing the vehicle) ensured the passage through the door, the vehicle corrected the position error and found its way back out of the door again.

5. CONCLUSION

An algorithm was showed, that is capable of doing a incremental position and orientation estimation in global coordinates for an AMR by building a kind of map of its environment during the AMR‘s task without a geometrical interpretation of this environment. Future investigations need to be done in reliability if the map is not only used for preplanned paths but for autonomous exploration of the environment.

References

Ball, G. A. (1968). Korrelationsmeßgeräte. *Deutsche Ausgabe VEB Verlag Technik Berlin, 1972,* pp.17-18.

Hinkel R., Knieriemen T., von Puttkamer E. (1988). Laser Radar Dataprocessing and Environment Mapping for an Autonomous Mobile Robot. *ICSI 1988; International Computer Science Conference, Hong Kong, 19.-21. December 1988,* pp. 457-464

Kurz A., Camacho L. (1992). Schritthaltende Erkennung von Umweltkonturen aus Infrarot-Radarbildern. *AMS ’92; 8. Fachgespräch über autonome mobile Systeme, Karlsruhe, 26.-27. November 1992,* pp. 209-221.

Ruß A., Lanser S., Munkelt O., Rozmann M. (1992). Kontinuierliche Lokalisation mit Video- und Radarsensorik unter Nutzung eines geometrisch-topologischen Umgebungsmodells. *AMS ´93; 9. Fachgespräch über autonome mobile Systeme, München, Germany, 28.-29. October 1993,* pp. 313-327.

Weiß G., Wetzler C., von Puttkamer E. (1994). Keeping Track of Position and Orientation of Moving Indoor Systems by Correlation of Range-Finder Scans. *IROS ´94, International Conference on Intelligent Robots and Systems 1994, München, Germany, 12.-16. September 1994,* pp. 595-601.