Strategies for Contour-Based Self-Localization in Large-Scale Modern Warehouses

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***Abstract*—Latest Automated Guided Vehicles (AGVs) localize themselves by triangulation based on reflector landmarks detected by Laserscanners. The number of reflectors ranges from hundreds to thousands. Every reflector must be mounted and precisely located by skilled personnel. Additionally, the AGV cannot locate itself if no reflectors are in the field of view; furthermore, any change in the factory layout requires the position of the reflectors to be modified accordingly. One aim of the PAN-Robots project[1] is a seamless transition between reflector- and contour-based localization as well as localization in unknown areas to guarantee optimal localization performance for safe and efficient AGV operation.**

I. Introduction

In currently existing warehouses, AGVs localize themselves by triangulation based on reflector landmarks detected by Laserscanners (see Fig. 1).

The number of reflectors ranges from hundreds to thousands. This reflector system must be mounted and precisely located by skilled personnel. Additionally, the AGV cannot locate itself if no reflectors are in the field of view. Furthermore, any change in the factory layout requires the position of the reflectors to be modified and mapped accordingly.

Localization based on natural landmarks or occupancy grid maps is widely applied in research (see e.g. [2]–[13]) but is not yet applied broadly in industrial environments. One aim of PAN-Robots is a seamless transition between reflector- and contour-based localization as well as localization in yet unknown areas to guarantee optimal localization performance for safe and efficient AGV operation. Three levels of localization will be developed and implemented based on Laserscanners supporting a smooth transition between the following techniques:

- A combination of state of the art reflector based localization and new localization based on existing natural landmarks, registered in a digital map. This system will overcome the need of numerous reflectors.
- Exclusively existing natural landmark-based localization (landmarks are registered in a digital map), enabling a reliable localization in areas without any reflectors.

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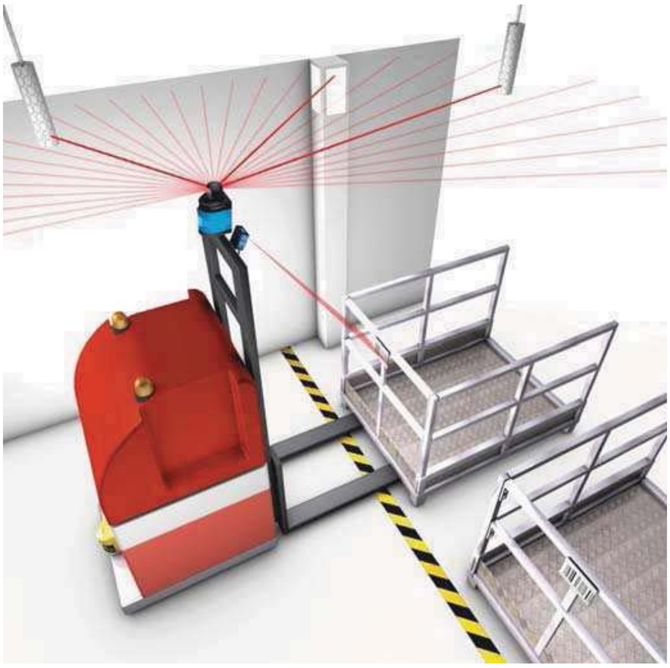

Fig. 1. Reflector-based localization like performed by the SICK NAV 350 Laserscanner is currently state of the art in AGV localization in industrial environments. [1]

- Localization in unknown areas by simultaneous localization and mapping (SLAM) where not even a map of existing natural landmarks is available [3].

The PAN-Robots initial plant exploration process will register special features, e.g. artificial landmarks (reflectors) or natural geometrical landmarks. These will then be used for localization. This paper is organized as follows:

- In Section II, the technical objects of PAN-Robots in general and the particular objectives for the localization module are described.
- Section III describes the process of contour-based self-localization and gives some details on the used digital map, landmark extraction and association.
- Some preliminary evaluation results of the described system are given in Section IV.
- We conclude this paper in Section V and outline future work in Section VI.

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II. General Objectives of PAN-Robots

Today, product processing and packaging have reached a high degree of automation, in which energy consumption, agile manufacturing and product customization are well addressed. On the other hand transportation of raw materials and final products from or to storage and shipment points usually requires the use of manually operated forklifts. However, automation and optimization should be applied to the whole manufacturing chain.

Thus, factory logistics represents a major bottleneck in production and packaging of mass products. In addition today's AGV system technology is still in an early stage of development and its deployment in the factory requires a lot of effort by skilled staff, e.g. for planning the layout of up to thousands of reflectors, mounting the reflectors, mapping their precise locations and testing the complete system.

