Mobile robotics: using laser range data for robot localization

PILZ
THE SPIRIT OF SAFETY

White Paper

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1. Edition

At a glance

Autonomous vehicles perform more and more tasks in industry as well as in many service sectors in a cost-effective, reliable, and safe way. Sensors like laser scanners can be seen as the eyes of these vehicles: Through them these vehicles get indispensable information about their environment. Safety laser scanners provide safety by preventing collisions with people and objects and at the same time they enable localisation and navigation.

The safety laser scanner offers distance range data via ROS or C++ interfaces and allows localization and navigation using the ROS package SLAM Toolbox. Static measurements show a high resolution and data accuracy.

Contents

1. Laser scanners for localisation and navigation

Not only in the industrial environment, but also in many service sectors, autonomous vehicles perform more and more tasks in a cost-effective, reliable, and safe way. This requires the capability of orientation, i.e. localisation in its environment, as well as the ability of autonomous navigation in a map of this environment – be it self-created or predefined.

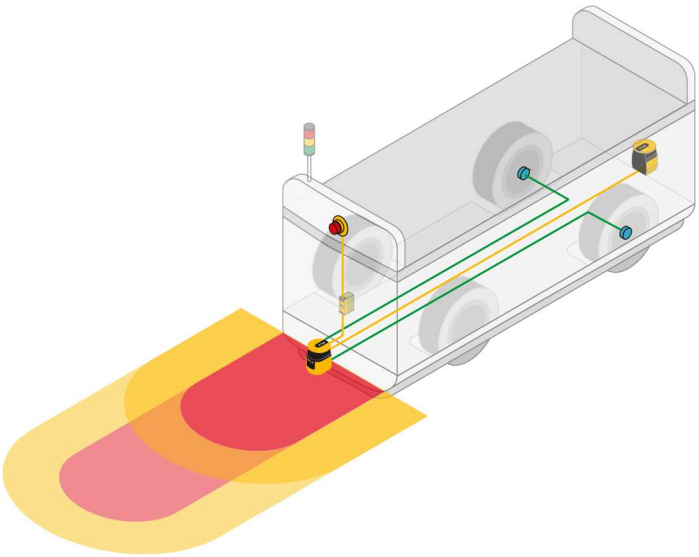

Figure 1: AGV equipped with safety laser scanner providing speed-dependent zone switching

For these operative tasks, the safety laser scanner is the most appropriate sensor and gives a strong ability of seeing to these autonomous vehicles. Furthermore, it is also highly adaptable to many special conditions and satisfies the highest safety requirements at the same time.

Different products are on the market - what can they do and how are they to be assessed? This paper will look closer at a selection of laser scanners, including their features and their performance.

1.1. Laser scanners: How do they work?

The basic principle is the time of flight measurement of a laser beam. The focused near-infrared light is sent out from the scanner in very short pulses at defined time increments via a rotating mirror and the reflections of these pulses can be measured in terms of angle, travel time and intensity. The light is partially reflected by most materials with very few exceptions (glass, reflectors, …). Dust and fog in the air may hinder the measurements as well as dirt on the laser cover. The scanner can detect only objects in the line of sight. Therefore, the scanner must be moved in order to look behind objects.

Scanners can be used in safety applications (if they are specified accordingly) as well as for mapping and navigation of mobile robots. In this paper, the mapping and navigation functions are discussed.

1.2. AGVs and AMRs

Traditional automated guided vehicles (AGVs) can perform simple transportation tasks, but due to their limited navigation capabilities they require fixed routes to follow (lines, wires, reflectors,

etc.) using simple sensors. Equipped with safety sensors, they can stop at obstacles but can't navigate around them (Figure 2).

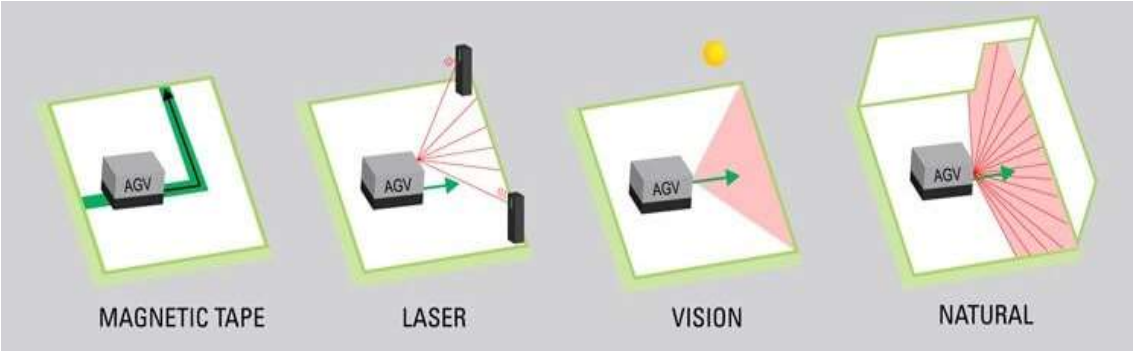

Figure 2: Usage of sensors to follow routes (Source: https://www.atriainnovation.com/wp-content/uploads/2020/06/AGV_Sensores.jpg)

Autonomous mobile robots (AMRs) on the other hand use dynamic maps for navigation and permanently calculate the current best path, even around temporary obstacles in variable environments (Figure 3). The data they work with is created via cameras or scanners and processed by powerful computers.

Since they do not depend on expensive infrastructure, the use of AMRs is often cheaper compared to the total costs of AGVs.

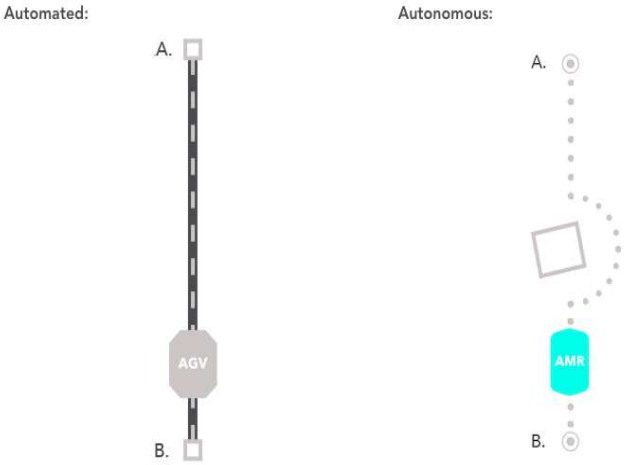

Figure 3: AGV vs. AMR; source: https://s3.amazonaws.com/assets.ottomotors.com/content-images-v2/AMR-vs-

1.3. Localisation and navigation

The first condition before an AMR can start moving autonomously is creating a map (but it could also use a predefined one) and localising itself in this map. A method called Simultaneous Localisation And Mapping (SLAM) allows this to happen in parallel. From now on, the information of the map is matched with the actual information of the sensors of the AMR to localise it in its environment. Thus, an AMR can navigate to any target. The information about the environment's natural features is regularly updated by permanently provided scans or images supported by the odometry of the vehicle. Since it takes lots of calculations and statistics to perform localisation and navigation tasks, a combination of powerful software and high-capacity computers is required. There are several ROS software packages as well as commercial ones available that can do this job.

1.4. Example of an application (map using AMR and laser scanners)

To generate a map of a completely unknown area this area is captured with a laser scanner. Processing the raw distance information from the laser scanner, the SLAM Toolbox software starts building a map. As soon as the laser scanner is moved around, the successive scans are put together and processed to form a consistent map of the environment. More images and sophisticated calculations, in combination with information about the actual movements of the vehicle, provide an almost perfect mapping of the environment. This map, combined with the information about restrictions in the way the vehicles are allowed to move, is the base for all consequent navigation tasks in the mapped environment. Lasting alterations in the topography detected by scanners or cameras cause an update of the map.

Besides these localisation tasks, safety laser scanners also provide several features to reliably prevent collisions between the vehicles and persons or objects by either looking for a way around the obstacle or by safely stopping the vehicle if necessary.