The objective of PAN-Robots is to develop, demonstrate and validate a generic automation system for factory logistics in modern factories based on advanced AGVs. The concept of PAN-Robots is visualized in Fig. 2.

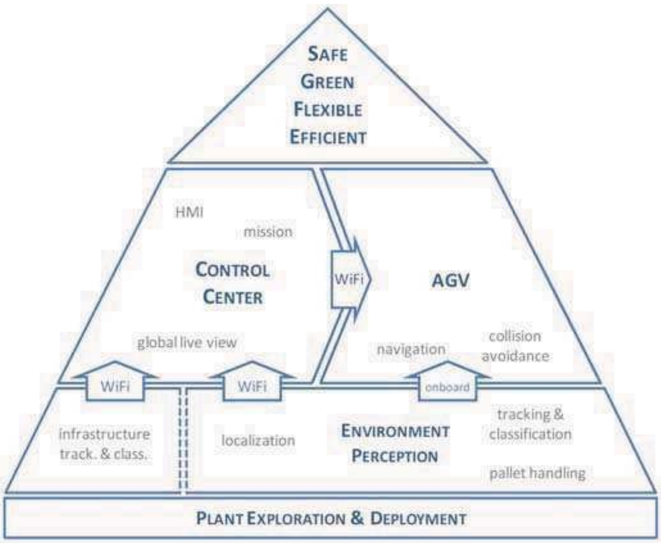

Fig. 2. The concept visualization of the PAN-Robots project.

This paper outlines the contour-based self-localization system that will be used in the newly developed PAN-Robots AGVs as shown on the right side of Fig. 2. The contour-based self-localization system plays a key role in enabled more flexible and more efficient AGV operation. There are three basic requirements a self-localization system needs to fulfill are efficiency, accuracy, and robustness.

A. *Efficiency*

We consider the localization system to be efficient if the frequency of the position updates is sufficient for the tasks relying on the localization system like local path planning, pallet loading and unloading. In current AGV operation, position updates with 8 Hz are sufficient to fulfill these tasks successfully. We adopt this frequency and require that the contour-based localization system delivers position estimates at least every 125 ms.

B. *Accuracy*

The required accuracy for localization based on contour data depends on the tasks an AGV has to fulfill, and also on its environment. We therefore distinguish the following tasks and environments:

- One-way corridors
- Two- or three-way corridors
- Pallet handling in gravity racks and block storage

In current AGV operation, safety Laserscanners are used to guarantee collision-free AGV operation. If an object in the driving direction of the AGV is detected within its warning zone, the AGV slows down to shorten its breaking distance. While guaranteeing safe operation, this behavior increases the mission time of the AGV. It is therefore important that the localization accuracy is high enough so that the AGV keeps a sufficient distance between its warning zone and structural elements, manual forklifts or pedestrians.

In one-way corridors as shown in Fig. 3, the required localization accuracy therefore depends only on the minimum corridor width $w_{corridor}$ and the maximum width of an AGV w_{AGV}:

$$accuracy \leq \frac{w_{corridor} - w_{AGV}}{2}$$

Fig. 3. A one-way corridor in the Casbega warehouse in Madrid, Spain.

Two- or more way corridors, as depicted in Fig. 4, impose higher requirements on the accuracy of the localization system since other AGVs using the same localization system pass by. In current AGV operation, there are situations where the lanes of two AGVs have only a distance of 0.3 m. Thus, the position tolerance of each AGV is less than 0.15 m. If we require this accuracy within three sigma, we get a required localization accuracy of 5 cm and $\pm$ 5 deg within one sigma. The same requirements therefore apply to 3-way corridors which are common in picking zones in front of production areas.

Pallet handling imposes similar requirements on the self-localization accuracy. AGVs must be able to position themselves in front of a specific pallet in front of a gravity rack (Fig. 5) or block storage (Fig. 6) to be able to start visual

Fig. 4. A three-way corridor in the Casbega warehouse in Madrid, Spain.

Fig. 5. A gravity rack in the Casbega warehouse in Madrid, Spain.

servoing. The figures show typical picking or placing positions in front of gravity racks and block storage areas.

The width of a pallet w_{pallet} varies; typical widths are 0.8 m or 1 m. The distance d_{pallet} between two pallets is roughly 0.2 m. The required localization accuracy can therefore be computed as:

$$accuracy \leq \frac{w_{pallet} - d_{pallet}}{2}$$

Thus, when using pallets with a width of 0.8 m positioned in a distance of 0.2 m, the required localization accuracy has to be less than 0.5 m to assure to be in front of the right pallet. To conclude, the required localization accuracy is 5 cm and $\pm$ 5 deg within one sigma since the position tolerance of each AGV is less than 0.15 m in two-way corridors.