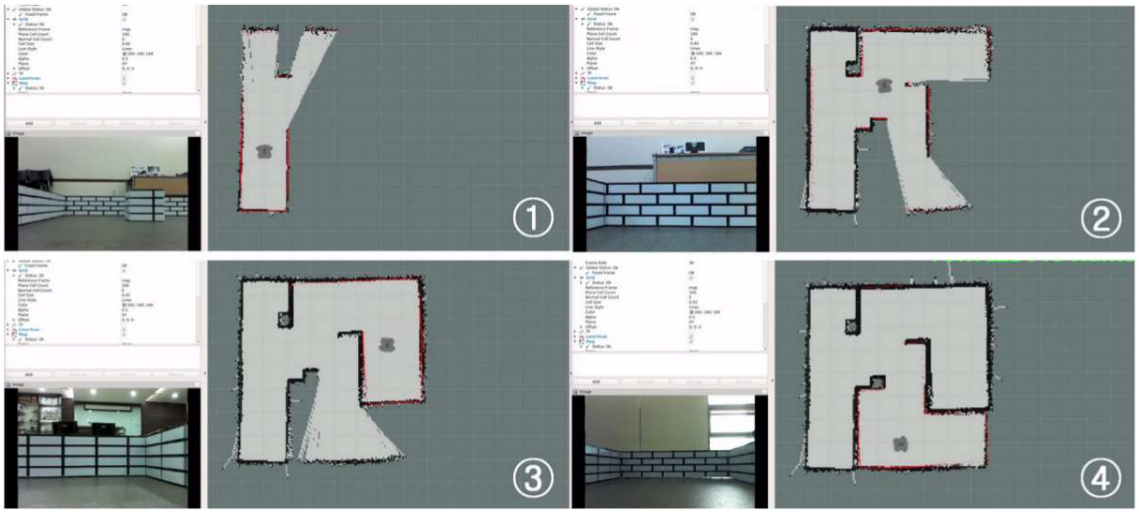

Figure 4: Generation of a map by systematically driving around (Source: https://emanual.robotis.com/assets/images/platform/turtlebot3/slam/slam_running_for_mapping.png)

2. Market overview

2.1. Relevant properties (resolution, frequency, …)

A wide variety of laser scanners is available on the market. All of these scanners vary slightly in a number of parameters. While it is obvious that low energy consumption is favourable, there are lots of other parameters - such as size of the housing, angular resolution, scanning frequency, maximum scanning angle and maximum range - which are sometimes contradictory. Their influences are more difficult to estimate. The shape of the laser beam may be different, also the wavelength of the laser light source. When used as safety scanners, warning and protection zones must be defined. Some scanners also deliver additional values in the raw measurement

data like the measured intensity of the reflected laser beam. This allows further calculations by defining additional observation options.

There is a difference between safety scanners and LiDAR scanners. While some LiDAR scanners have high resolutions and a long range, most of them are not capable to fulfil the high safety requirements when operating together with people.

2.2. Technical Data

The relevant extract of typical technical data of the safety laser scanner are shown in the following table

Table 1: Technical data of the devices under test

Parameter	**Typically values of Laser scanners**
Angular resolution	0.1°
Sector width	1.7 mm/m
Protective field	5.5 m
Distance resolution	1 mm
Total angle	275°
Min. distance	50 mm
Max. distance	40 m
Scan time	0.03 sec

2.3. Semi-transparent objects

Laser scanners have difficulties in correctly recognizing semi-transparent surfaces. Screenshots show, that high quality scanners recognizes an acrylic board with a disturbed signal at its original position, while other scanners have difficulties with this situation (Figure 5).

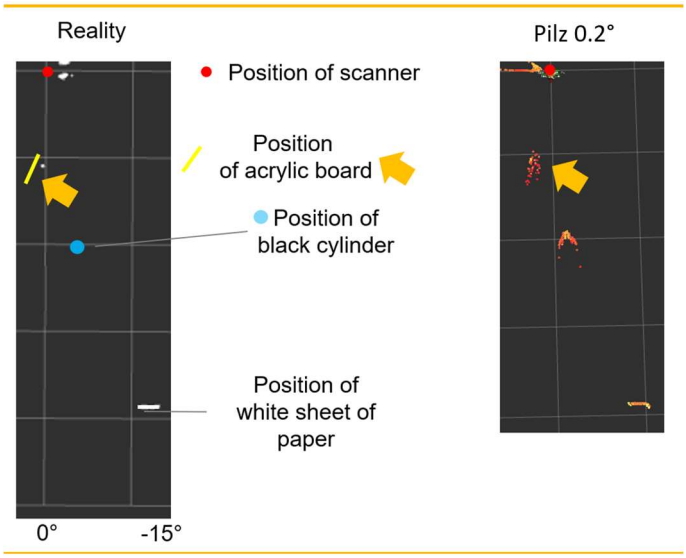

Figure 5: Recognition of a clear acrylic board and other objects (screenshots RViz)

3. Localization Accuracy

The static measurements give an impression of slightly different characteristics of the tested scanners. The use of the scanners in real AGV or AMR applications will not be static but under dynamic conditions as provided by an experimental AMR.

3.1. Setup

The AMR was equipped with additional scanners, that deliver their data to a ROS software, where all scanner data are stored together with the data of the odometry of the vehicle and the camera data. The ROS software package “SLAM Toolbox” is used for processing and storage of the data.

The vertical distance between the scan levels of the tested scanners is less than 90 mm with practically no relevant structures in the surroundings to be seen or missed in between.