C. Robustness

Finally, the localization system needs to be able to tolerate to some degree the occlusion of reflectors or natural landmarks by other AGVs, manual forklifts or pedestrians.

Fig. 6. A block storage area in the Casbega warehouse in Madrid, Spain.

III. Contour-Based Self-Localization

This section outlines the software modules of the contour-based self-localization system. The software architecture of this sub-system is shown in Fig. 7.

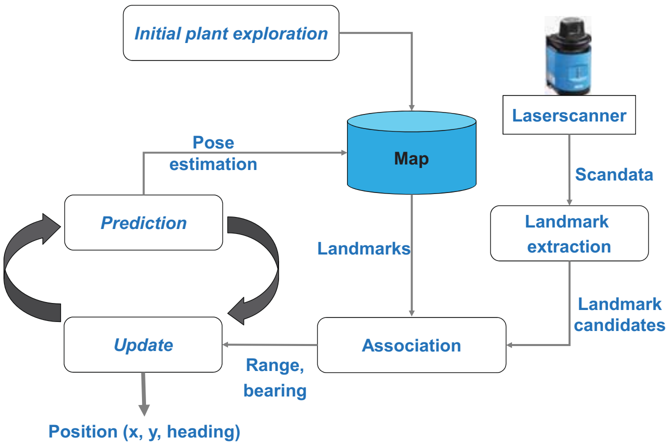

Fig. 7. Architecture of contour-based self-localization system.

The software modules of self-localization sub-system can be distinguished in the following four main modules:

- Digital map containing natural landmarks generated by initial plant exploration
- Online extraction of natural landmarks from scan data
- Online association of landmarks from map with landmark candidates from scan data
- Localization core module performing prediction and update of pose

A. Digital Map

A prerequisite for the self-localization is a map that contains a sufficient amount of appropriate landmarks. The map is generated during the initial plant exploration. The number of landmarks in the map is sufficient, if at least one unique landmarks or more landmarks with unique distances between each other are detected in all positions in the warehouse.

B. Landmark Extraction

There are various possibilities to perform contour-based self-localization. By contour-based we mean using only range and angle information of scan data, without relying on the reflectivity of artificial markers like reflectors as described in [14]. One possibility to perform self-localization is to accumulate scans in an occupancy grid map, another possibility is to extract features (natural landmarks) like posts, poles, corners or walls from the scan data. Fig. 8 shows examples of possible natural landmarks.

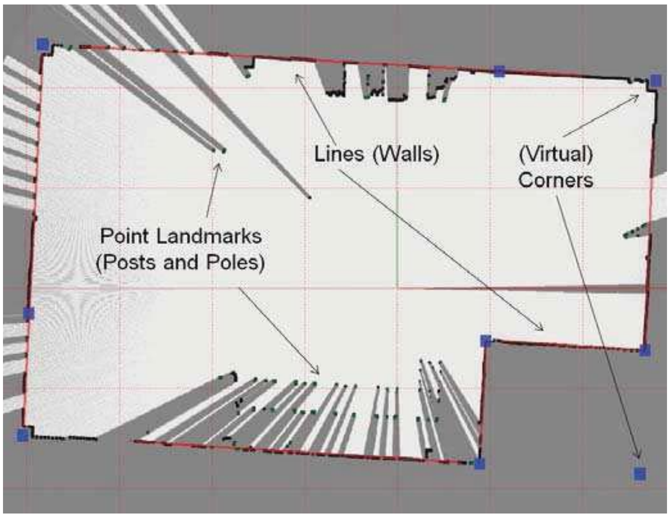

Fig. 8. Extraction of various different natural landmarks.

In addition, e.g. a curvature detector can be used to extract peaks from the scan data that can be used as natural landmarks [15]. Feature-based and grid-based approaches each have advantages and disadvantages. Within PAN-Robots we will first evaluate the feasibility of feature-based localization and then continue with the evaluation of grid-based methods.

C. Association

The association of landmarks from the map with landmark candidates from scan data will be done in several ways:

- Use of scan-point based descriptor
- Geometric considerations of distances between landmarks
- Plausibility checks

All these measures will make sure that a sufficient number of associations of features to landmarks are passed to the self-localization core module.

D. Localization Algorithm

The core module of the self-localization system is an Extended Kalman Filter algorithm [3] which has three tasks:

- Initialization by means of global localization
- Prediction of the next likely pose to extract near landmarks from the map
- Update of the estimated pose by associated landmark detections

The global localization is done via distance comparison of landmark candidates detected in a scan and landmarks contained in the digital map. The estimation of the pose will be done with the same rate as the Laserscanner sends scan data. Current Laserscanners used for navigation in warehouses typically send scan data at a rate of 8 Hz.

IV. Preliminary Evaluation Results

We present preliminary results as a proof-of-concept for our contour-based self-localization system.

A. Evaluation Setup

We recorded scan data at the premises of our project partner Casbega in Madrid, Spain. The scan data has been recorded while the AGV fulfills a mission and delivers a pallet. As reference we used the position estimated by a NAV 350 that utilized the existing reflector installation for localization. The digital map containing natural landmarks has been generated by using the NAV 350 position as reference. In a later stage of the project, we will use SLAM to build this map. Fig. 9 shows one of the trajectories that have been used to evaluate the preliminary localization module. For visualization purposes, it is plotted in the grid map of the warehouse.

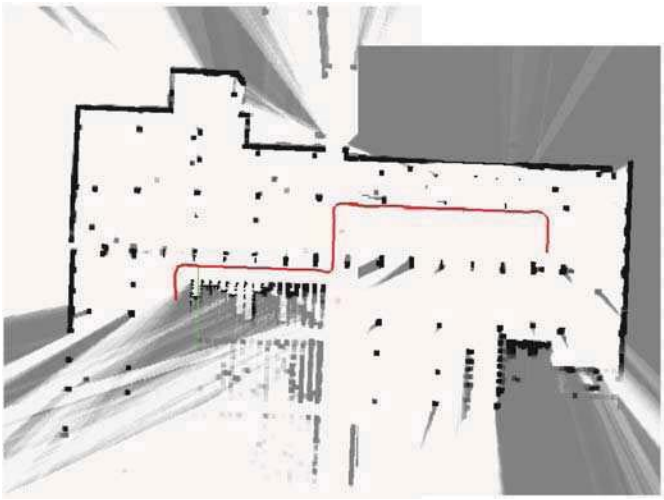

Fig. 9. The trajectory used for evaluation plotted in the grid map of a part of the warehouse of Casbega in Madrid, Spain.

B. Preliminary Results

The comparison of the different trajectories is shown in Fig. 10. It can be seen that both trajectories match very well. The absolute position difference is shown in Fig. 11. The mean difference is 0.035 m (standard deviation 0.046 m, median 0.026 m), which is sufficient for our application, but we have to reduce the maximum deviation of 0.33 m. The angular difference between the localization algorithms is shown in Fig.

12. The mean angular difference is -0.047 deg (standard deviation 0.247 deg, median -0.039 deg), which is already sufficient for our use case. The complete localization algorithms can be executed in real time when using a Core 2 Duo processor with 2.5 GHz. An improvement of the execution time will be future work. While the localization approach already works in most of the warehouse areas with automatically generated maps we will increase the robustness in the progress of PAN-Robots.

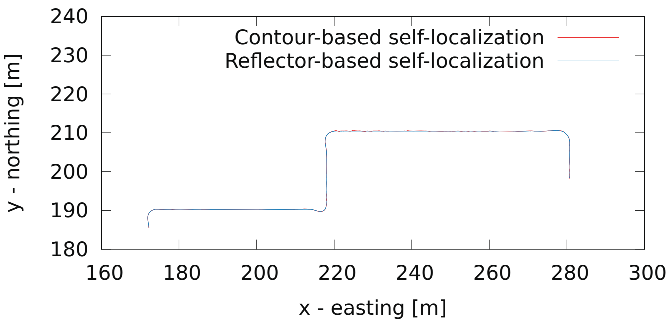

Fig. 10. Comparison of the trajectory of the contour-bases self-localization with the reflector-based self-localization done by the SICK NAV 350. Both trajectories align at this resolution, the difference is plotted in Fig. 11 and 12.

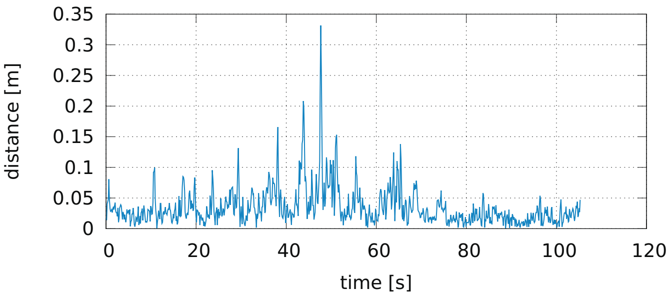

Fig. 11. The position difference between the contour-based and the reflector-based self-localization.