Two markers are located on the floor in a fully furnished laboratory with a somewhat rugged environment (marker 0 and marker 1), whereas the markers 2 and 3 are between clean and straight walls. The AMR is steered by joystick and the markers are reached via more or less identical paths.

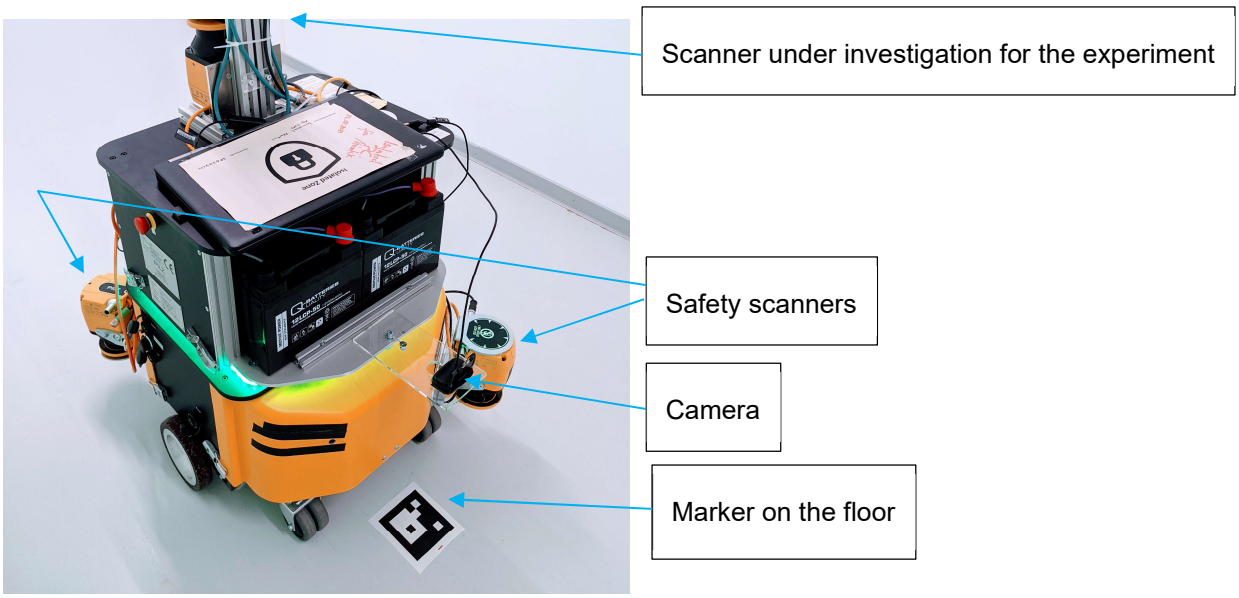

Figure 6: The AMR carrying several scanners with different tasks and the camera for recognition of markers

3.2. Data acquisition

The data for map generation is recorded simultaneously from all the scanners. In manual mode, the AMR is moved through the laboratory area to show as much as possible of the environment to the scanners. The calculations for map generation are made afterwards offline.

Maps are generated with a resolution of 5 cm and a resolution of 1 cm.

The data for localisation is recorded while driving a route defined by four markers on the floor in a given sequence and in a given direction. Steering is via a joystick. Data is collected during 11 rounds. When reaching a marker in the appropriate direction and position, the AMR is stopped, and a signal is generated by pushing a button on the joystick. Equal conditions for the tested scanners are thus guaranteed because of simultaneous recording of all data.

Finally, the position of each marker is calculated using the scanner data and several geometric transformations, at the same moment the AMCL calculation determines the position based on scanner data.

The map generated out of laser scanner data is shown in Figure 7.

Figure 7: Map with a resolution of 1 cm generated by safety laser scanner

3.3. Data processing

The comparison of the positions determined from the scanner data and the corresponding marker-based positions is drawn in Figure 88 and doesn't show significant differences between the sets of scanner data.

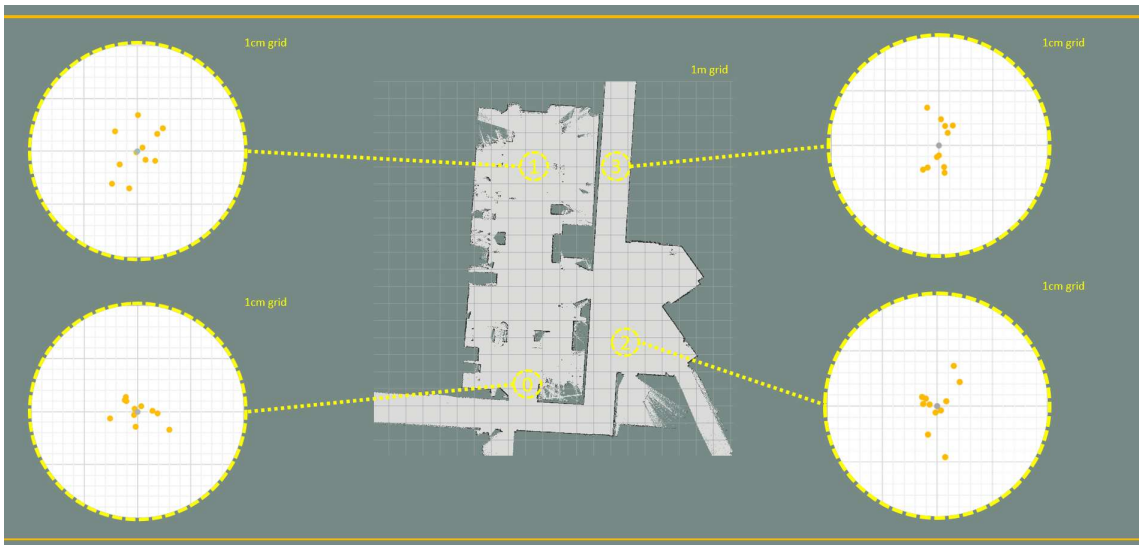

Figure 8: Map (resolution 1 cm) generated from data of a safety laser scanner including visualization of the localization results

The standard deviation of the distances to the respective mean value is about 2 - 3 centimetres, as shown in Table 2.

Table 2: Standard deviation of the measured positions with reference to the markers

Std. Dev.	Marker 0	Marker 1	Marker 2	Marker 3	Total Ø
1 cm map	1.9 cm	2.7 cm	2.5 cm	2.3 cm	2.3 cm

3.4. Application of data in the field

With a precision of 2 – 3 cm it is possible to locate the vehicle within its environment between plain walls as well as in a furnished laboratory. This is a common range for applications using state-of-the-art laser scanners.

4. Conclusions: What does a safety laser scanner offer?

In mobile robotics, safety laser scanners are essential to guarantee safe operation of autonomous vehicles. The use of the scanners is not limited to safety. The raw measurement data is also available for localisation and navigation and there's no need for extensive additional infrastructure or an extra LiDAR.

The measurement data of the tested state-of-the art scanners are highly precise and competitive. The generation of maps and the localisation in various environments are solved with the data with equally good results.

Precompiled ROS and C++ driver packages are used in the tests and work especially together with an open source ROS navigation stack. For advice, please see here: https://www.ros.org/ and https://www.cplusplus.com/doc/tutorial/ .

Slave devices can be connected in series to extend the field-of-view completely around mobile vehicles.

5. Table of figures

6. Glossary

Automated Guided Vehicles (AGVs) are material handling systems or load carriers that travel autonomously throughout a warehouse, distribution centre, or manufacturing facility, without an onboard operator or driver.

Autonomous Mobile Robot (AMR) is any robot that can understand and move through its environment without being overseen directly by an operator or on a fixed predetermined path.

Bias is a systematic deviation of measurements resulting from non-distortion-free sensors.

C++ is a general-purpose programming language.

LiDAR is a detection system which works on the principle of radar but uses light from a laser measuring the time off light of light pulses.

Neobotix GmbH is a producer of mobile robots from Heilbronn / Germany.

Noise is the opposite of precision in measurements and leads to a scattered signal.

Odometry is a method to estimate the pose (position and orientation) of a mobile system from data of its drive system.

Raw data are the unprocessed data out of the measuring equipment.

ROS is an open-source robotics middleware suite and a collection of software frameworks for robot software development.

Safety Application is a technical system designed to avoid unwanted occurrences using the principles of functional safety.

Safety Laser Scanner uses a pulsed laser source. An integrated rotating mirror creates a two-dimensional scan of surrounding objects reflecting the light.

Safety Sensor is a self-monitoring sensor that issues a warning about or prevents a hazard.

Simultaneous Localisation And Mapping (SLAM) is a key computational problem in the field of Artificial Intelligence and mobile robotics that addresses the problem of localisation and mapping when a prior map of the workspace is not accessible

SLAM Toolbox is a is a set of tools and capabilities for 2D SLAM built by Steve Macenski within ROS

Time of Flight Measurement is calculating a distance based on the measured time between emitting a laser pulse and the return of the reflection via speed of light.

Warning Zone, Protection Zone can be defined in the software of a laser safety scanner. If an object is detected within such a zone the scanner reacts with an output signal.