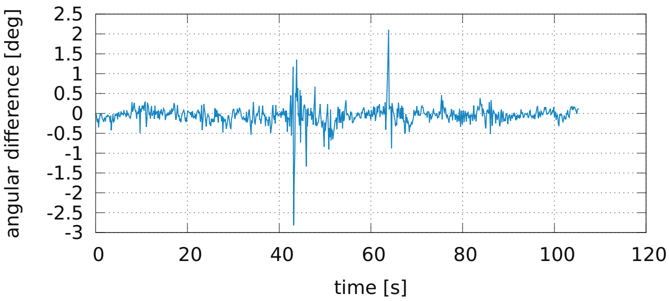

Fig. 12. The angular difference between the contour-based and the reflector-based self-localization.

V. Conclusion

In this paper, we described one key aspect of the PAN-Robots project: a contour-based self-localization system that will be able to deliver an accurate, efficient and robust pose estimation in large warehouse environments. The preliminary evaluation results are encouraging and will be extended in the progression of PAN-Robots.

VI. Future Work

In addition to a landmark-based self-localization approach we will evaluate a combined approach also using grid-based Monte-Carlo localization and eventually Simultaneous Localization and Mapping (SLAM) [3] to be able to cope with dynamic changes of the environment without needing to generate a completely new map for the whole warehouse.

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References

[1] SICK AG, "NAV 350 operating manual," 2011.

[2] S. Thrun, A. Bcken, W. Burgard, D. Fox, A. B. Wolfram, B. D. Fox, T. Frhlinghaus, D. Hennig, T. Hofmann, M. Krell, and T. Schmidt, "Map learning and high-speed navigation in rhino," 1996.

[3] S. Thrun, W. Burgard, and D. Fox., *Probabilistic Robotics*. MIT Press, 2005.

[4] J.-S. Gutmann, T. Weigel, and B. Nebel, "A fast, accurate and robust method for self-localization in polygonal environments using laser range finders," *Advanced Robotics*, vol. 14, no. 8, pp. 651–667, 2001.

[5] J. Röwekämper, C. Sprunk, G. D. Tipaldi, S. Cyrill, P. Pfaff, and W. Burgard, "On the position accuracy of mobile robot localization based on particle filters combined with scan matching," in *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Villamoura, Protugal, 2012. [Online]. Available: http://www.informatik.uni-freiburg.de/ tipaldi/papers/sprunk12iros.pdf

[6] G. D. Tipaldi, M. Braun, and K. O. Arras, "Flirt: Interest regions for 2d range data with applications to robot navigation," in *Proceedings of the International Symposium on Experimental Robotics (ISER)*, Dehli, India, 2010. [Online]. Available: http://www.informatik.uni-freiburg.de/ tipaldi/papers/tipaldiISER10.pdf

[7] T. Bailey, "Mobile robot localisation and mapping in extensive outdoor environments," Ph.D. dissertation, The University of Sydney, 2002.

[8] D. Chetverikov, D. Svirko, D. Stepanov, and P. Krsek, "The trimmed iterative closest point algorithm," in *IEEE Conference on Computer Vision and Pattern Recognition*, vol. 3, 2002, pp. 545–548.

[9] J. Gonzlez and R. Gutirrez, "Direct motion estimation from a range scan sequence," *Journal of Robotic Systems*, vol. 16-2, pp. 73–80, 1999.

[10] J. Levinson, M. Montemerlo, and S. Thrun, "Map-based precision vehicle localization in urban environments," in *Proceedings of Robotics: Science and Systems*, Atlanta, GA, USA, June 2007.

[11] S. Thrun, M. Montemerlo, D. Koller, B. Wegbreit, J. Nieto, and E. Nebot, "Fastslam: An efficient solution to the simultaneous localization and mapping problem with unknown data association," *Journal of Machine Learning Research*, 2004.

[12] S. Thrun, D. Fox, W. Burgard, and D. F., "Robust monte carlo localization for mobile robots," *Artificial Intelligence*, vol. 128, no. 1-2, 2001.

[13] S. Thrun, W. Burgard, and D. Fox, "A probabilistic approach to concurrent mapping and localization for mobilerobots," *MachineLearning and Autonomous Robots (joint issue)*, no. 31/5, 1998.

[14] D. Ronzoni, R. Olmi, C. Secchi, and C. Fantuzzi, "Agv global localization using indistinguishable artificial landmarks," in *IEEE International Conference on Robotics and Automation (ICRA)*, 2011.

[15] G. Tipaldi and K. Arras, "FLIRT - interest regions for 2D range data," in *Robotics and Automation (ICRA), 2010 IEEE International Conference on*, 2010, pp. 3616–3622.